Life cycle inventory (LCI) study
2020 data release

Seventh global LCI study for steel products

worldsteel ASSOCIATION

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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 ozone creation potential
worldsteel	World Steel Association

1 Project context

This report presents a summary of the 7th 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. The study was originally carried out for 1994/1995 steel production data. The first update was then undertaken for 1999/2000 steel production, with subsequent updates published in 2010 (based on steel production in 2005/2006) and then published annually from 2017 to this latest update, the 2020 data release, which includes additional steel production data from 2017, 2018 and 2019.

The main goal of this study is to update the LCI data for steel products on a global and regional basis by updating a proportion of the datasets and releasing results on an **annual basis**. This reflects worldsteel's change of strategy in 2017 to publish annual data and the industry's ongoing commitment to improving data quality. Currently, regional data is available for Europe and Asia for certain products where sufficient data is available. It is believed that some of the other available datasets on steel have been derived with limited accuracy, representation, limited industry input and/or contain out of date information.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 2020 LCI study, 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, all previous versions of the methodology report 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 updated in the future.

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

worldsteel LCI data can be requested from worldsteel.org.

2 Goal of the study

This 2020 release of steel industry data is the 6th update of the 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. These updates also enable more companies to join the LCI data collection programme as each company feels the need to become more engaged in life cycle assessment.

The LCI results alone shall not be used for comparisons intended to 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 are 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 worldsteel LCI data is also available in public and proprietary databases.

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 approximately every 5 years. 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 enables worldsteel member companies to provide data when it is most appropriate, and not only once every five years. This allows worldsteel to produce the most recent and complete steel industry product LCIs on a global and, where possible due to data availability, regional basis, and make this data 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 an LCA study is defined in ISO 14044: 2006 section 4.2.3.1, which among other things, outlines the function, functional unit, system boundary and cut-off criteria of the study which all need to be specified. 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.

Fifteen steel products (Table 1) were included in the study – Both ECCS and UO pipes have been removed from the study due to the age of the data being older than 5 years and a reduction in new data being submitted, resulting in insufficient data to calculate a new global average. The previous ECCS and UO pipe data is still available from worldsteel. The products included in the worldsteel LCI study 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 and can be included in future updates of the database, as and when necessary. The detailed specifications of each steel product, such as size range, gauge and coating thickness, is detailed in Appendix 1. This information varies from site to site and are a function of the technology, equipment and product ranges at the sites involved. 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 Organic coated steel Welded pipes Seamless 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 ISSF[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, includes 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 study does not include the manufacture of the downstream final products or their use. If the user of the steel LCI datasets 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 credits is available as an inventory separate to the cradle-to-gate LCI data, for implementation by the user themselves.

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

For this 2020 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. This newly collected data is combined with data that has been previously collected 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	42	Electrogalvanizing	8
Sinter making	38	Hot-dip galvanizing	38
Pellet plant	7	Tinplate mill	13
Blast furnace	47	Organic coating line	20
Direct reduced iron	10	Section mill	23
Basic oxygen furnace	47	Heavy plate mill	13
Electric arc furnace	44	Rebar	26
Hot strip mill	45	Welded pipe	9
Pickling plant	43	Seamless Pipe	6
Cold rolling mill	41	Wire rod	21
Annealing & tempering mill	39	Engineering steels	6
Total processes			**586**

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). 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 over 26% (480 million tonnes) of global crude steel production (1875 million tonnes) and the contributing sites (which cover 14% of global steel production, 263 million tonnes) are located in the largest of the principal producer countries. The highest represented region is Europe: the sites participating represent over 35% of European steel production. The list of participating companies is shown in Appendix 3.

124 sites located in 28 countries participated in the study – this includes 40 sites providing data in 2020 from 22 steelmaking companies. The major steel producing countries and regions are included. These are listed below in Table 3.

Argentina	Germany	Russia
Australia	India	Saudi Arabia
Austria	Italy	Spain
Belgium	Japan	Sweden
Bosnia	Luxembourg	Thailand
Brazil	Mexico	Turkey
Canada	Morocco	UK
China	Netherlands	USA
Finland	Poland	
France	Romania	

Table 3: Countries participating in the 2020 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 2014 to 2019 (see Appendix 9) and is believed to be representative of global steel production during this time frame. The new sites contributing data in 2020 have provided primary data from 2017, 2018 or 2019 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 2019, 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 2016 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 using this data 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.

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 does not routinely provide impact category information with the LCI profiles, except for the following CML impacts, 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. Primary energy demand is also included for information purposes with the LCI data. The same selection of LCIA results have therefore been included in this report for illustrative purposes only and are included in further detail in Section 5 and 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.

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 95% 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 emissions.
- Eutrophication potential (EP): an impact assessment level with local effect; within the steel industry, EP is mainly caused by NO_x emissions.
- Photochemical ozone 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 10.0.1.92 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 GaBi model was created in 2006 by a team of experts including worldsteel, Sphera and the worldsteel members and represents the steel production and finishing processes. Site data were collected using Sphera's 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 access rights in SoFi by an administrator 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 for steel companies to assist those in 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 the 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 2019, 99.6% of crude steel production was produced either via the BOF or EAF route. Open hearth production and ingot cast steel production, accounting for approximately 0.4% 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 slags can be used in cement manufacture (in cement making and as a replacement for cement), for road construction or aggregate, or as a fertiliser. On average for the sites participating in this study, 0.28 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, 97% of the total amount of BF slag produced is recovered, of which 84% 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	97%	84%	15%	< 1%
BOF slag	> 87%	11%	86%	3%
EAF slag	87%	9%	91%	0%

Table 4: Slag recovery rates and usages

System expansion is used to deal with the slags. This method allows discriminating 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 in the industry. Allocation by mass scenarios do not integrate the actual use of co-products. For example, allocation by mass applied to BF slags only considers the mass of slag recovered and does not differentiate between the environmental benefits of 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 which are then recovered. Details of the assumptions made for all recovered material are included in Appendix 8.

With further analysis, the processes linked with system expansion retain their initial (actual) inventories of the process (e.g. cement or fertiliser production) and the expanded system processes are also reported 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 0 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 5.
- 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 0.

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 10.0.1 CUP2020.1 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. This team of people provided training and support to the worldsteel member companies who individually provided data through a secure online system. 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, 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. Detailed database documentation for GaBi datasets can be accessed at http://documentation.gabi-software.com/.

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 avoids 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 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.

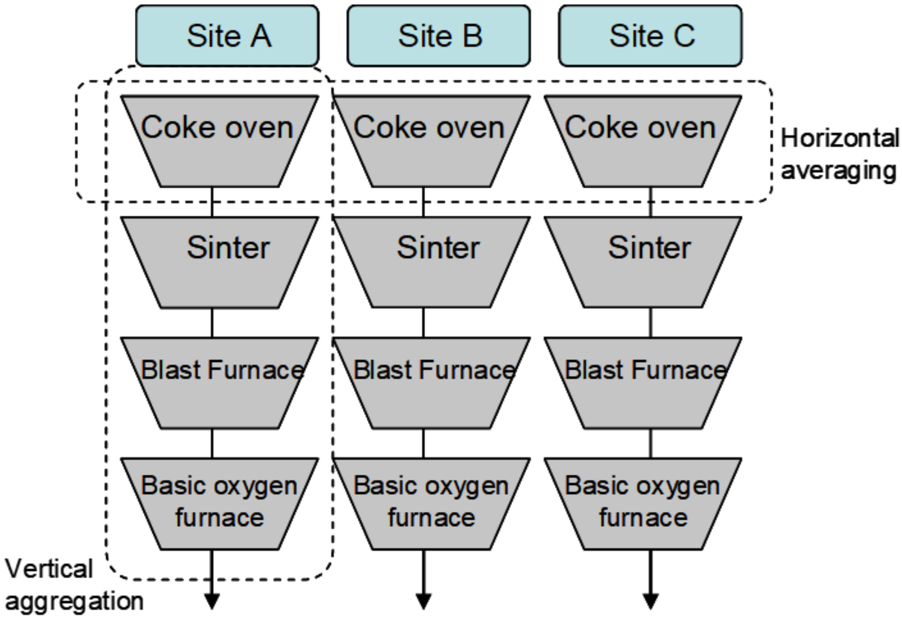


Figure 1: Horizontal averaging and vertical aggregation

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. However, water data forms part of the LCI of the steel products but should be treated with caution. Better metering and monitoring will help to reduce this in 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. 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 15 new and 2 old steel product datasets and is freely available in GaBi or on request via worldsteel.org. 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. 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. 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 the 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 around 85% of all steel is 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 / Energy	**LCIA for 1kg steel scrap**
Primary energy demand, MJ	15.15
Global warming potential (100 years) kg CO_2-e	1.63
Acidification potential, kg SO_2-e	0.0024
Eutrophication potential, kg Phosphate-e	1.83E-04
Photochemical ozone creation potential, kg Ethene -e	0.00075

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 to the product LCI. 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.

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 0.67 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 0.08 tonnes per tonne of hot-dip galvanised steel and 0.14 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-e}	AP kg SO_{2-e}	EP kg Phosphate-e	POCP kg ethene-e
Sections, 1kg	Cradle-to-gate	19.2	1.58	0.0037	0.00032	0.00067
	Net recycling benefit	-2.6	-0.28	-0.0004	-0.00003	-0.00013
	Cradle-to-gate including recycling	16.6	1.29	0.0033	0.00029	0.00054
Hot rolled coil, 1kg	Cradle-to-gate	25.4	2.35	0.0053	0.00041	0.00092
	Net recycling benefit	-10.7	-1.16	-0.0017	-0.00013	-0.00053
	Cradle-to-gate including recycling	14.7	1.19	0.0036	0.00028	0.00039
Hot-dip galvanized steel, 1kg	Cradle-to-gate	30.6	2.67	0.00603	0.00053	0.00097
	Net recycling benefit	-11.6	-1.25	-0.00187	-0.00014	-0.00058
	Cradle-to-gate including recycling	19.0	1.42	0.00416	0.00039	0.00039

Table 6: Life cycle impact assessment results of steel products

The recycling credit that can be seen in Table 6 and the following figures varies depending on the net recycling credit level. 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.

