LIFE CYCLE INVENTORY STUDY

2019 data release

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This study report corresponds to the latest steel LCI data released in December 2019 for 16 products. This is the 6th worldsteel LCI study and has been carried out in accordance with the worldsteel LCI methodology report, 2017.

Acronyms

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

1. Project context

This report presents a summary of the 6th 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 data, then 2005/2006[1], then with 2012-2015 data and again with 2016 and 2017 data. This latest update, the 2019 data release, includes new steel production data from 2017 and 2018.

The main goal of this study, which reflects worldsteel's change of strategy in 2018 and the industry's ongoing commitment to improving data quality, is to update the LCI data for steel products on a global and regional basis by updating a proportion of the datasets and releasing results on an **annual basis**. Currently, regional data is available for Europe, Asia and Latin America for certain products. It is believed that other available datasets on steel have been derived with limited accuracy or representation and/or contain out of date information.

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

Whilst this report aims to describe the details of the LCI study 2019, the methodology follows the World Steel Association LCI methodology report 2017[2]. This study has been undertaken in accordance with ISO 14040: 2006[3] and 14044: 2006[4] 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 improved in the future.

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

worldsteel LCI data can be requested from www.worldsteel.org.

2. Goal of the study

This 2019 release of steel industry data is the 5th update of worldsteel LCI data, first released in 1995. The industry has regularly collected data and released updates to ensure that the data remains representative of the current steelmaking technologies and their associated emissions and impacts.

The LCI results alone shall not be used 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 will be made available for many different external applications of the data, for technical and non-technical use, including customers of the steel industry, policy makers, LCA practitioners and academia. The data will also be made available in 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 every 5 years or so. This strategy changed in 2018 when worldsteel changed its strategy on LCI data to update the data on a more regular basis. As such, since 2017, worldsteel updates a proportion of the steel production data in the database on an annual basis and removes data older than 5 years. Upstream data will also be updated annually to ensure the most relevant and up-to-date data is used. In addition, this change in strategy allows worldsteel member companies to provide data when it suits them, and not only once every five years. This allows worldsteel to produce the most recent and complete steel industry product LCIs for both global and, where possible, regions of interest and make them available for general use in the LCA community. It also allows new product datasets to be generated when there is sufficient data available. As no data supplied by the steel companies is older than 5 years old, the datasets comply with as many EPD schemes with age restriction constraints as possible.

3. Scope of the study

3.1 Study description overview

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

3.2 Functional unit

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

Sixteen steel products (Table 1) were included in the study – 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 UO pipe data is still available from worldsteel. These products have been chosen as they cover the vast majority of steel products being produced today (> 95%). Additional products which have not been included at this stage are generally processed from one of the products listed below. The detailed specifications of each steel product, such as size range, gauge and coating thickness, vary from site to site and are a function of the technology, equipment and product ranges at the sites involved and are detailed in Appendix 1. The range of specifications within a product category will to some extent influence the regional and global LCI results.

Product category	Manufacturing route	List of products
Long products	Basic oxygen furnace route and Electric arc furnace route	Sections Rebar Wire rod Engineering steels
Flat products	Basic oxygen furnace route and Electric arc furnace route	Plate Hot rolled coil Cold rolled coil Pickled hot rolled coil Finished cold rolled coil Electrogalvanized steel Hot-dip galvanized steel Tin-free steel (ECCS) 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[5].

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 steel uses steel datasets including the end-of-life credits on the material level, it has to be checked that no double-counting occurs when the user models the end-of-life of the downstream product. Note that the data for net end-of-life recycling can be provided separately to the cradle-to-gate LCI data, for implementation by the user themselves.

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

For this study, primary data were collected for 24 separate steelmaking process steps (Table 2 shows the break down and the number of sites contributing to this study), plus boilers, compressors, water intake, effluents, stockpile emissions and transport. A representation of one of these processes, the basic oxygen furnace module, is given in Appendix 2. Data were also collected regarding the use of steel industry co-products such as process gases and slags.

Process stage	Number of sites	Process stage	Number of sites
Coke making	38	Hot-dip galvanizing	34
Sinter making	40	Tin-free mill (ECCS)	4
Pellet plant	7	Tinplate mill	13
Blast furnace	46	Organic coating line	13
Direct reduced iron	10	Section mill	23
Basic oxygen furnace	47	Heavy plate mill	16
Electric arc furnace	43	Rebar	26
Hot strip mill	43	Welded pipe	9
Pickling plant	40	Seamless Pipe	4
Cold rolling mill	38	Wire rod	23
Annealing & tempering mill	37	Engineering steels	8
Electrogalvanizing	9		
Total processes			**574**

Table 2: Number of process stages represented in the study

The steel product manufacturing flow diagrams via the basic oxygen furnace route and the electric arc furnace route are shown in the 2017 worldsteel LCI methodology report Appendix 1.

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 20% (364 million tonnes) of global crude steel production (1808 million tonnes) and the contributing sites (which cover 14% of global steel production) are located in the largest of the principal producer countries. The highest represented region is Europe: the sites participating represent over 34% of European steel production. The list of participating companies is shown in Appendix 3.

121 sites located in 29 countries participated in the study – this includes 20 sites providing data in 2019 from 5 steel making companies. The major steel producing countries and regions are included. These are listed below in Table 3.

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

Table 3: Countries participating in the worldsteel 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 2018 and is believed to be representative of global steel production during this time frame. The new sites contributing data in

2019 have provided primary data from 2017 or 2018 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 2018, 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 2015 for each of the steel sites, as outlined in Appendix 6. Each secondary dataset is listed in Appendix 5.

3.4 Application of LCIA categories

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

The goal of the study is to provide the LCI profiles for a number of different steel products and not to analyse the impact categories as they are not included in an LCI profile. In addition, normalisation, grouping and weighting are not applied to the worldsteel LCI data. worldsteel 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. Therefore, the same selection of LCIA results have been included in this report for illustrative purposes only and are included in further detail in Section 6. The impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University, CML 2001 – Jan. 2016[6].

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

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

3.5 Data collection

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

GaBi 9.2 was used to create the worldsteel LCI model and datasets, which was based on the previous steel industry model for the 2018 data collection. The initial model was created in 2006 by a team of experts including worldsteel, thinkstep and the worldsteel members and represents the steel production process. Site data were collected using the internet-based SoFi Web Questionnaire. The questionnaires are uploaded to the web-platform and each company has individual password protected access to their specific questionnaires. A separate questionnaire is available for each of the process stages for each site (a full list of questionnaires is shown in Appendix 10), an example of which is shown in Appendix 4, as well as for ancillary utilities such as boilers/power plants, compressors, alternators etc. Each of the questionnaires contains a list of input and output flows which fall into the following categories: material and energy inputs, air and water emissions, wastes, products and co-products and recovered material that can be processed internally to displace raw material inputs. Transport data for the raw materials and internal transportation fuel used was also provided in the questionnaires. The central allocation of 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 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 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 2017, 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 this study, 0.29 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 78% 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%	78%	21%	< 1%
BOF slag	> 86%	8%	91%	< 1%
EAF slag	86%	18%	82%	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 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 then recovered. Details of the assumptions made for all recovered material are included in Appendix 8.