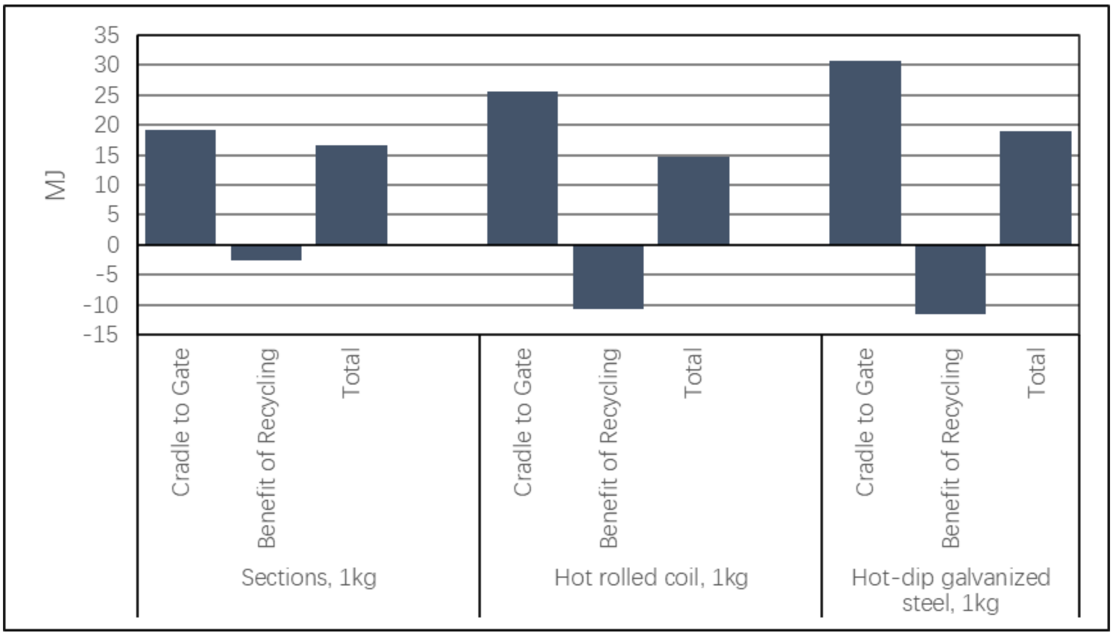


Figure 2: Primary energy demand (MJ) of steel products

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

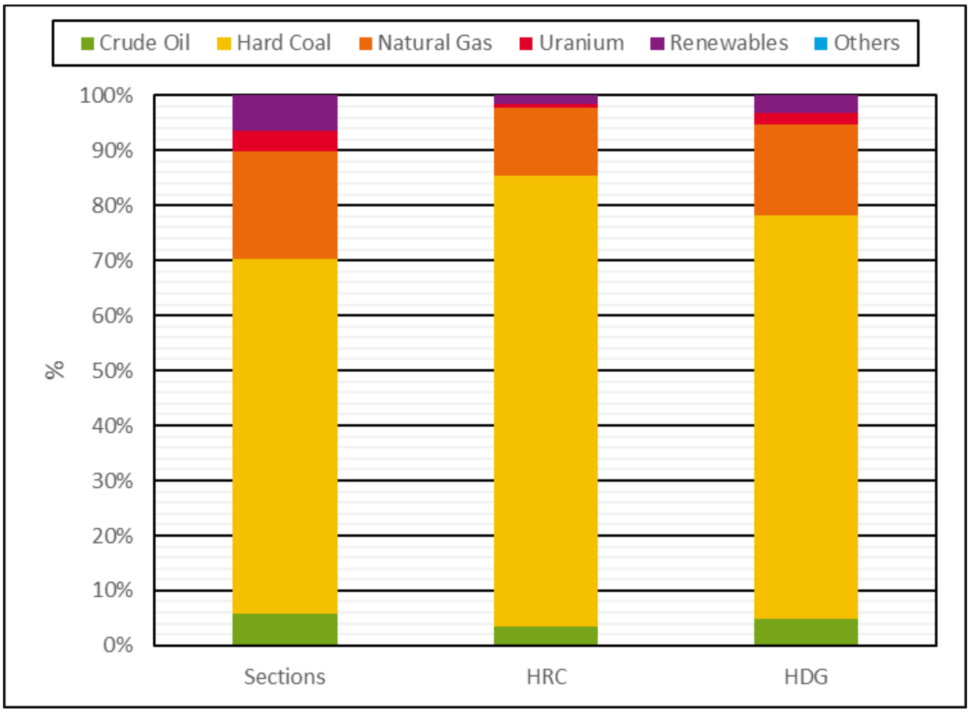


Figure 3: Contributions to primary energy demand of steel products

5.2.2 Global warming potential, GWP

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

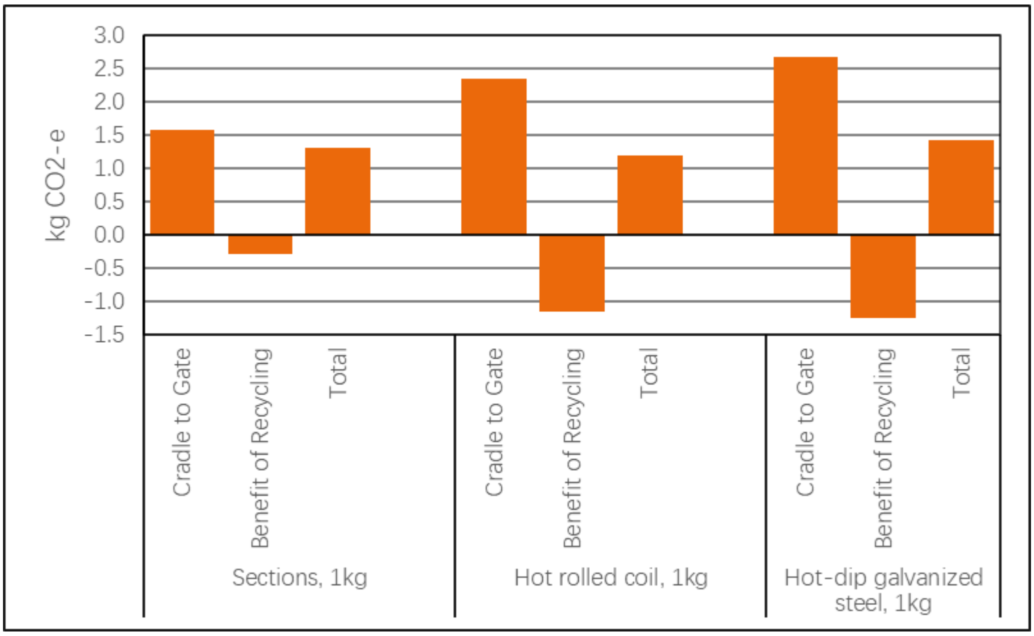


Figure 4: Global warming potential (CO_2-e) of steel products

The GWP for steel products is dominated by CO_2 and methane emissions, which combined 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 steelmaking processes 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.

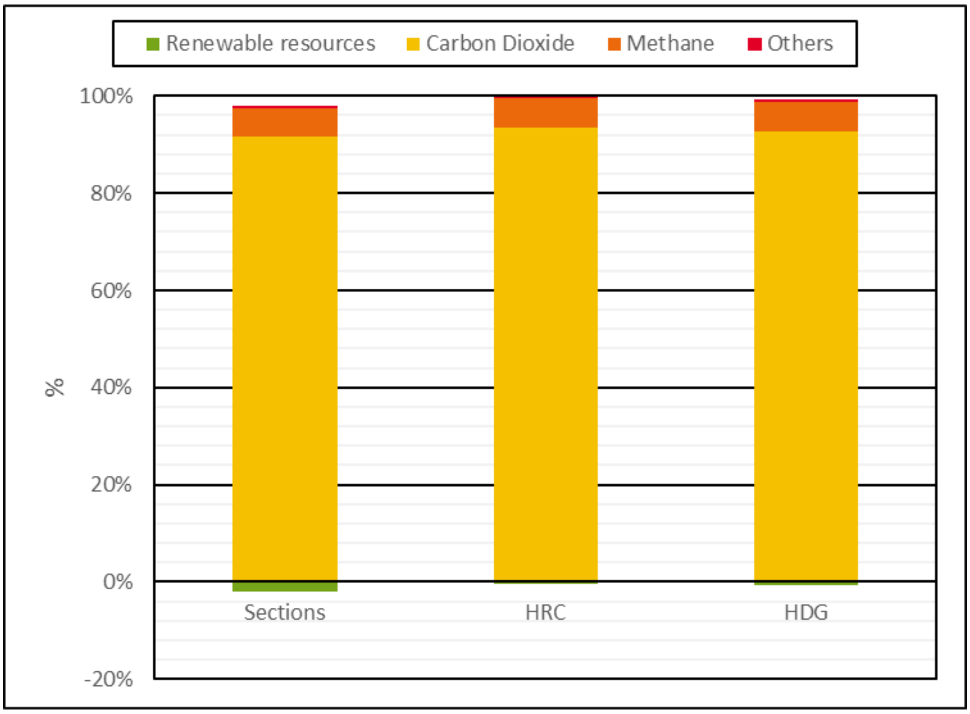


Figure 5: Contributions to global warming potential of steel products

5.2.3 Acidification potential, AP

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

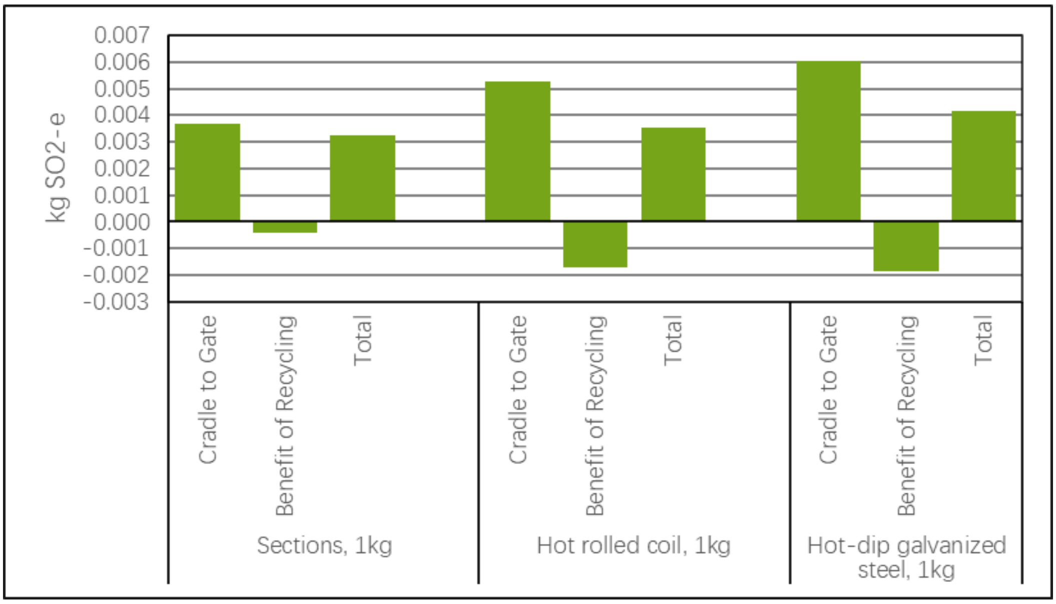


Figure 6: Acidification potential (SO_2-e) of steel products

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. The SO_2 and NO_x emissions come from a mix of sources, including upstream raw material processes, on-site emissions and raw material transportation.

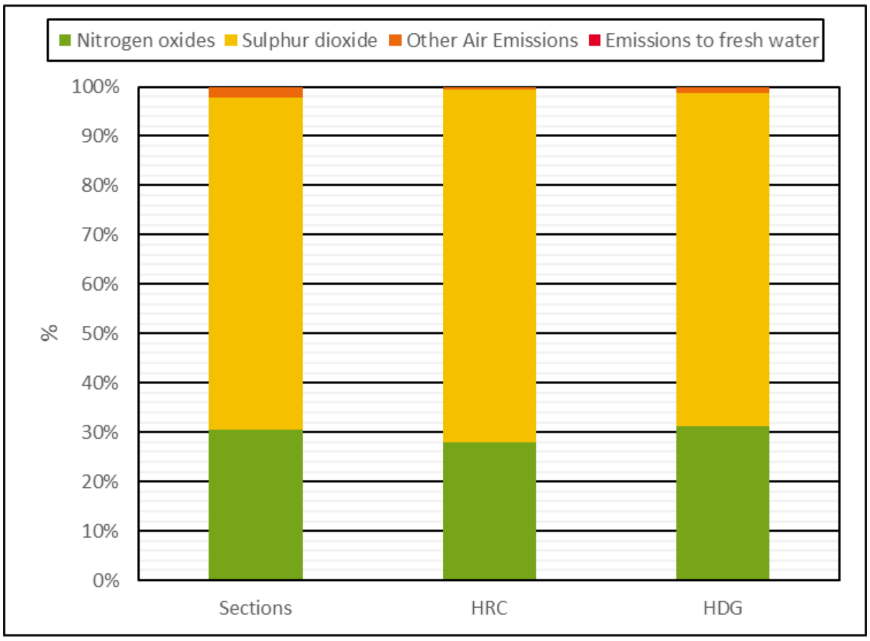


Figure 7: Contributions to acidification potential of steel products

5.2.4 Eutrophication potential, EP

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

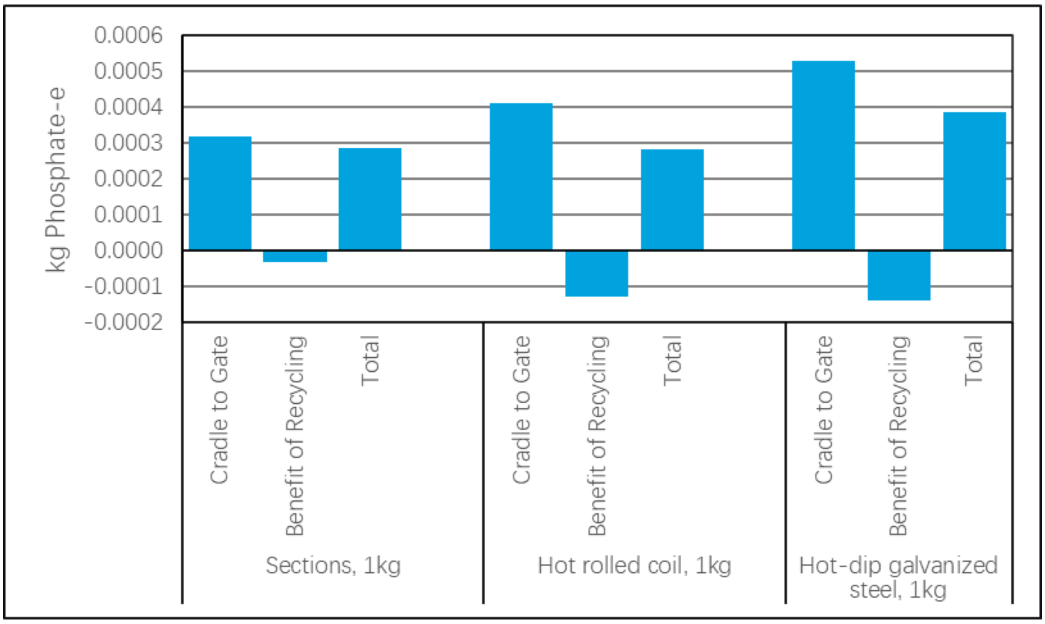


Figure 8: Eutrophication potential (PO_4^{3-}-e) of steel products

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. The nitrogen oxides emissions, as mentioned in section 0, come from a mix of sources, including upstream raw material processes, on-site emissions and raw material transportation.

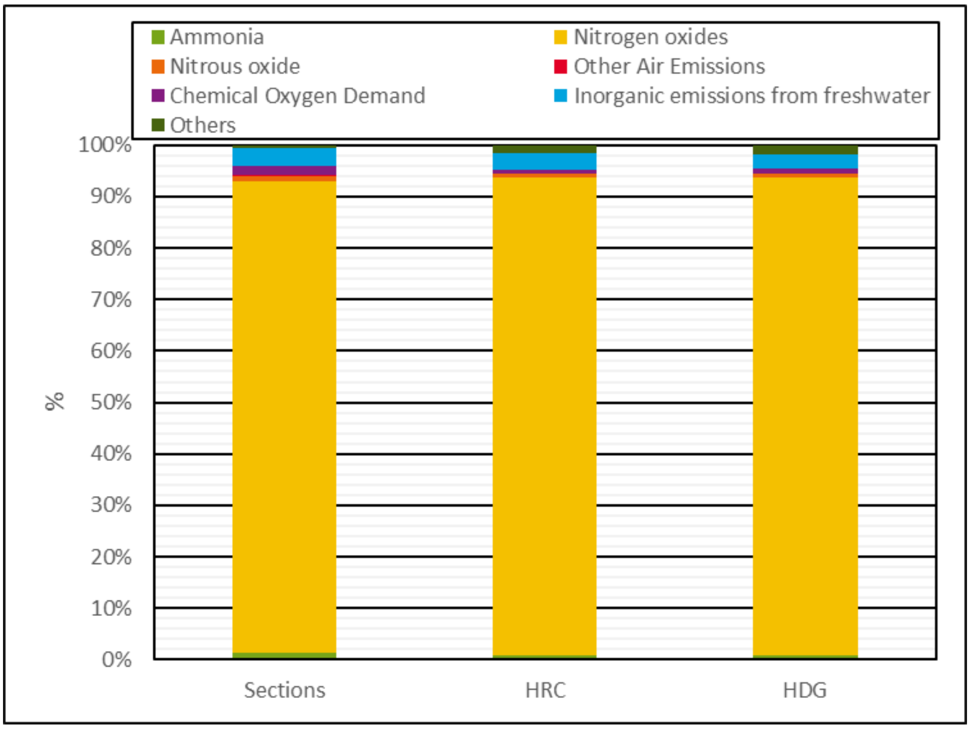


Figure 9: Contributions to eutrophication potential of steel products

5.2.5 Photochemical ozone creation potential, POCP

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

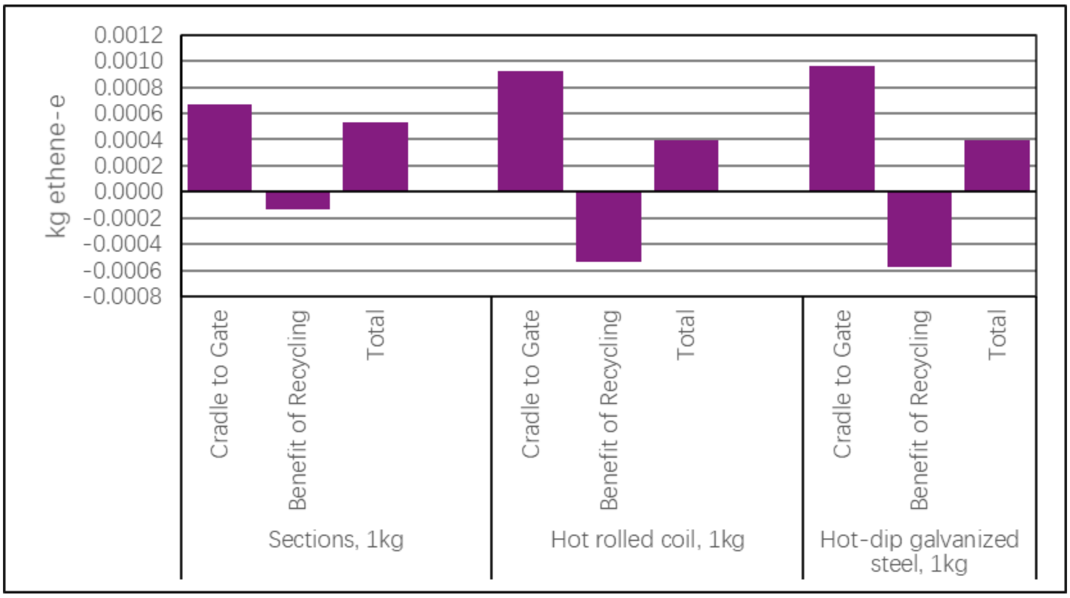


Figure 10: Photochemical ozone creation potential (C_2H_4-e) of steel products

The photochemical ozone creation potential for steel products is dominated by carbon monoxide, which accounts for over 64% of the contribution to this impact. The carbon monoxide emissions come from on-site processes, due to process gas releases or incomplete fuel combustion. All other major substances contributing to the POCP are shown in Figure 11.

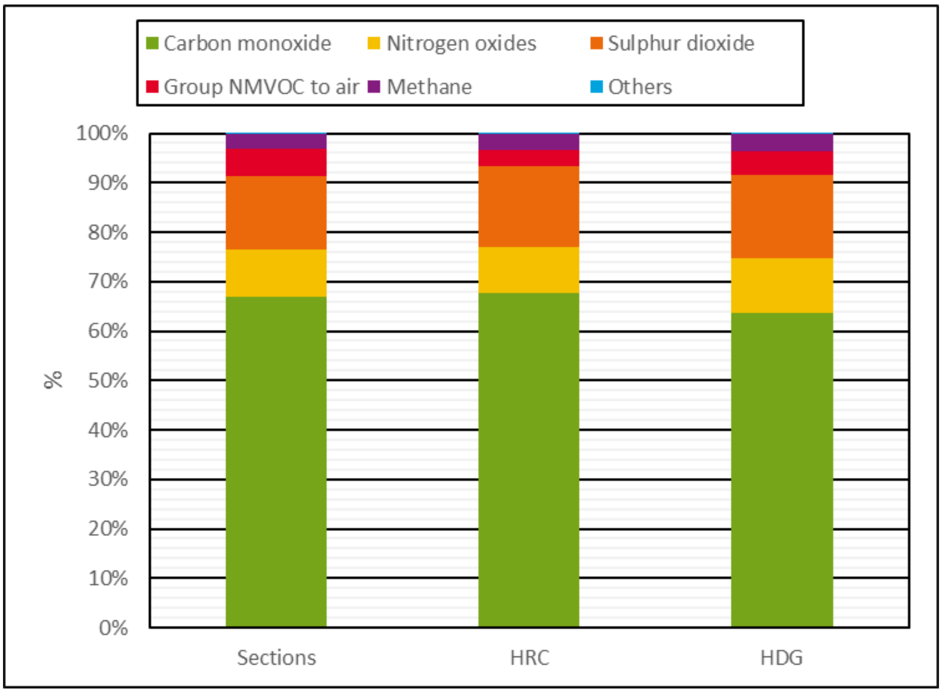


Figure 11: Contributions to POCP of steel products

5.3 Breakdown of where impacts arise for selected steel products.

The analysis 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 hot rolled coil or sections, 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 steelmaking sites). Finally, transport impacts for the main raw materials to the steelmaking site are 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 (Figures 12, 13 and 14) show 11 of the impacts that can be calculated. These impact categories are: 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 and process route being studied, the amount of processing that takes place and the specific environmental impact being assessed.

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, such as GWP.