With further analysis, the processes linked with the system expansion retain their initial (actual) inventories of the process (e.g. cement or fertiliser production) and the expanded system processes are 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. The interpretation addresses the following topics:

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

3.8 Critical review

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

4. Data quality

4.1 Data quality requirements

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

- Primary data collected from worldsteel member companies, gate-to-gate data.
- Primary data for some upstream inputs, e.g. aluminium, from industry associations or producers, cradle-to-gate data.
- Cradle-to-gate data, plus background system from the GaBi 9.2 SP39 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 was managed in the following way. The project was led by the worldsteel LCA manager, reporting to the Head of Sustainability. Data was provided individually by the worldsteel member companies and they were supported by worldsteel LCA Expert Group members, thinkstep and the worldsteel LCA manager. The data was reviewed by the worldsteel LCA Manager and thinkstep for GaBi supplied datasets.

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.

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 datasets and documentation relating to these datasets is given within the dataset or can be obtained directly from the supplying industry associations.

Upstream GaBi data

All data from the GaBi Professional database were created with consistent system boundaries and upstream data by thinkstep. Expert judgement and advice was 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 had been set up by worldsteel and thinkstep. In this way, all relevant flows, processes and interconnections between the processes were included in the model. The data collector was able to specify the data in their preferred units within the data collection system to avoid human error when entering the data, for the conversion from one unit to another. For example, natural gas could be entered as kg, MJ, GJ, Nm^3, kWh etc.

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. In addition to the worldsteel LCA Manager, the worldsteel LCA Expert Group ‘verified’ the LCI results to ensure their validity. The experts applied their knowledge of the steelmaking processes to ensure the data was consistent with known steelmaking practices.

4.2.1 Raw data

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

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

4.2.2 Process, site and route data.

Data checks were done at the process, site (gate-to-gate) and cradle-to-gate 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.

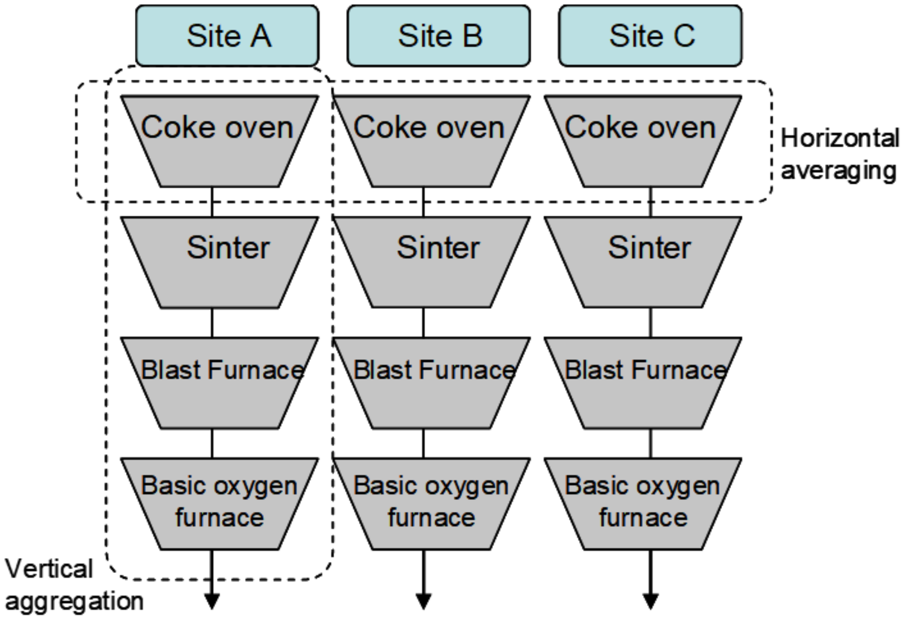

Figure 1: Horizontal averaging and vertical aggregation

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 differences explored to understand why they have occurred.

4.2.3 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 and water emissions. 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 this was not possible, the average value, based on data collected from other steel production sites, was incorporated into the dataset where it was missing. For all these accounted air and water emissions, this average approach was taken. This 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 16 steel products and is freely available on request via www.worldsteel.org. The data are provided using the GaBi Envision tool, which enables the data to be easily generated directly from the GaBi 9.2 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.

Table 6 shows typical impacts for three main steel industry products: steel sections, hot rolled coil and hot-dip galvanized steel, which cover a wide range of use of steel 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, with a typical end-of-life recycling rate (RR) of 85%

This end-of-life recycling rate means that 85% of the steel within the final product 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%. 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 which requests a different end-of-life recycling rate, this specified rate can be used.

5.1 LCI value of steel scrap

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

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

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

Impact category	LCIA for 1kg steel scrap
Primary energy demand, MJ	13.4
Global warming potential (100 years) kg CO_2-e	1.62
Acidification potential, kg SO_2-e	0.0026
Eutrophication potential, kg Phosphate-e	1.34E-04
Photochemical ozone creation potential, kg Ethene -e	0.00081

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. 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 www.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 0.64 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 0.06 tonnes per tonne of hot-dip galvanised steel and 0.13 tonnes per tonne of hot rolled coil.

		PED MJ	GWP kg $CO_{2\text{-e}}$	AP kg $SO_{2\text{-e}}$	EP kg Phosphate-e	POCP kg ethene-e
Sections, 1kg	Cradle-to-gate	18.9	1.60	0.0037	0.00033	0.00070
	Net recycling benefit	-2.8	-0.33	-0.0005	-0.00003	-0.00017
	Cradle-to-gate including recycling	16.2	1.26	0.0031	0.00030	0.00053
Hot rolled coil, 1kg	Cradle-to-gate	23.8	2.33	0.0052	0.00043	0.00097
	Net recycling benefit	-9.6	-1.17	-0.0018	-0.00010	-0.00058
	Cradle-to-gate including recycling	14.2	1.16	0.0034	0.00033	0.00039
Hot-dip galvanized steel, 1kg	Cradle-to-gate	30.0	2.81	0.0062	0.00057	0.00106
	Net recycling benefit	-10.6	-1.28	-0.0020	-0.00011	-0.00064
	Cradle-to-gate including recycling	19.4	1.53	0.0042	0.00046	0.00042

Table 6: Life cycle impact assessment results of steel products

The recycling credit that can be seen in Table 6 and the following charts 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 low 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 low and therefore the net scrap end-of-life credit is much higher 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.