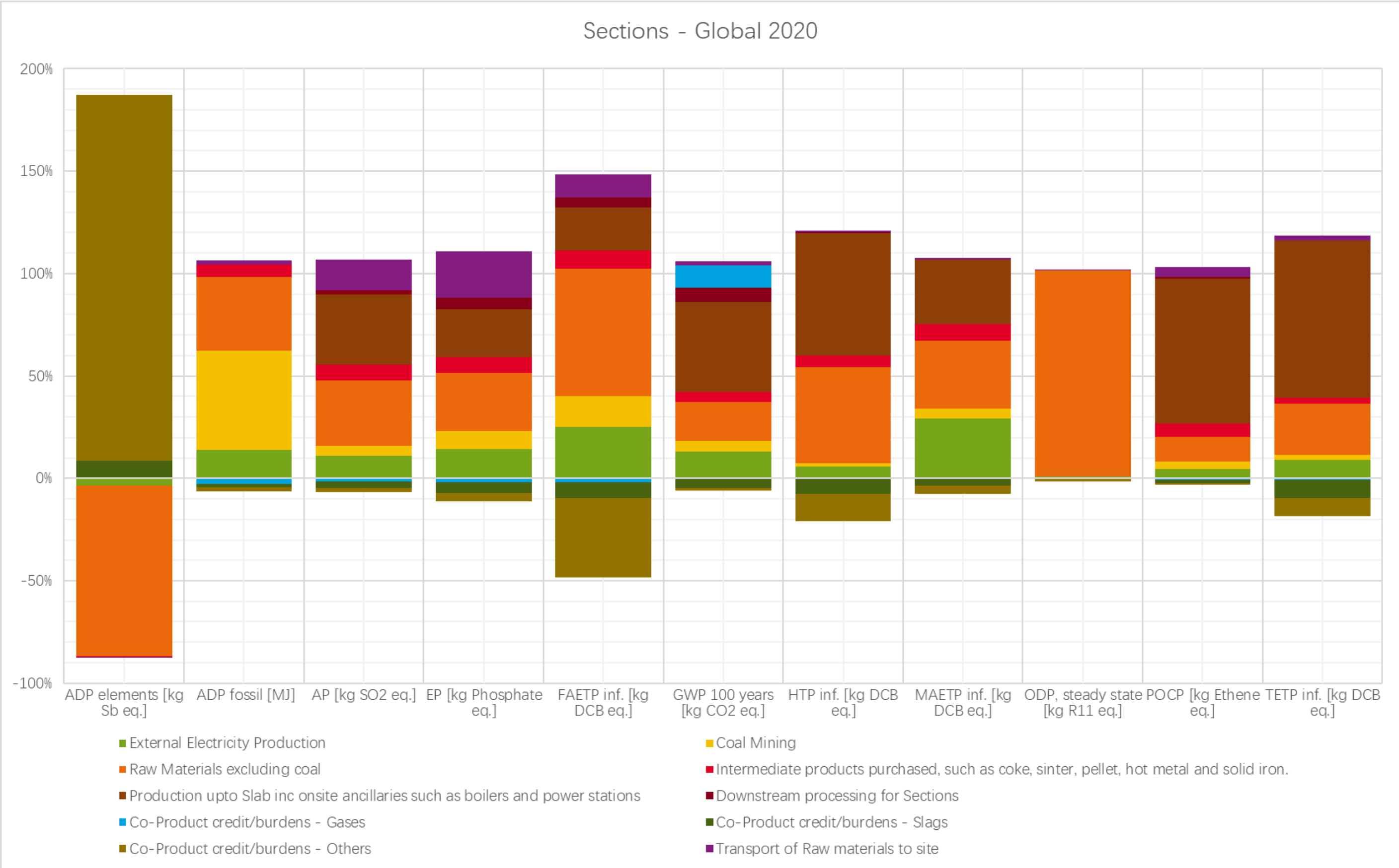


Figure 12: Contribution to environmental impacts for steel sections

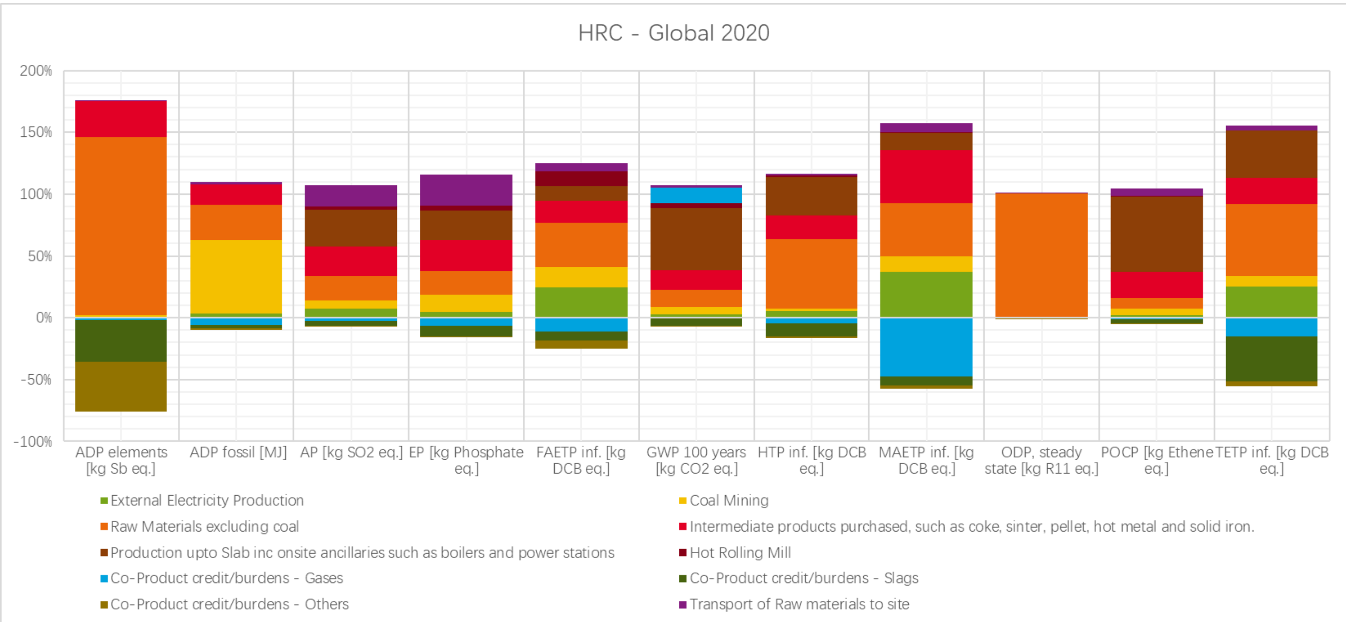


Figure 13: Contribution to environmental impacts for HRC

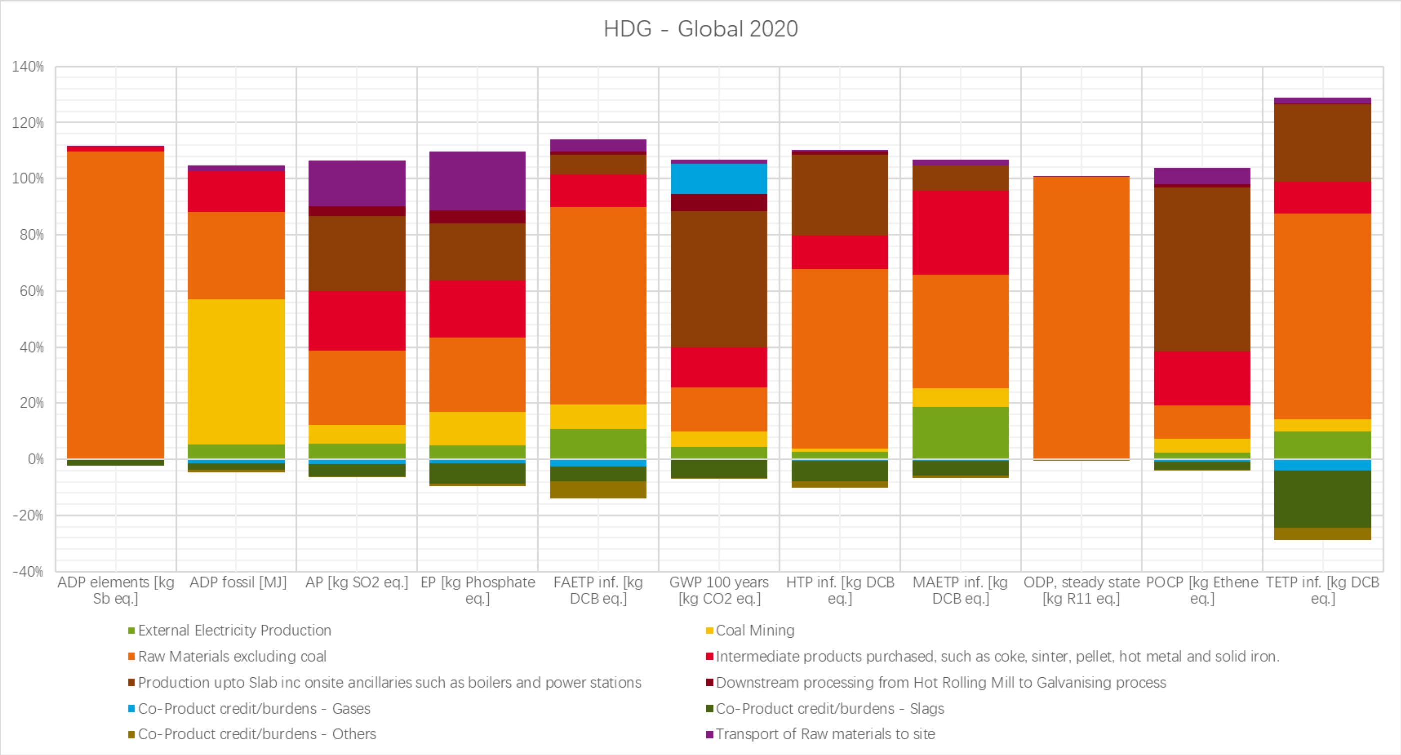


Figure 14: Contribution to environmental impacts for steel sections HDG

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 assessed 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 allocation of steelmaking co-products. 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. The amount of scrap input to the product is determined by those sites providing data to the LCI data collection and is therefore not possible to modify. 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 (which have been calculated using the system expansion approach as outlined in section 3.6 of the worldsteel LCI methodology report) and end-of-life recycling generally reduce the overall impact of the products as shown. For GWP however, this is not the case for the BOF steel production route as the co-product element of the impact is typically a burden rather than a credit. This is because the combustion of process gases from the steelworks 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 products.

For steel scrap, if the end-of-life recycling rate is lower than the amount of scrap input to the product, this will result in a net increase in the final impact assessment results for all categories.

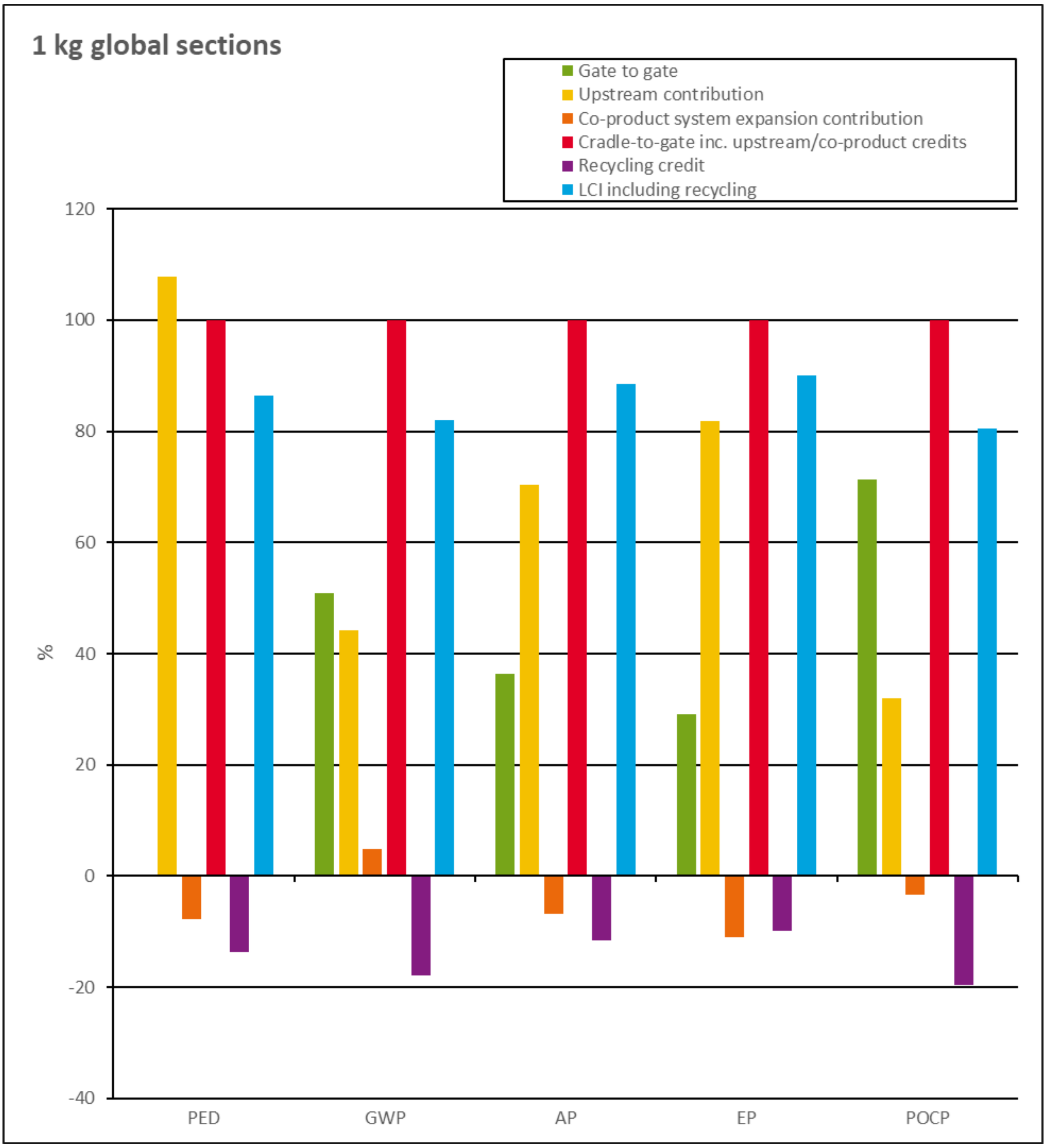


Figure 15: Life cycle contribution to PED and impact categories for steel sections

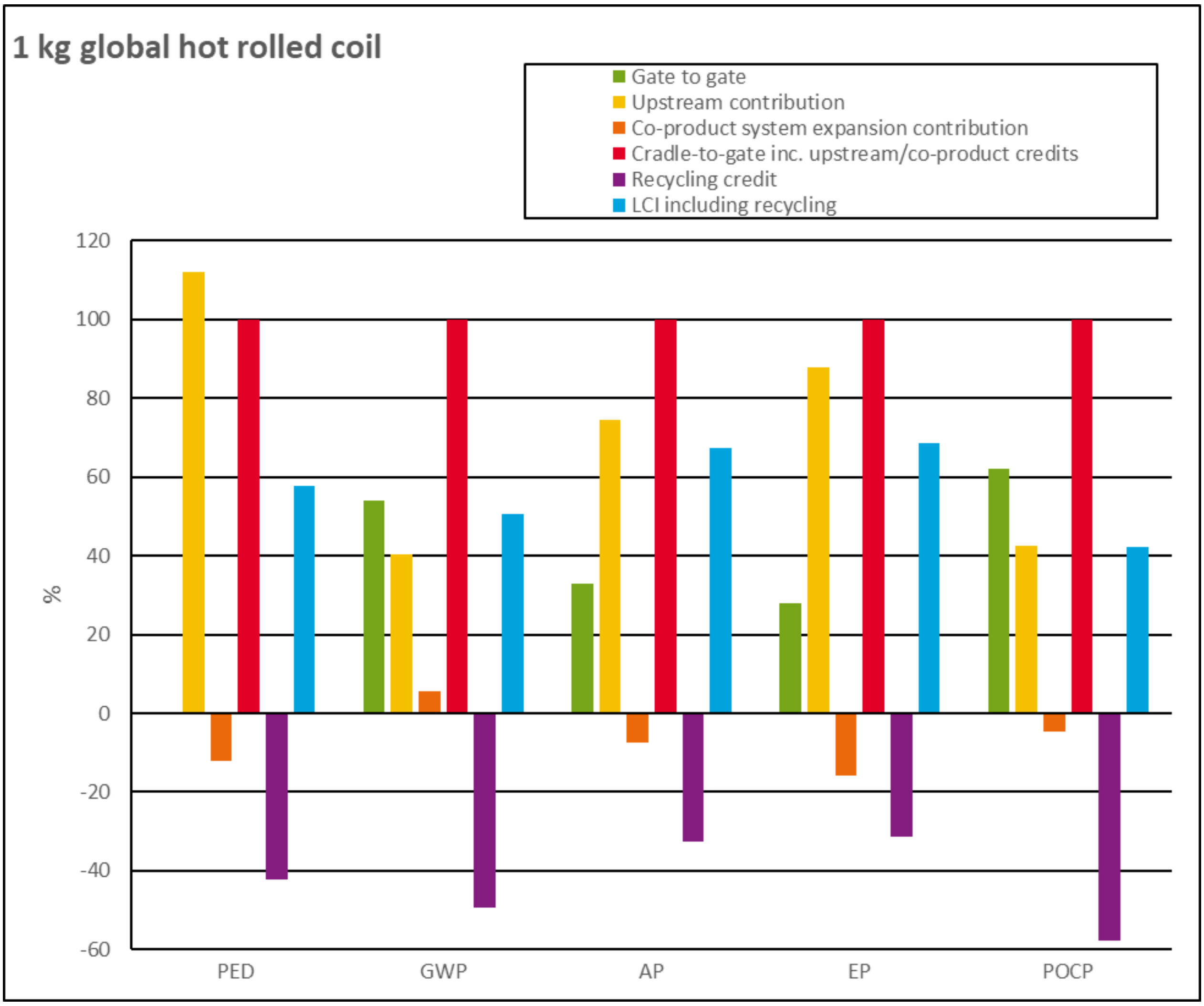


Figure 16: Life cycle contribution to PED and impact categories for HRC

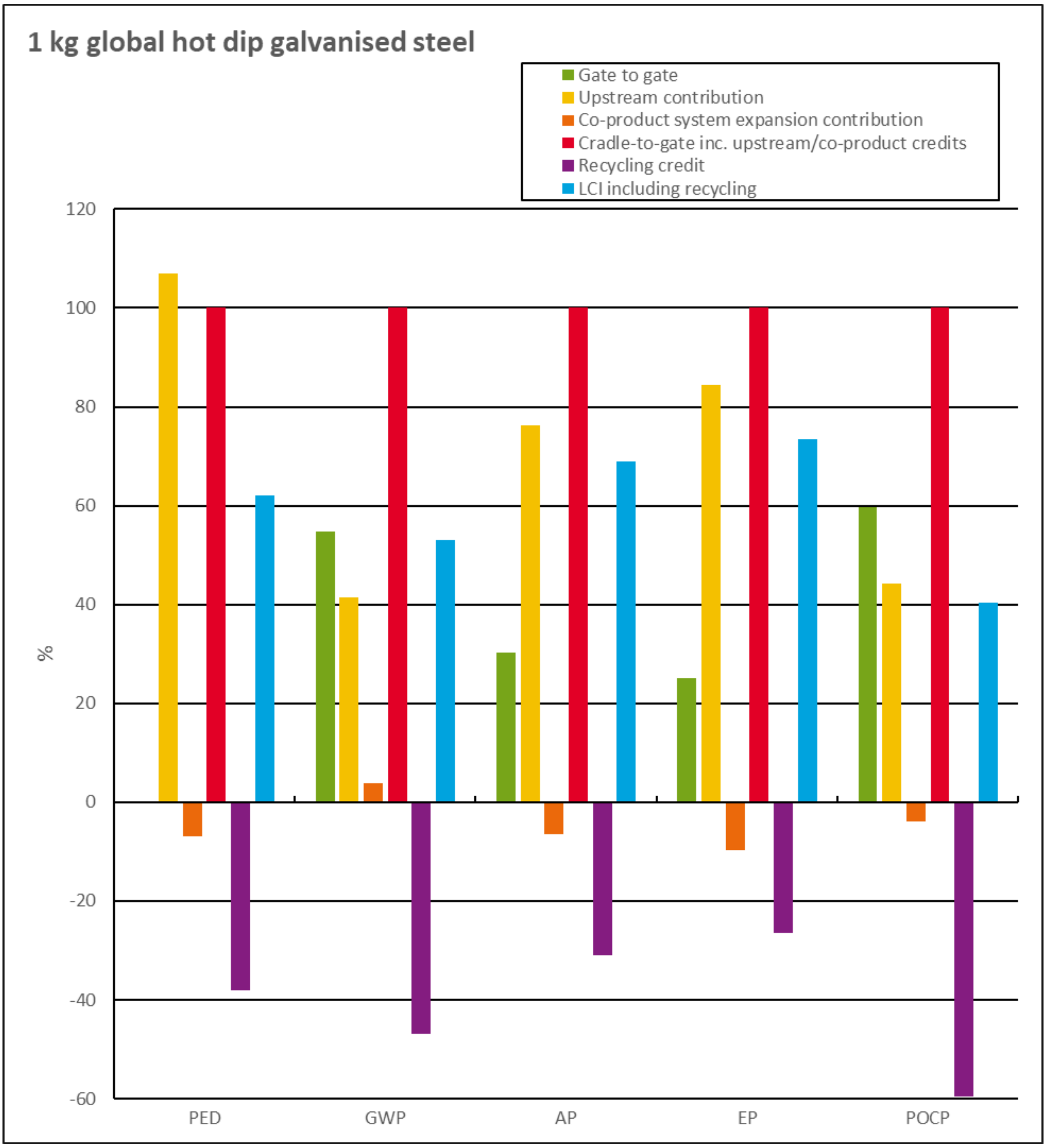


Figure 17: Life cycle contribution to PED and impact categories for HDG

Table 7 summarises the main contributors to each of the impact categories and PED, giving typical or indicative contributions for each main input or output. 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 steelworks, 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 (63 – 82%)
Crude Oil (4 – 6%)
Natural gas (12 – 19%)
Renewables (2 – 6%)</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 (>90%)
Methane (~ 6%)</td><td>Gate-to-gate (> 51%)
Upstream (41 – 44%)</td></tr>
<tr><td>Acidification potential</td><td>Sulphur dioxide (67 – 72%)
Nitrogen oxides (28 – 31%)
Others (~1%)</td><td>Gate-to-gate (30 – 36%)
Upstream (70 – 76%)</td></tr>
<tr><td>Eutrophication potential</td><td>Nitrogen oxides (>91%)
Nitrous oxide (~ 1%)
Chemical Oxygen Demand (1 - 2%)
Inorganic emissions to fresh water (~3%)</td><td>Gate-to-gate (25 – 29%)
Upstream (82 – 87%)</td></tr>
<tr><td>Photochemical ozone creation potential</td><td>Carbon monoxide (64 – 68%)
Sulphur dioxide (15 – 17 %)
Nitrogen oxides (9 - 11%)
NMVOCs (3 - 6%)
Methane (~3%)</td><td>Gate-to-gate (59 – 71%)
Upstream (31 – 44%)</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 same three products have been selected, which cover a wide range of steel product applications.

	Cradle-to-gate data	GWP	PED
		kg CO_2-e	MJ
Sections, 1kg	**Excluding system expansion**	1.50	20.7
	Including system expansion	1.58	19.2
	% difference	5.2%	-7.2%
Hot rolled coil, 1kg	**Excluding system expansion**	2.21	28.5
	Including system expansion	2.34	25.5
	% difference	5.9%	-10.8%
Hot-dip galvanized steel, 1kg	**Excluding system expansion**	2.57	32.7
	Including system expansion	2.67	30.6
	% difference	4.0%	-6.4%

Table 8: Sensitivity analysis of system expansion for co-products

Table 8 shows the influence that the use of 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 +4 to 6%. 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 route does not produce process gases (but might use them if co-located on a BOF route site) 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 -6 and -10%. This is due to the recovery of the co-products from the carbon intensive processes (coke oven, BF and BOF) 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 EAF routes; 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 gas (energy) 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 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 introduced to include the combustion of the fuel, in addition to the production of the fuel, which had always been included. An average energy requirement per kg crude steel was found to be 0.0035 MJ from internal diesel, gasoline and LPG consumption. For this 2020 study, modelling of the combustion impacts of these fuels has been calculated to produce an additional 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 data collection questionnaires, as this material is a steel product and data are therefore 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 steelmaking technologies worldwide and covers over 26% (480 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 15 new and 2 old steel product datasets (see Table 1) on a global level, of which a number of products are also represented on a regional level (Europe and Asia). The addition of new sites is an ongoing process in order to increase the geographical spread and representativeness of the data. These will be 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 2014 to 2019 (see Appendix 9). With continuing measures to improve the environmental performance of these companies, it should be noted that 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 are 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.