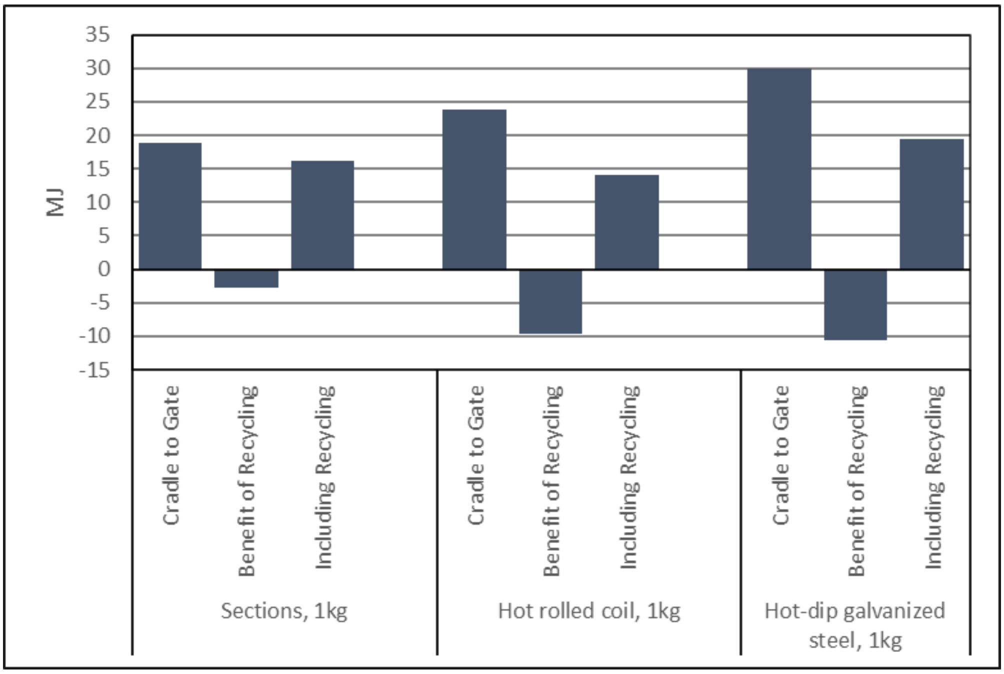

Figure 2: Primary energy demand (MJ) of steel products

This PED is made up of both renewable and non-renewable resources. 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, see Figure 3. The consumption of uranium is only associated with the upstream profiles of electricity consumption.