The results from the study reflect global steel production from 2014 to 2019 (see Appendix 9) 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. It should be noted that there may be a time delay between the data being published by worldsteel and it becoming available in the LCA software tools. 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 typical uses of steel products

Appendix 12: Critical review: World Steel Association life cycle inventory study for steel products

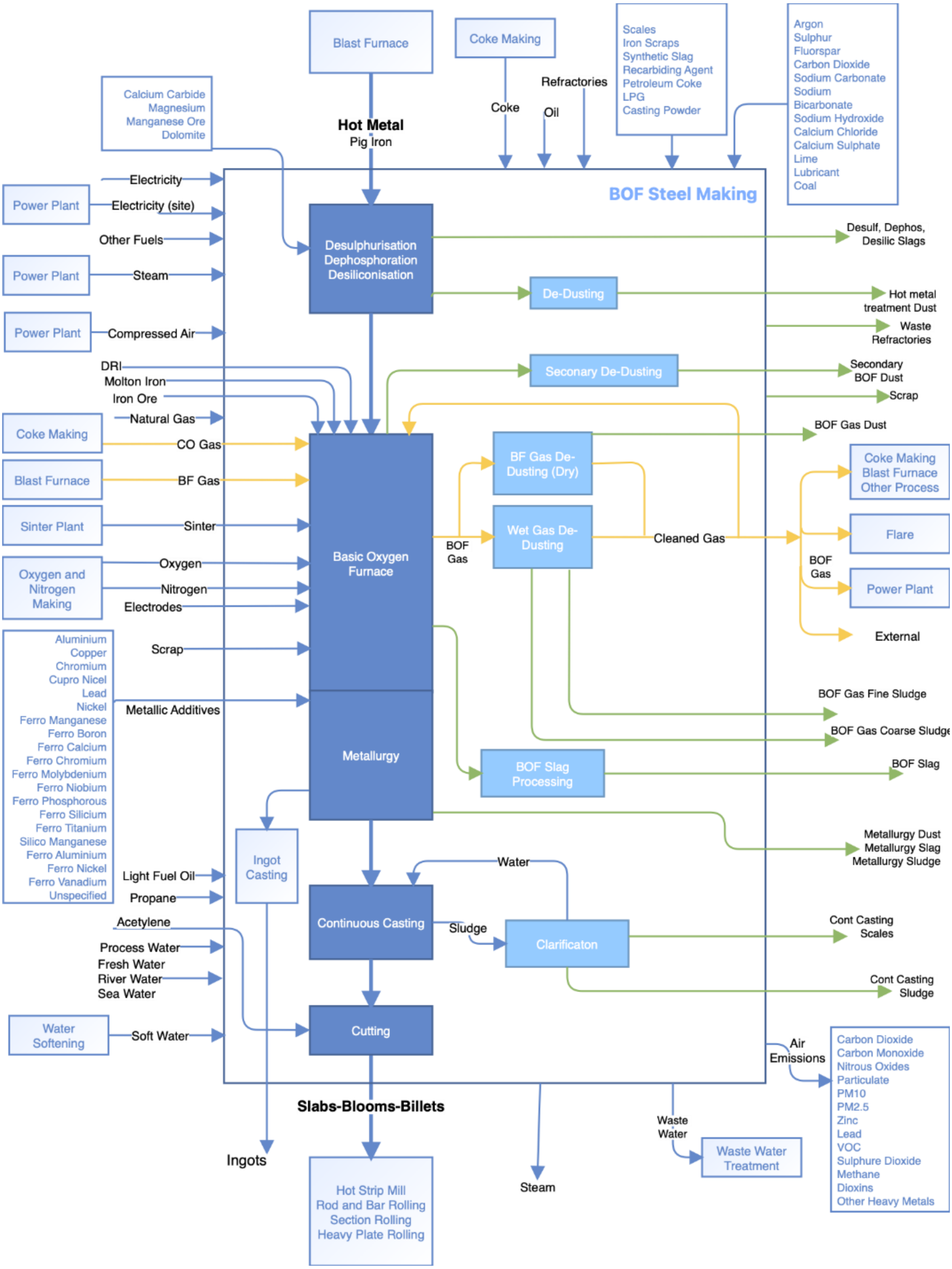
Appendix 1: Description of steel products covered by the study

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).

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.
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.
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

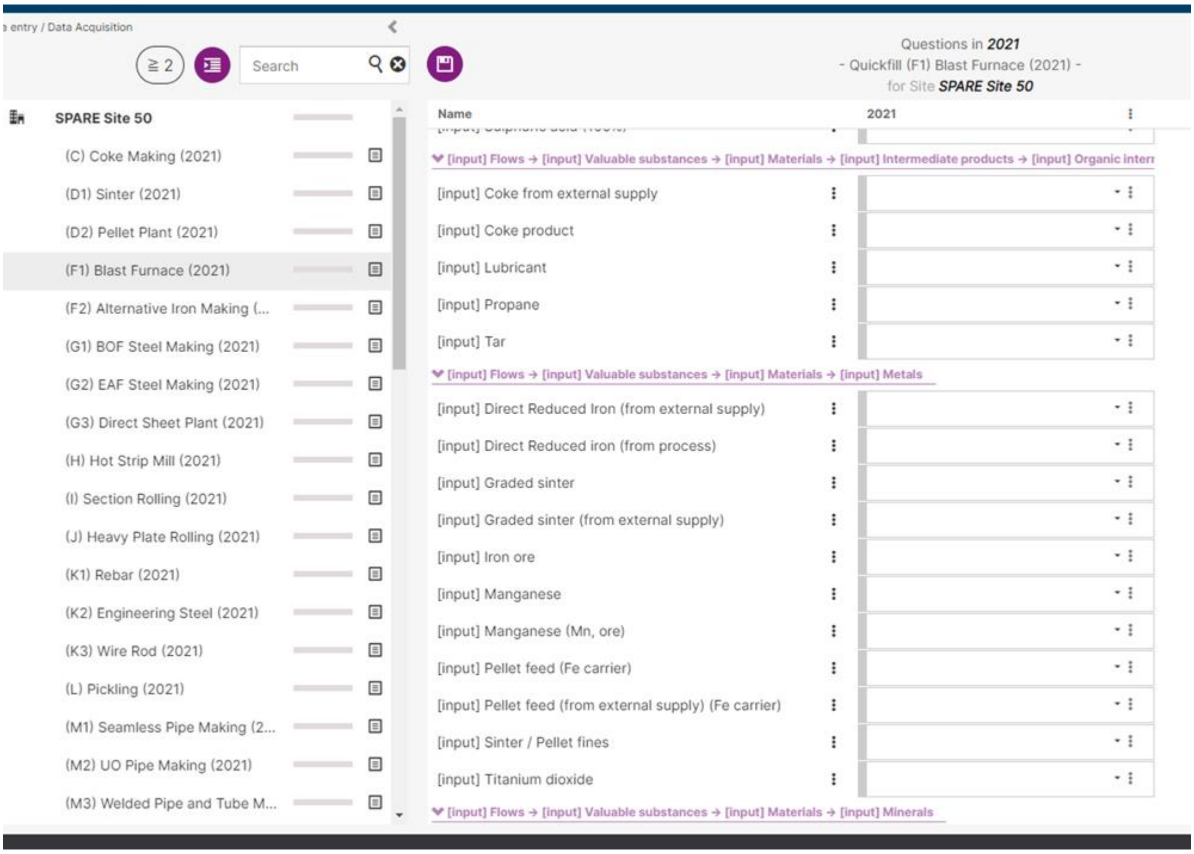


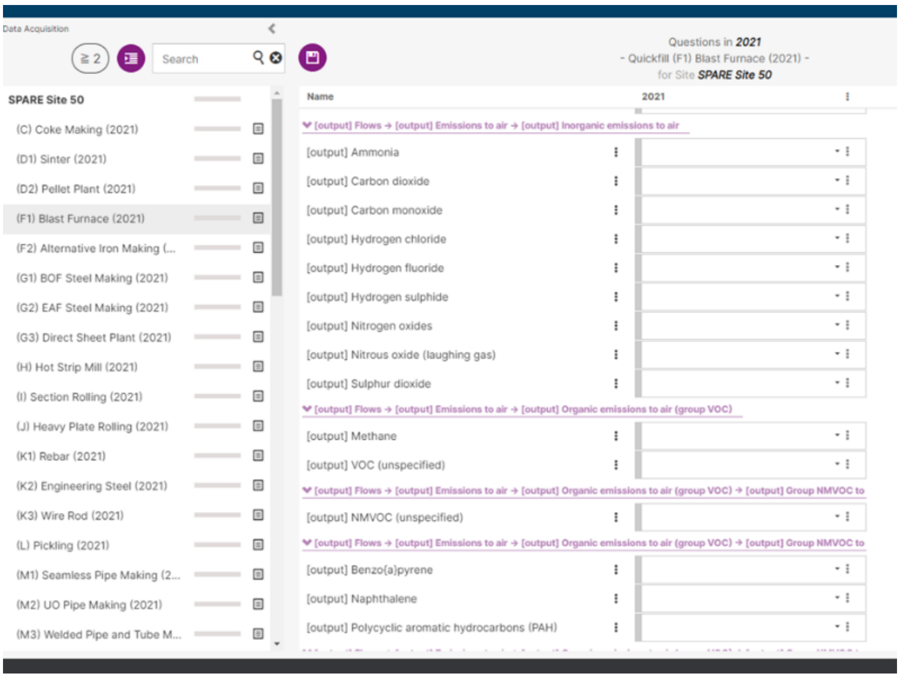
Appendix 3: List of participating companies

The companies that contributed to the data released in 2020 are listed below:

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

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	2019	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	2019	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	2019	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	2019	Sphera
Aluminium sulphate	Aluminium sulphate	DE	2019	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	2019	Sphera
Ammonium sulphate	Ammonium sulphate mix (by-product)	DE	2019	Sphera

Item	Process Information	Country	Year	Source
Anthracite	Country specific data, based on hard coal mix for each country	Country specific	2016	Sphera
Argon	Gaseous, LINDE process	DE	2019	Sphera
Bauxite	Opencast and underground mining	EU-28	2019	Sphera
Benzene	Technology mix, from pyrolysis gasoline, reformate and toluene dealkylation	EU-28	2019	Sphera
BOF slab	1kg global BOF slab, weighted average	GLO	2020	worldsteel
Calcium chloride	From epichlorohydrine synthesis	DE	2019	Sphera
Carbon dioxide	From HABER-BOSCH process (ammonia synthesis, NH_3/CO_2)	DE	2019	Sphera
Catalyst	Ethylene glycol	EU-28	2019	Sphera
Cement	Cement (CEM I 42.5) (EN15804 A1-A3)	EU-28	2019	Sphera
Charcoal	Site data for production	GLO	2015	worldsteel
Coal	Country specific data, based on hard coal mix for each country	Country specific	2016	Sphera
Coal for coke making	Coking coal global consumption mix including transport to border of country of production	GLO	2016	Sphera

Item	Process Information	Country	Year	Source
Coal for injection	Country specific data, based on hard coal mix for each country	Country specific	2016	Sphera
Coke	1kg global coke, weighted average	GLO	2020	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	2019	Sphera
Corrugated board	EU-27: Corrugated board incl. paper production, average composition 2015 ts/FEFCO	EU-27	2019	Sphera
Diesel	From crude oil processing and distillation. Country/region specific	Country / region specific	2016	Sphera
Diesel (high Sulphur)	From crude oil processing and distillation. Country/region specific	Country / region specific	2016	Sphera
Diesel (low Sulphur)	From crude oil processing and distillation. Country/region specific	Country / region specific	2016	Sphera
Direct Reduced Iron	1kg global DRI, weighted average	GLO	2020	worldsteel
Dolomite	Decarboxylation process by burning mined dolomite	EU-28	2019	Sphera
Dolomite (crude)	Dolomite extraction	DE	2019	Sphera

Item	Process Information	Country	Year	Source
EAF Slab	1kg global EAF slab, weighted average	GLO	2020	worldsteel
Electricity	See Appendix 6 – Country specific	Country specific	2016	Sphera
Electrode	Baking petrol coke, pitch and hard coal tar	ZA	2019	Sphera
Embankment	Gravel (Grain size 2/32) (EN15804 A1-A3)	DE	2019	Sphera
Ferric chloride	Direct chlorination of iron scrap	DE	2019	Sphera
Ferro chrome	Ferro Chromium (high carbon)	GLO	2019	Sphera
Ferro manganese	Production of ferro-manganese (77% Mn) with high carbon content.	ZA	2019	Sphera
Ferro molybdenum	Ferro molybdenum (67% Mo)	GLO	2017	IMOA
Ferro nickel	Ferro nickel (29% Ni)	GLO	2019	Sphera
Ferro silicum	Ferro silicon mix (91%)	GLO	2019	Sphera
Ferro vanadium	Ferro vanadium (FeV 80%)	ZA	2019	Sphera
Ferrous sulphate	Iron (II) sulphate	EU-28	2019	Sphera
Gasket (seal)	EPDM gaskets for aluminium profile (EN15804 A1-A3)	DE	2019	Sphera

Item	Process Information	Country	Year	Source
Gasoline	From crude oil and bio components	EU-28	2016	Sphera
Glass wool	For glass wool production, the pure mineral primary glass is melted in a melting vat at approx. 1400°C	EU-28	2019	Sphera
Glue	Mixer of Methylenediphenyl diisocyanate, (p)MDI, and Aromatic Polyester Polyols (APP) production mix	EU-28	2019	Sphera
Heavy fuel oil	Country/region specific	Country / region specific	2016	Sphera
Hot metal	1kg global hot metal, weighted average	GLO	2020	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	2019	Sphera
Hydrogen	Steam reforming - natural gas	EU-28	2019	Sphera
Hydrogen peroxide	50% H_2O_2. Anthraquinone process	DE	2019	Sphera
Iron Ore	worldsteel production mix of 4 thinkstep datasets	GLO	2020	Sphera
Kerosene	From crude oil	EU-28	2016	Sphera
Lead	Lead (99.995%), primary lead produced on the traditional process route. Does not include lead and zinc recovery.	RNA	2019	Sphera

Item	Process Information	Country	Year	Source
Light fuel oil	Country/region specific	Country / region specific	2016	Sphera
Lime	Calcination of limestone	DE	2019	Sphera
Limestone	Mining and beneficiation	DE	2019	Sphera
Liquefied petroleum	Liquefied gas (LPG; 70% Propane; 30% Butane), refining process	DE	2016	Sphera
Lubricants	The data set covers the entire supply chain of the refinery products.	EU-28	2016	Sphera
Magnesium	Magnesium Pidgeon process	CN	2019	Sphera
Manganese	South Africa and Australia cover 90% of the world manganese production (International Manganese Institute). 80% of the mining takes place underground and 20% in open cast operations. The beneficiation is done at the mining site. The manganese ore is crushed and processed. The concentrate is then reduced by intense heating in a calcination process. Manganese metal is produced during electrolysis by addition of ammonia and sulphuric acid. The end product is manganese 99%.	ZA	2019	Sphera
MDI (Isocyanate)	80% of the mining takes place underground and 20% in open cast operations. The beneficiation is done at the mining site. The manganese ore is crushed and processed.	DE	2019	Sphera
Mineral rock wool	The concentrate is then reduced by intense heating in a calcination process. Manganese metal is produced during electrolysis by addition of ammonia and sulphuric acid.	DE	2019	Sphera
Natural gas	Country specific data, based on natural gas mix for each country.	Country specific	2016	Sphera

Item	Process Information	Country	Year	Source
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	2019	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	2019	Sphera
Nitrogen	Air and power to produce gaseous nitrogen, country specific electricity.	Country specific	2007	Sphera
Olivine	Silica sand (Excavation and processing)	DE	2019	Sphera
Oxygen	Air, cooling water and power to produce gaseous oxygen, country specific electricity.	Country specific	2007	Sphera
Paint (epoxy, melamine)	Mix of three powder coating upstream datasets, red, black and white	DE	2019	Sphera
Paint (epoxy, phenolic)	Mix of three powder coating upstream datasets, red, black and white	DE	2019	Sphera
Paint (polyester, melamine)	Mix of three powder coating upstream datasets, red, black and white	DE	2019	Sphera
Paint (polyurethane)	Mix of water and solvent based primer	DE	2019	Sphera
Paint (polyvinyl chloride)	Underbody protection PVC	DE	2019	Sphera

Item	Process Information	Country	Year	Source
Paint (silicon modified polyester)	Mix of Coating water-based red, black and white	DE	2019	Sphera
Paint (PVDF, acrylic)	Mix of Coating solvent-based red, black and white	DE	2019	Sphera
Pellet	1kg global pellet, weighted average	GLO	2020	worldsteel
Pentane	Estimated via Butane	EU-28	2019	Sphera
Petroleum coke	Country / region specific data, based on hard coal mix for each country	Country / region specific	2016	Sphera
Phosphoric acid	100%, wet process	DE	2019	Sphera
PMDI	Methylenediphenyl diisocyanate, (p)MDI	EU-28	2010	Sphera
Polyethylene	Polyethylene low density granulate (PE-LD)	EU-28	2019	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	2019	Sphera
Propane	Regional specific	Region specific	2016	Sphera
Protection Foil (PE-LD)	Polyethylene Film (PE-LD) without additives	EU-28	2019	Sphera

Item	Process Information	Country	Year	Source
Quartz 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	2019	Sphera
Refractories (all)	Sand-lime insulation brick	EU-28	2019	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	2019	Sphera
Serpentine	Mined, as kaolin, normally together with silica sand and feldspar using bucket excavators or bucket chain dredgers.	DE	2019	Sphera
Silico Manganese	Ferro-manganese high carbon proxy	ZA	2019	Sphera
Silicon mix	Purified, electric arc furnace process, from quartz sand	GLO	2019	Sphera
Sinter	1kg global sinter, weighted average	GLO	2019	worldsteel
Sinter/pellet fines	1kg global sinter, weighted average	GLO	2019	worldsteel
Sodium carbonate	Soda (Na_2CO_3), produced by the Solvay process	DE	2019	Sphera
Sodium chloride	Rock salt is obtained from salt mines by use of machines or leaching techniques.	EU-28	2019	Sphera
Sodium hydroxide	100% caustic soda from brine extraction, electrolysis and purification	EU-28	2019	Sphera
Sodium hypochlorite	50% solution	DE	2019	Sphera

Item	Process Information	Country	Year	Source
Sodium sulphate	Sodium sulphate is a by-product in the production of boric acid.	GLO	2019	Sphera
Steam	Process steam from natural gas 85%	EU-28	2016	Sphera
Steel scrap	See section 3.6.2.	GLO	2020	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	2020	worldsteel
Sulphur	From Crude Oil	EU-28	2016	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	2019	Sphera
Surface cleaning agent	Non-ionic surfactant (fatty acid derivative)	GLO	2019	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	2019	Sphera
Tar	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	EU-28	2016	Sphera

Item	Process Information	Country	Year	Source
Thermal energy	Mix of thermal energy from peat and biomass	FI	2016	Sphera
Timber	Timber pine (12% moisture; 10.7% H_2O content) (EN15804 A1-A3)	DE	2019	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	2019	Sphera
Titanium dioxide	Chloride process	EU-28	2019	Sphera
Varnish	Clear coat solvent-based (2K)	DE	2019	Sphera
Zinc	Special high-grade zinc	GLO	2019	IZA

Appendix 6: Electricity grid mix information

The national power grid mix that is used for each site is relevant to the location of each steelmaking site, by country (and 4 regions of the USA, where more specific grid mix data is recorded and is related to the location of the steel making activities). All data has been taken from the GaBi 10.0.1 CUP2020.2 software and is listed in more detail below. The data is a cradle-to-gate inventory and has been developed in line with ISO 14040: 2006 and 14044: 2006. The age of the grid mix data is somewhat behind other data sources, due to the source of the data (IEA) and the time it takes to collate all of the information on a global level (including country imports and exports) and incorporate it into the GaBi database.

Country	Age	Grid
Argentina	2016	51.19% Natural gas, 25.67% Hydro,14.24% Heavy fuel oil, 5.63% Nuclear, 1.28% Hard coal, 1.16% Biomass, 0.45% Coal gases, 0.38% Wind, 0.01% Photovoltaic.
Australia	2016	44.56% Hard coal, 19.65% Natural gas, 19.02% Lignite, 5.97% Hydro, 4.75% Wind, 2.42% Photovoltaic, 2.17% Heavy fuel oil, 0.96% Biomass, 0.5% Biogas.
Austria	2016	62.81% Hydro, 12.57% Natural gas, 7.66% Wind, 5.39% Biomass, 2.98% Hard Coal, 2.82% Coal gases, 1.76% Waste, 1.6% Photovoltaic, 1.45% Heavy fuel oil, 0.95% Biogas.
Belgium	2016	51.2% Nuclear, 26.01% Natural gas, 6.39% Wind, 3.99% Biomass, 3.63% Photovoltaic, 2.65% Coal gases, 2.51% Waste, 1.75% Hydro, 1.2% Biogas, 0.46% Hard coal, 0.22% Heavy fuel oil.
Bosnia and Herzegovina	2015	37.55% Hard coal, 35.52% Hydro, 26.43% Lignite, 0.31% Heavy fuel oil, 0.19% Natural gas.
Brazil	2016	65.84% Hydro, 9.76% Natural gas, 8.62% Biomass, 5.79% Wind, 2.74% Nuclear, 2.64% Heavy fuel oil, 1.7% Hard coal, 1.5% Coal gases, 1.24% Lignite, 0.13% Biogas, 0.01% Photovoltaic.
Canada	2016	58.03% Hydro, 15.16% Nuclear, 9.29% Natural gas, 8.16% Lignite, 4.61% Wind, 1.73% Biomass, 1.24% Heavy fuel oil, 1.15% Hard coal, 0.45% Photovoltaic, 0.15% Biogas, 0.04% Waste, 0.01% Coal gases.
China	2016	66.76% Hard coal, 19.19% Hydro, 3.81% Wind, 3.43% Nuclear, 2.74% Natural gas, 1.46% Coal gases, 1.21% Photovoltaic, 1.04% Biomass, 0.18% Waste, 0.17% Heavy fuel oil.
Czech	2016	43.58% Lignite, 28.97% Nuclear, 6.86% Hard coal, 6.86% Natural gas, 3.85% Hydro, 3.11% Biogas, 2.56% Photovoltaic, 2.48% Biomass, 0.81% Coal gases, 0.6% Wind, 0.22% Waste, 0.11% Heavy fuel oil.

Country	Age	Grid
Finland	2016	33.88% Nuclear, 23.07% Hydro, 15.48% Biomass, 10.18% Hard coal, 5.46% Natural gas, 4.48% Wind, 4.25% Peat, 1.38% Waste, 0.92% Coal gases, 0.59% Biogas, 0.29% Heavy fuel oil, 0.02% Photovoltaic.
France	2016	72.57% Nuclear, 11.77% Hydro, 6.27% Natural gas, 3.85% Wind, 1.52% Hard coal, 1.47% Photovoltaic, 0.82% Waste, 0.55% Biomass, 0.46% Heavy fuel oil, 0.37% Coal gases, 0.34% Biogas.
Germany	2016	23.1% Lignite, 17.34% Hard coal, 13.08% Nuclear, 12.71% Natural gas, 12.14% Wind, 5.89% Photovoltaic, 5.28% Biogas, 4.04% Hydro, 2.05% Waste, 1.77% Coal gases, 1.67% Biomass, 0.9% Heavy fuel oil, 0.03% Geothermal.
India	2016	64.01% Hard coal, 10.62% Lignite, 9.31% Hydro, 4.82% Natural gas, 3.04% Wind, 2.77% Biomass, 2.57% Nuclear, 1.59% Heavy fuel oil, 0.96% Photovoltaic, 0.15% Coal gases, 0.11% Waste, 0.08% Biogas.
Italy	2016	43.64% Natural gas, 15.31% Hydro, 12.23% Hard coal, 7.65% Photovoltaic, 6.12% Wind, 4.49% Biogas, 4.2% Heavy fuel oil, 2.18% Geothermal, 1.7% Waste, 1.43% Biomass, 0.97% Coal gases, 0.09% Lignite.
Japan	2016	39.22% Natural gas, 30.6% Hard coal, 8.21% Hydro, 8.15% Heavy fuel oil, 4.92% Photovoltaic, 3.11% Coal gases, 1.79% Waste, 1.74% Nuclear, 1.43% Biomass, 0.57% Wind, 0.24% Geothermal, 0.02% Biogas.
Luxembourg	2016	69.58% Hydro, 11.75% Natural gas, 5.05% Waste, 4.6% Wind, 4.55% Photovoltaic, 3.32% Biogas, 1.14% Biomass.
Mexico	2016	60.01% Natural gas, 10.68% Hard coal, 10.59% Heavy fuel oil, 9.58% Hydro, 3.3% Nuclear, 3.24% Wind, 1.92% Geothermal, 0.41% Biomass, 0.12% Coal gases, 0.08% Photovoltaic, 0.05% Biogas, 0.02% Waste.
Morocco	2015	57.21% Hard coal, 19.34% Natural gas, 8.42% Wind, 7.63% Hydro, 7.39% Heavy fuel oil, 0.02% Solar thermal.