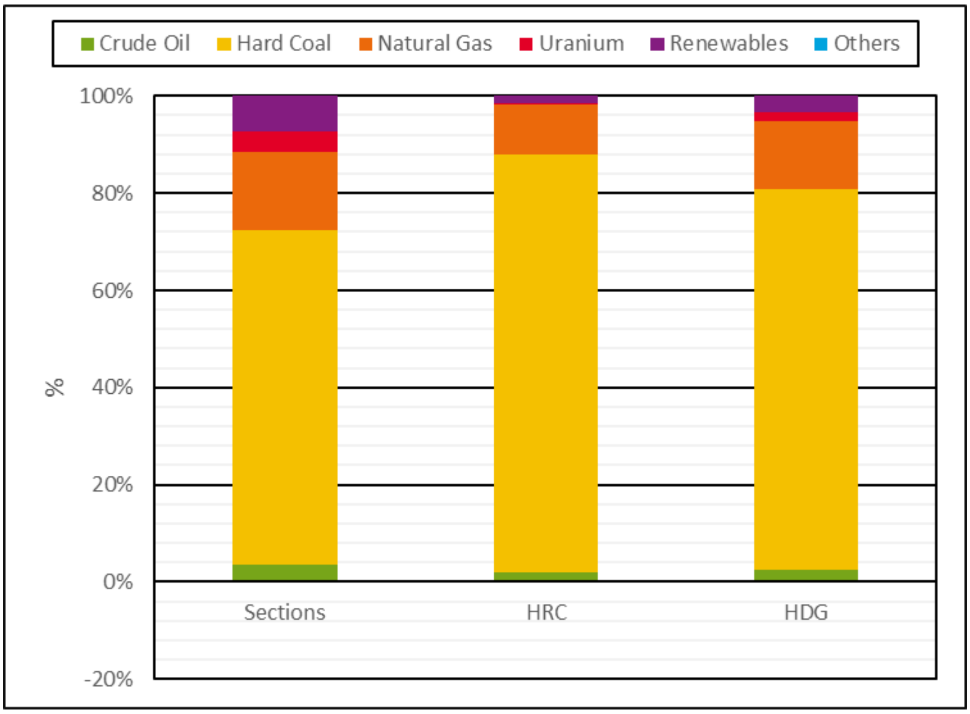

Figure 3: Contributions to primary energy demand of steel products

5.2.2 Global warming potential, GWP

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

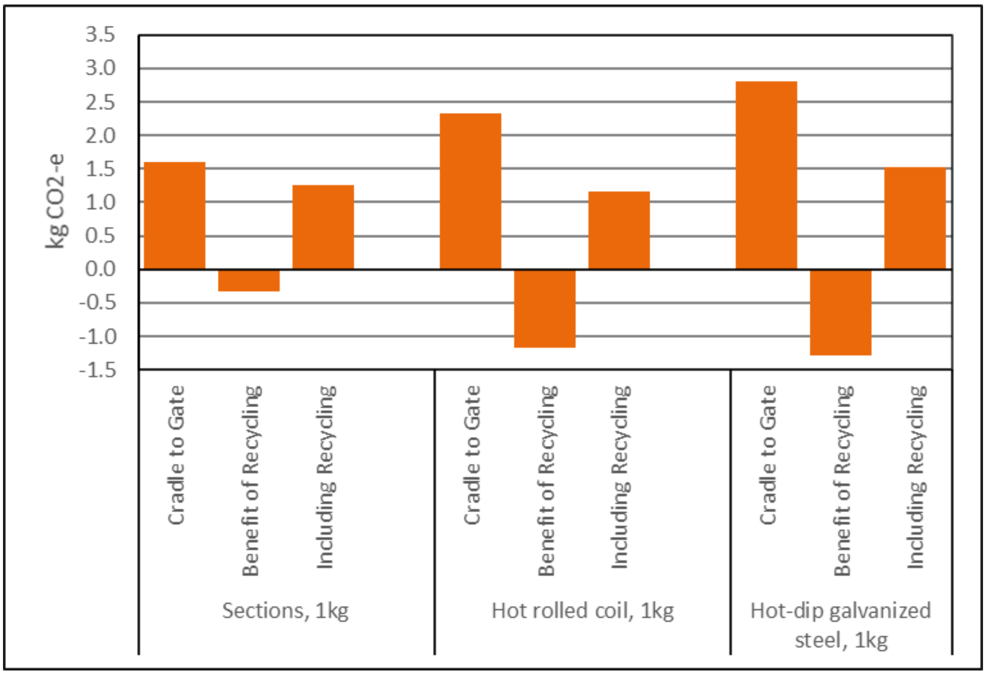

Figure 4: Global warming potential (CO_2-e) of steel products

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

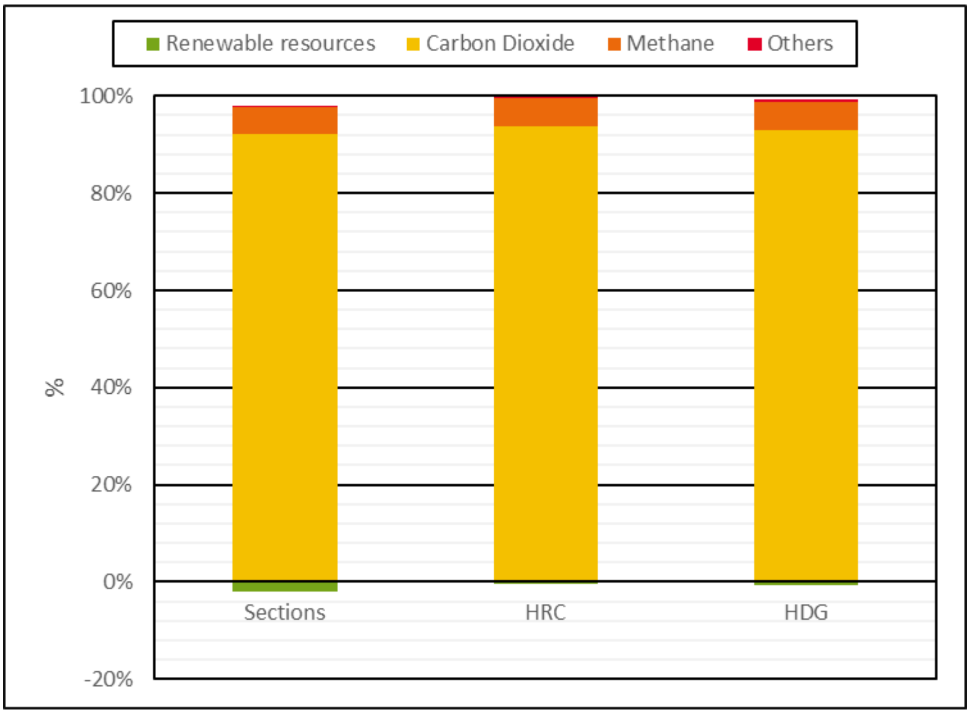

Figure 5: Contributions to global warming potential of steel products

5.2.3 Acidification potential, AP

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

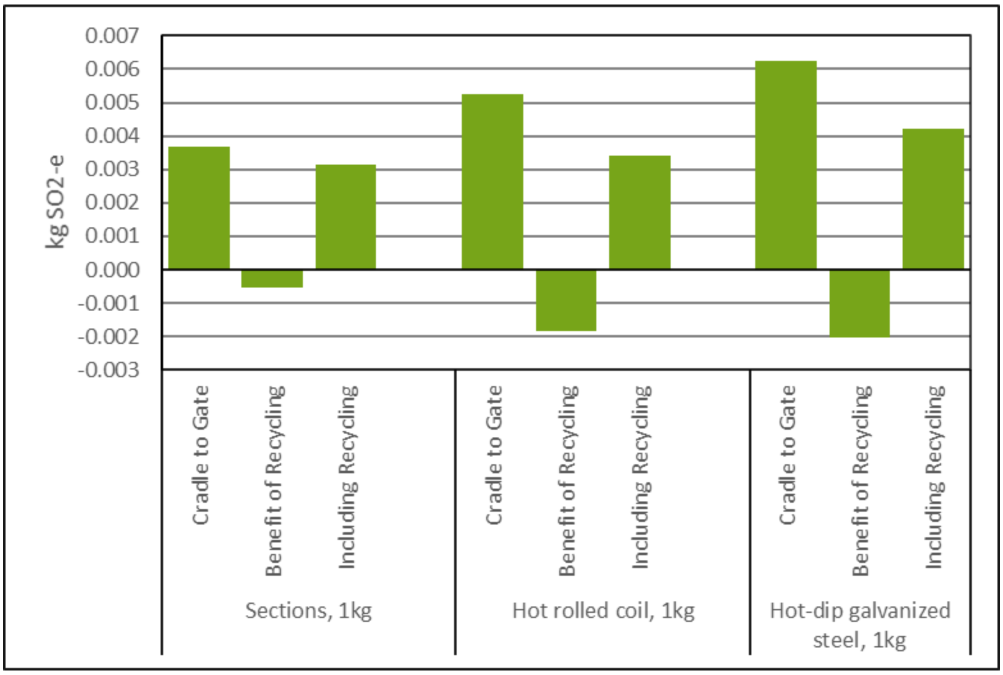

Figure 6: Acidification potential (SO_2-e) of steel products

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.

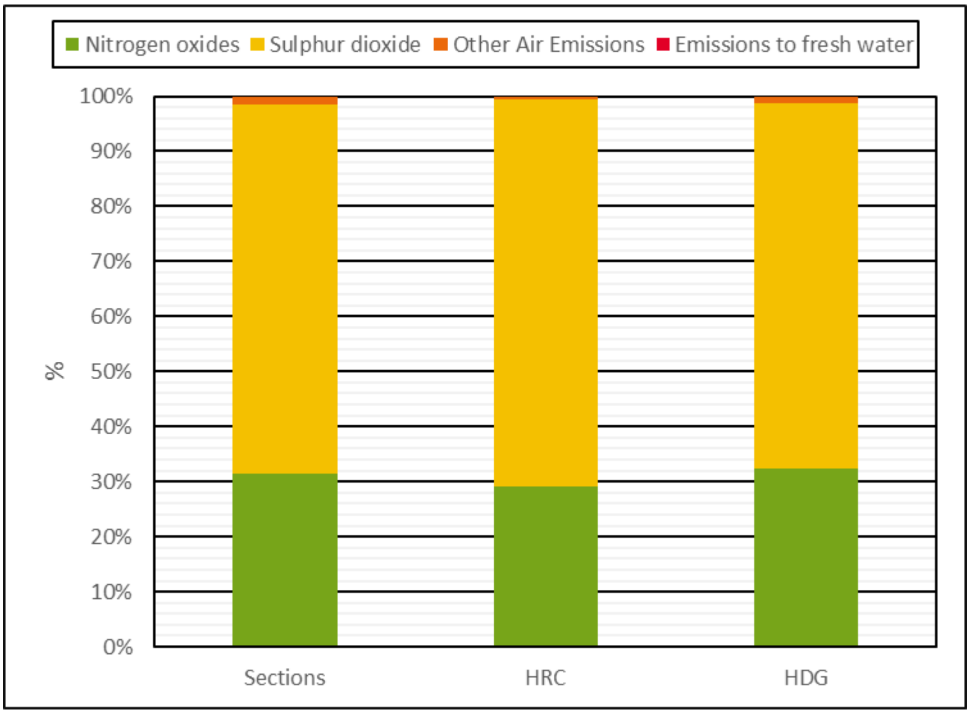

Figure 7: Contributions to acidification potential of steel products

5.2.4 Eutrophication potential, EP

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

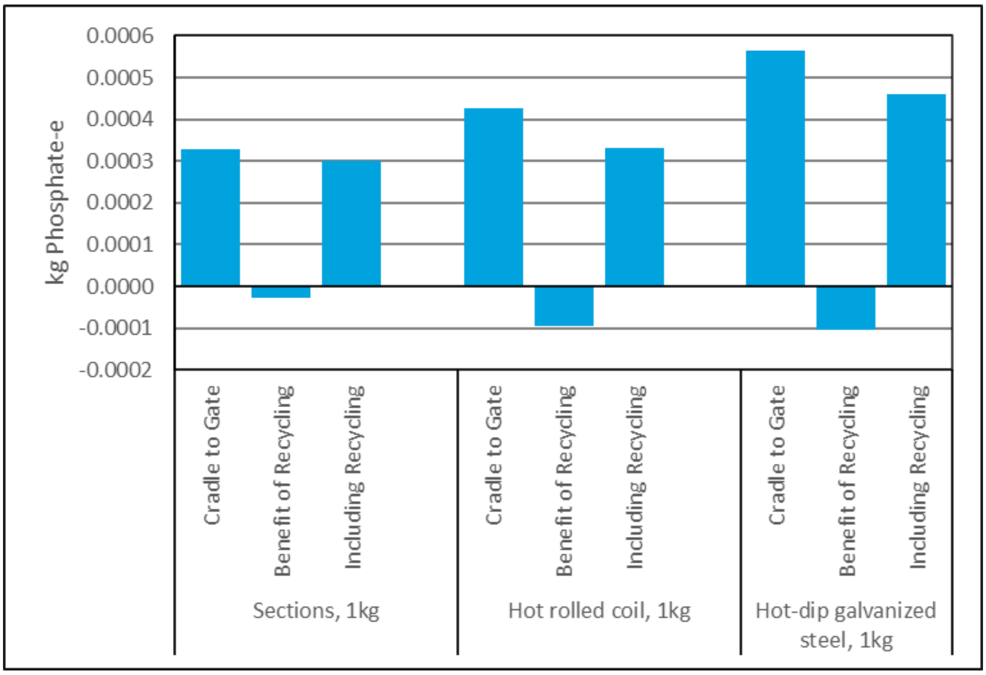

Figure 8: Eutrophication potential (PO_4^{3-}-e) of steel products

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

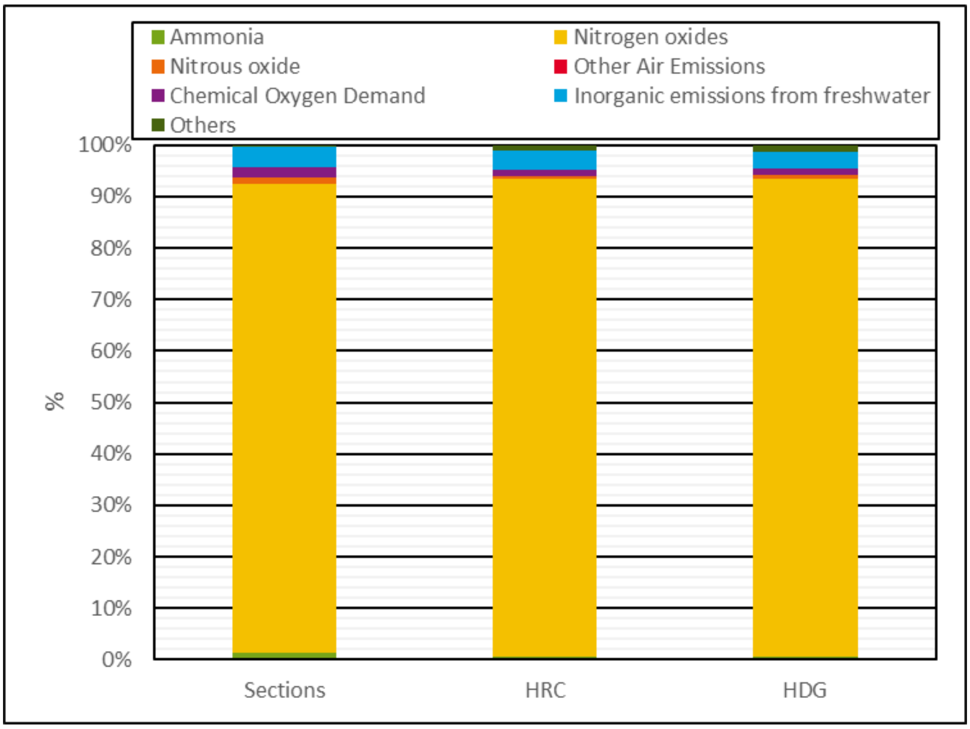

Figure 9: Contributions to eutrophication potential of steel products

5.2.5 Photochemical ozone creation potential, POCP

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

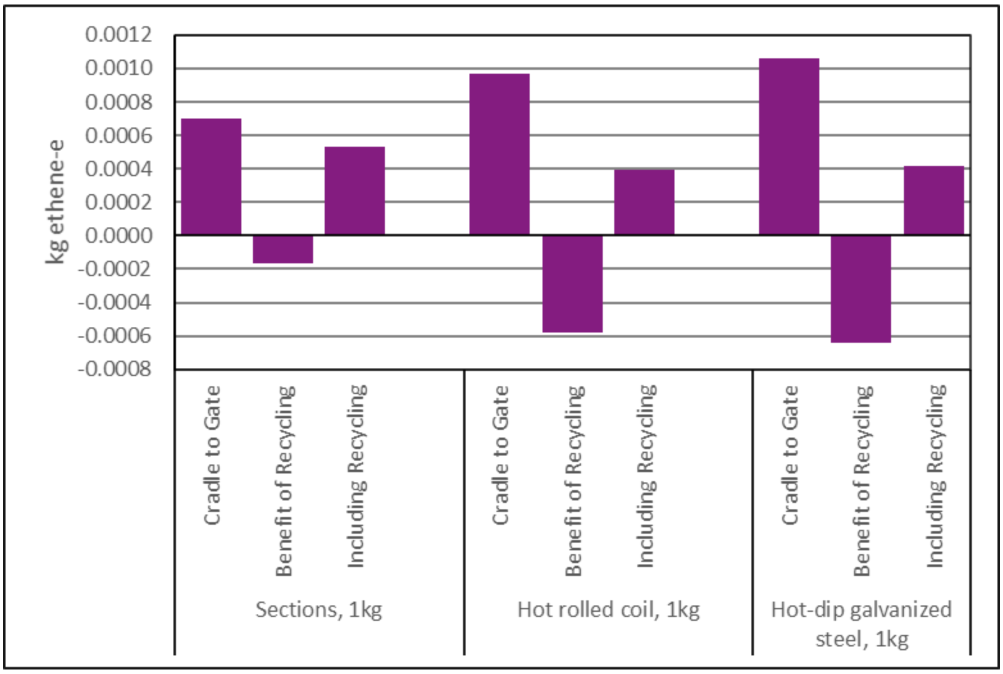

Figure 10: Photochemical ozone creation potential (C_2H_4-e) of steel products

The photochemical ozone creation potential for steel products is dominated by carbon monoxide, which accounts for over 66% of the contribution to this impact. All other major substances contributing to the POCP are shown in Figure 11.