Country	Age	Grid
Netherlands	2016	46.86% Natural gas, 31.94% Hard coal, 7.11% Wind, 3.44% Nuclear, 3.23% Waste, 2.34% Coal gases, 1.66% Biomass, 1.36% Photovoltaic, 1.11% Heavy fuel oil, 0.86% Biogas, 0.09% Hydro.
Poland	2016	47.67% Hard coal, 30.57% Lignite, 7.56% Wind, 4.7% Natural gas, 4.15% Biomass, 1.57% Coal gases, 1.38% Hydro, 1.38% Heavy fuel oil, 0.62% Biogas, 0.14% Waste, 0.07% Photovoltaic.
Romania	2016	28.47% Hydro, 24.18% Lignite, 17.34% Nuclear, 14.83% Natural gas, 10.12% Wind, 2.8% Photovoltaic, 1.08% Heavy fuel oil, 0.72% Biomass, 0.22% Hard coal, 0.15% Coal gases, 0.1% Biogas.
Russia	2016	47.83% Natural gas, 18.02% Nuclear, 17.11% Hydro, 7.96% Hard coal, 7.09% Lignite, 1.01% Heavy fuel oil, 0.6% Coal gases, 0.22% Waste, 0.06% Peat, 0.04% Photovoltaic, 0.01% Wind.
Saudi Arabia	2015	55.8% Natural gas, 44.2% Heavy fuel oil.
Spain	2016	21.35% Nuclear, 19.23% Natural gas, 17.81% Wind, 14.51% Hydro, 12.59% Hard coal, 6.16% Heavy fuel oil, 2.94% Photovoltaic, 2.03% Solar thermal, 1.47% Biomass, 0.67% Lignite, 0.54% Waste, 0.37% Coal gases, 0.33% Biogas.
Sweden	2016	40.45% Nuclear, 39.83% Hydro, 9.92% Wind, 6.25% Biomass, 2.1% Waste, 0.4% Natural gas, 0.37% Coal gases, 0.26% Heavy fuel oil, 0.17% Hard coal, 0.14% Peat, 0.09% Photovoltaic, 0.04% Biogas.
Taiwan	2016	32.8% Hard coal, 31.52% Natural gas, 11.99% Nuclear, 11.62% Lignite, 4.28% Heavy fuel oil, 3.73% Hydro, 1.75% Coal gases, 1.26% Waste, 0.55% Wind, 0.43% Photovoltaic, 0.07% Biomass, 0.01% Biogas.
Thailand	2016	65.21% Natural gas, 10.37% Hard coal, 9.26% Biomass, 8.93% Lignite, 3.65% Hydro, 1.77% Photovoltaic, 0.31% Biogas, 0.3% Heavy fuel oil, 0.18% Wind, 0.03% Waste.

Country	Age	Grid
Turkey	2016	32.6% Natural gas, 24.56% Hydro, 17.88% Hard coal, 15.14% Lignite, 5.67% Wind, 1.76% Geothermal, 0.7% Heavy fuel oil, 0.69% Coal gases, 0.57% Biogas, 0.38% Photovoltaic, 0.03% Biomass, 0.01% Waste.
United Kingdom	2016	42.24% Natural gas, 21.13% Nuclear, 11.01% Wind, 9.05% Hard coal, 5.77% Biomass, 3.07% Photovoltaic, 2.46% Hydro, 2.27% Biogas, 2.22% Waste, 0.54% Heavy fuel oil, 0.23% Coal gases.
United States of America	2015	32.85% Natural gas, 29.38% Hard coal, 19.46% Nuclear, 6.77% Hydro, 5.32% Wind, 1.89% Lignite, 1.08% Biomass, 1.08% Photovoltaic, 0.81% Heavy fuel oil, 0.43% Waste, 0.43% Geothermal, 0.32% Biogas, 0.1% Coal gases, 0.09% Solar thermal.

Full documentation for GaBi 10.0.1 can be found at:

http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/

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 10.0.1 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 excel or in the GaBi format and are available in some LCA software tools.

The GaBi Envision reports contain the following information:

7.1 LCI flows

Cradle-to-gate data is given as the standard data. 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 LCI for steel scrap is also provided, which can be used to account for the burden of using steel scrap as a raw material in the steelmaking 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 the 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.

7.2 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.

7.3 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 are 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 includes:

- Scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internally generated scrap (that is generated in the product boundary).
- Home scrap (from processes on the steelmaking site but downstream of the BOF or EAF) 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.

7.4 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 is defined by the Water Footprint Network[11] and is requested by some practitioners.

The quantity of salt water used by the steel plants is recorded within 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.

7.5 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 is also provided, for information only, as this is one of the most common indicators currently being requested.

7.6 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.

7.7 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.

7.8 Waste

Materials that cannot be recovered but which are sent to landfill, are incinerated or flared etc. are classified as waste. In order to comply with the European Commission's ILCD database[12] 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. This ensures a conservative approach is taken.

7.9 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 energy sources that are renewable, such as hydropower and biomass.

A full breakdown of energy is available on request.

7.10 Life cycle impact assessment

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

7.11 Other flows not reported

Within the data sheets, only the major raw materials are shown for simplification reasons as the overall LCI contains nearly 2800 flows. 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 availability. 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 slag per tonne of Portland cement (CEM I)	GaBi 10.0.1 (EU-28)
	Aggregate or roadstone	Gravel production	GaBi 10.0.1 (DE)
	Fertiliser	1 tonne replaces 0.5 tonnes Lime production	GaBi 10.0.1 (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 + burden of 0.275 kg CO_2/MJ BF Gas, 0.03667 kg CO_2/MJ COG, 0.1796 kg CO_2/MJ BOF Gas	GaBi 10.0.1 (Country specific for credit element of production and combustion)
	Electricity production	1MJ gas = 0.347 MJ electricity + burden of 0.275 kg CO_2/MJ BF Gas, 0.03667 kg CO_2/MJ COG, 0.1796 kg CO_2/MJ BOF Gas	GaBi 10.0.1 (Country specific for credit element from avoided generation)
Electric arc furnace dust	Zinc production	1 kg dust = 0.5 kg Zinc	GaBi 10.0.1 (IZA)
Electricity from energy recovery	Electricity production	Electricity production	GaBi 10.0.1 (Country specific)
Steam from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 10.0.1 (EU-28)
Hot water from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 10.0.1 (EU-28)
Ammonia	Any ammonia application	Ammonia production	GaBi 10.0.1 (EU-28)

Steel co-product	Co-product function	Avoided production	Data Source
Ammonium sulphate	Any ammonium sulphate application	Ammonium sulphate production	GaBi 10.0.1 (DE)
Benzene	Any benzene application	Benzene production based on different technologies	GaBi 10.0.1 (EU-28)
BTX	Any BTX application	Benzene production based on different technologies	GaBi 10.0.1 (EU-28)
Scales	Metallurgical input to steelmaking	Iron ore extraction	worldsteel (2020)
Sulphuric acid	Any sulphuric acid application	Sulphuric acid production	GaBi 10.0.1 (EU-28)
Tar	Any tar application	Bitumen production	GaBi 10.0.1 (EU-28)
Used oil	Heat generation	Coal, heavy fuel oil, light fuel oil or natural gas + burden of 3.2 kg CO_2/kg	GaBi 10.0.1 (Country specific)
Zinc	Any zinc application	Zinc production	GaBi 10.0.1 (IZA)
Zinc dust	Any zinc application	Zinc production	GaBi 10.0.1 (IZA)
Electrode	Electrode making	Electrode mix	GaBi 10.0.1 (ZA)

Appendix 9: Updates from the 2019 study report

This study report covers an update of the global steel industry LCI data and follows the 2017 worldsteel LCI methodology report. During this 2020 update, a number of changes and updates have been made (compared to the 2019 study), and for ease of comparison, these differences are summarised here. Further information can be found in relevant sections of the report. Previous study reports (2018 and 2019) also contain summaries of how these studies differ from the 2017 methodology report and these can be downloaded from worldsteel.org.

- The modelling software used for this update is GaBi 10.0.1 CUP2020.2. All upstream data which have not been collected by worldsteel from industry associations were updated and are based on GaBi 10.0.1 upstream data. The previous 2019 study used an earlier version of GaBi 9.2.
- Due to naming issues of some emission flows from older versions of the GaBi software and databases, where the flow names are embedded in the worldsteel model, these flows 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 are recorded in our data collection but are not modelled with a direct 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 2018. Specific country iron ore datasets are used to represent 4 regions of the world and the annual production tonnage from each region is used to calculate a tonnage weighted average of the iron ore production route.
- 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.
- Upstream datasets for 2020 were updated with the most recent data available in GaBi.
- An update for the Charcoal dataset was made utilizing the latest upstream processes after reviewing the Charcoal model.
- A new Ferro Molybdenum process replacing the existing process from association data and two new proxy datasets were added to cover the upstream impacts of Alumix and Silico Manganese which previously had no upstream impacts associated with their use
- As described in the 2017 worldsteel LCI methodology report, new companies and sites are added to the database and sites with data older than 5 years are removed from the database. This ensures that data complies with rules for many EPD programmes. However, in this 2020 LCI data update, an exception has been made to keep some data in the database which is 6 years old, i.e. from steel production in 2014, as a result of delays to data collection incurred by the COVID-19 pandemic. Updated data to replace this 2014 data will be included in worldsteel’s 2021 data release. An analysis of the 2020 average LCI datasets was conducted and while the vast majority of the datasets were not greatly affected by the inclusion of the 2014 data, there were changes to the availability of some of the regional datasets. Therefore, including this data ensures that the steel industry is still able to provide a large number of global and regional steel product LCI datasets.

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 typical uses of steel products

Application	1 = preferable 2 = possible	Plate	Pipe (UO / welded)	Seamless Pipe	Hot Rolled Coil	Pickled Hot Rolled Coil	Cold Rolled Coil	Finished Cold Rolled Coil	Electro-Galvanized	Hot-Dip Galvanized	Organic Coated	Tin Plate	Electrolytic Chromed Coated Steel	Section Rolling	Rebar	Engineering Steel	Wire Rod
Frame-Work	Profiles				1	1	2		2	1				1			
	Framing									1							
Automotives	Body in white					2		1	1	1	2						
	Structural parts					1		1	1	1	2						
	Engine															1	
	drives equipements															1	
	transmissions															1	
	wheels					1											
	tyres																1
Construction	Structural parts	1	1	1	1					2	1			1			
	walls elements								1	1	1						
	Basement													1	1		
	Concreete reinforcement														1		
	Cladding				2				1	1	1						
	Roofing									1	1						
	Farm building walls									2	1						
	Gutter system (ducts)									1	1						
	Chimney ducts				2												
	construstion 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							
Home appliances	furnnitures							2	1		1						
	white goods							1	1	1	1						
	heating, ventilation and air condition							1	1	1	1						
Packaging	Steel Food & General Line Cans										1	1	1				
	Pails												1				
	Beverage cans										1	1	1				
	Drums							1	1								
Machinery	Rail													1			
	Machines	2						1								1	
	Pipes		1	1													
Others	tubes			1	1	2		1									
	pools									2	2						
	water tanks									1							
	greennhouses									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 report and study reports. The critical review report of the 2017 methodology is available in appendix 3 of the methodology report.

References

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

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

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[11] The Water Footprint Network – The Water Footprint Assessment Manual – 2011

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