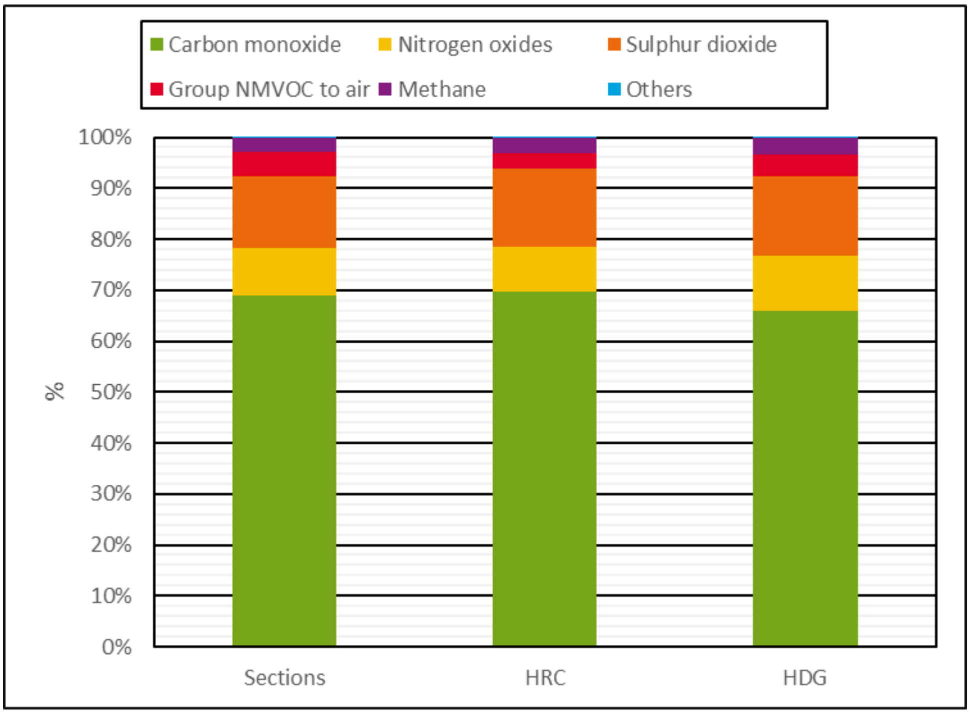

Figure 11: Contributions to POCP of steel products

6. Life cycle interpretation

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

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

6.1 Identification of significant issues

Figure 12 to Figure 14 show the life cycle contributions to the PED and the four impact categories discussed above, for global steel sections, hot rolled coil and hot-dip galvanised steel. The cradle-to-gate data is the 100% reference data. This is made up from the gate-to-gate data, the contribution from the upstream inputs to the steelmaking process, and the contribution from the co-product allocation. Following this, the end-of-life recycling credits are shown, followed by the overall value which is the cradle-to-gate, including end-of-life recycling. For this report, an example of 85% has been used as the amount of steel that will be recycled at the end-of-life of the steel product. PED, AP and EP are dominated by the upstream contribution, whereas the GWP and POCP impacts have a greater influence from the on-site, gate-to-gate, activities.

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

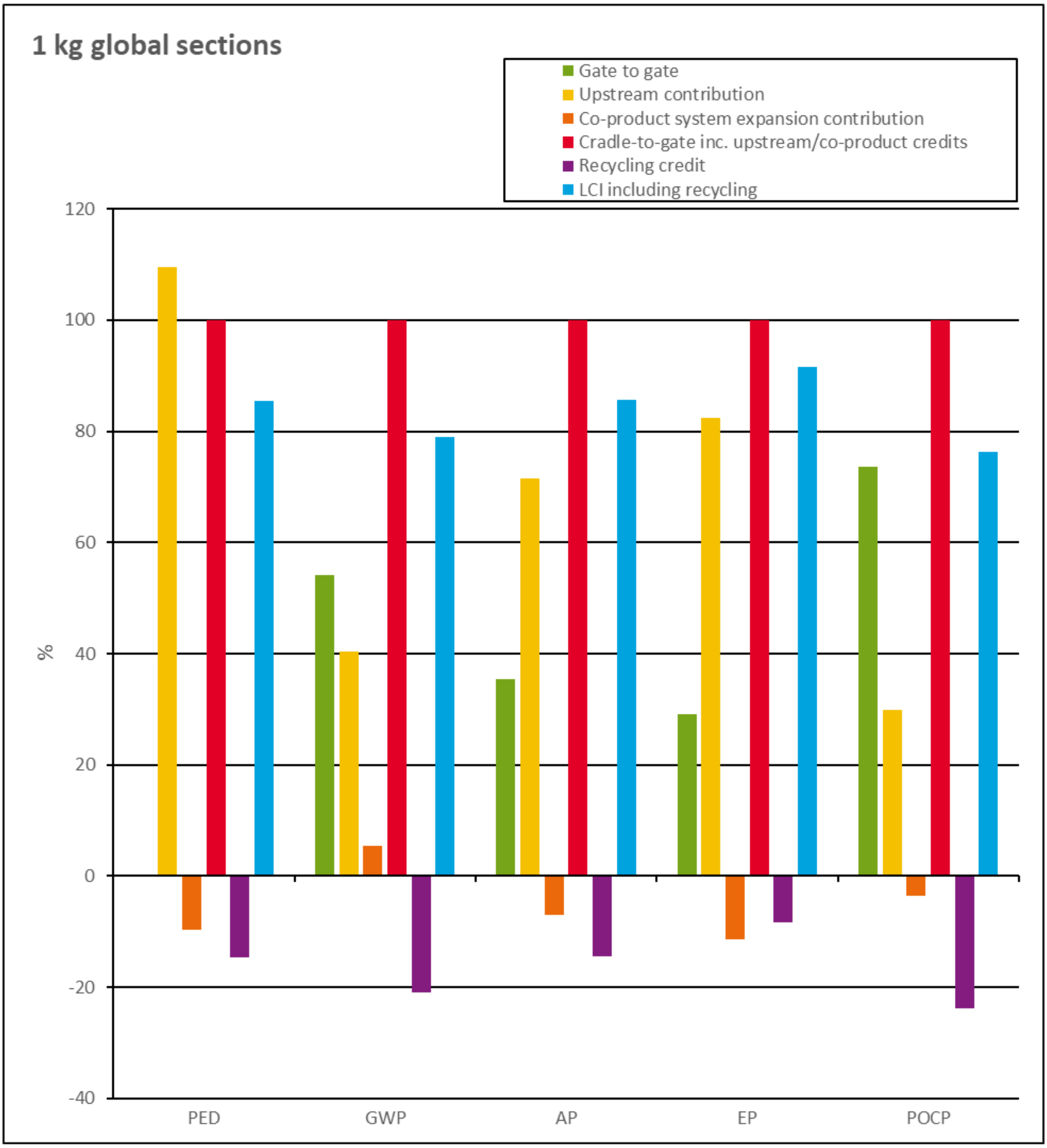

Figure 12: Life cycle contributions to PED and impact categories for sections

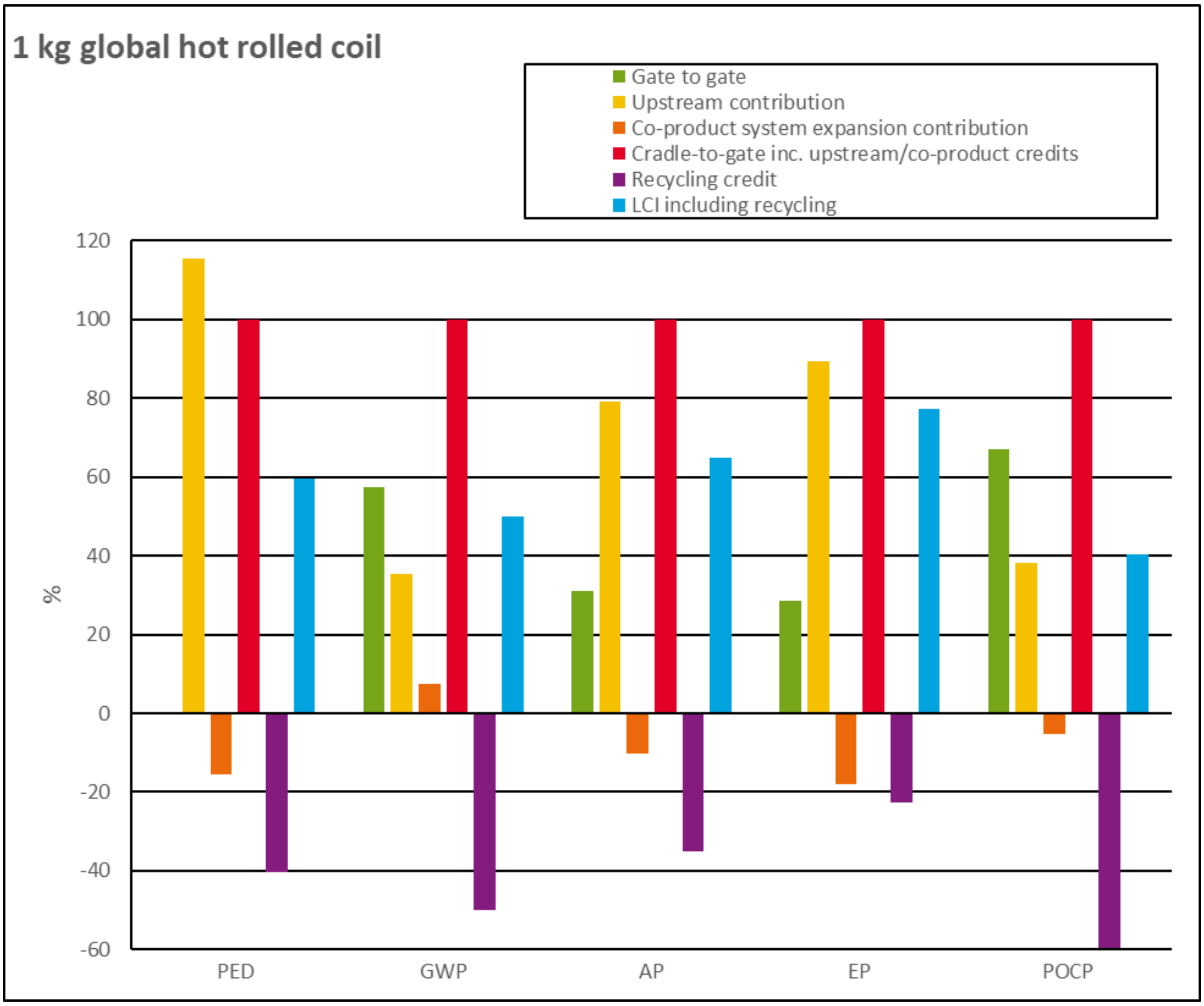

Figure 13: Life cycle contributions to PED and impact categories for HRC

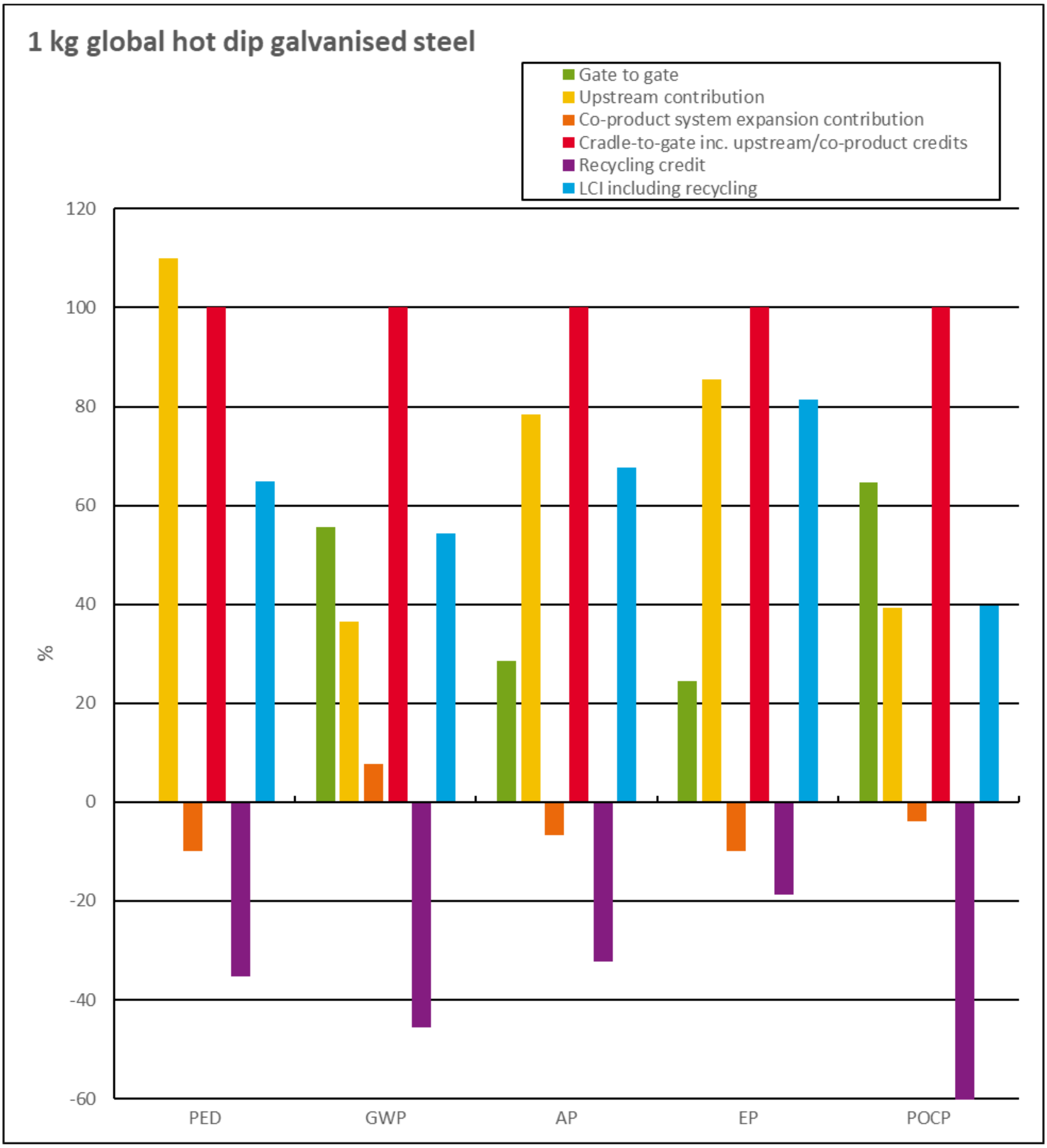

Figure 14: Life cycle contributions to PED and impact categories for HDG

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

<table>
<tr><th>Impact category</th><th>Main contributing input/output</th><th>Main life cycle phase</th><th>Main contributing processes</th></tr>
<tr><td>Primary energy demand</td><td>Hard coal (67 – 86%)
Natural gas (10 – 16%)</td><td>Upstream (~ 100%)</td><td rowspan="5">Upstream energy: electricity and fuels

Gate-to-gate: steel production processes up to slab production</td></tr>
<tr><td>Global warming potential (100 years)</td><td>Carbon dioxide (94%)
Methane (~ 6%)</td><td>Gate-to-gate (> 54%)
Upstream (35 – 40%)</td></tr>
<tr><td>Acidification potential</td><td>Sulphur dioxide (66 – 71%)
Nitrogen oxides (29 – 32%)
Others (~1%)</td><td>Gate-to-gate (28 – 35%)
Upstream (71 – 79%)</td></tr>
<tr><td>Eutrophication potential</td><td>Nitrogen oxides (>91%)
Nitrous oxide (~ 1%)
Chemical Oxygen Demand (1 - 2%)
Inorganic emissions to fresh water (~4%)</td><td>Gate-to-gate (24 – 29%)
Upstream (82 – 89%)</td></tr>
<tr><td>Photochemical ozone creation potential</td><td>Carbon monoxide (66 – 70%)
Sulphur dioxide (14 – 16 %)
Nitrogen oxides (9 - 11%)
NMVOCs (3 - 5%)
Methane (~3%)</td><td>Gate-to-gate (64 – 73%)
Upstream (30 – 40%)</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. Three products have been selected to cover a wide range of steel products.

	Cradle-to-gate data	**GWP**	**PED**
		Kg CO_2-e	**MJ**
Sections, 1kg	**Excluding system expansion**	1.51	20.7
	Including system expansion	1.60	18.9
	% Difference	5.7%	-8.8%
Hot rolled coil, 1kg	**Excluding system expansion**	2.16	27.5
	Including system expansion	2.33	23.8
	% Difference	8.0%	-13.4%
Hot-dip galvanized steel, 1kg	**Excluding system expansion**	2.59	33.0
	Including system expansion	2.81	30.0
	% Difference	8.5%	-9.0%

Table 8: Sensitivity analysis of system expansion

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

The contribution of system expansion to the GWP is +6 to 9%. Steel sections are made from both the EAF and BOF route. Due to the relatively high carbon intensity of the process gases, 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 (but might use if co-located on a BOF route site) process gases which are used to replace other forms of energy supply, either on site or replacing energy and electricity off-site.

The contribution of system expansion to the PED ranges between -9 and -13%. 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. The data already represents the energy consumption describing the production of steel as the main product and the process gases as co-products.

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

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

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

6.2.2.3 Sensitivity analysis on packaging

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

6.2.3 Consistency checks

Details of these are covered in Section 4.

7. Conclusions, limitations and recommendations

This study is representative of over 99% of steel technologies worldwide and covers over 20% (364 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 16 steel industry products on a global level, of which a number of products are also represented on a regional level (EU, Asia and Latin America, see Table 1). The addition of new sites is an ongoing process in order to increase the geographical spread and representativeness of the data. These will be added in due course.

In an 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 2018. With continuing measures to improve the environmental performance of these companies, it should be noted that some minor improvements will occur over the coming years and these will need to be incorporated into the steel product LCI data in future updates.

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

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

7.3 Recommendations for uses of the data

When an LCA study is to be conducted including steel LCI data, it is preferable that the practitioner contacts the worldsteel LCA Manager 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 2018 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 www.worldsteel.org.

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

8. Appendices

APPENDIX 1: DESCRIPTION OF STEEL PRODUCTS COVERED BY THE STUDY
APPENDIX 2: REPRESENTATION OF THE BOF PROCESS
APPENDIX 3: LIST OF PARTICIPATING COMPANIES
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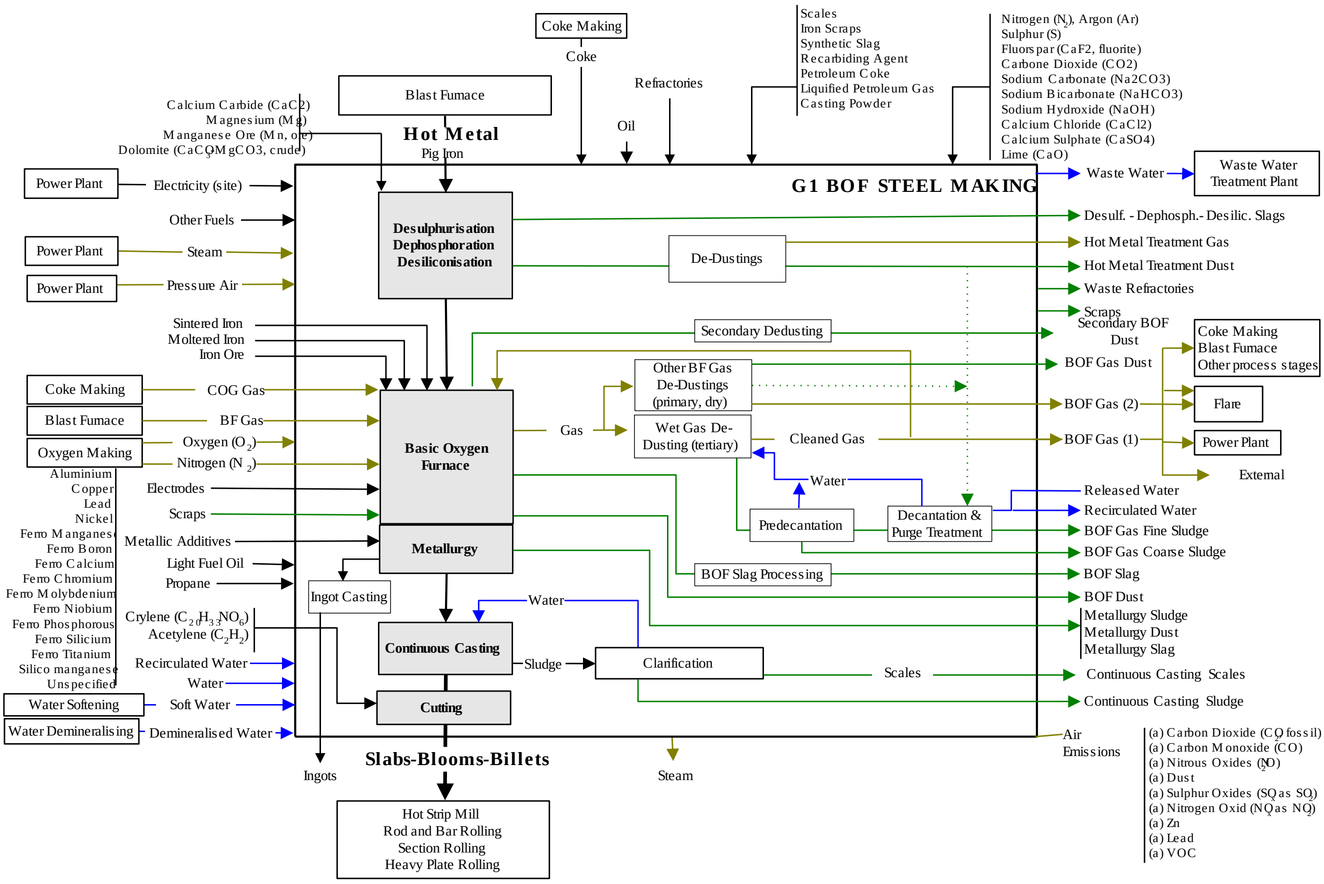
APPENDIX 5: LIST OF UPSTREAM INPUTS AND THEIR SOURCES
APPENDIX 6: ELECTRICITY GRID MIX INFORMATION
APPENDIX 7: STEEL LCI DATA EXPLANATION
APPENDIX 8: SYSTEM EXPANSION ASSUMPTIONS
APPENDIX 9: UPDATES FROM THE 2018 STUDY REPORT
APPENDIX 10: LIST OF ALL AVAILABLE QUESTIONNAIRES
APPENDIX 11: MATRIX OF USES OF STEEL PRODUCTS
APPENDIX 12: CRITICAL REVIEW: WORLD STEEL ASSOCIATION LIFE CYCLE INVENTORY STUDY FOR STEEL PRODUCTS

APPENDIX 1: DESCRIPTION OF STEEL PRODUCTS COVERED BY THE STUDY

Product	Product Description
Plate	A flat steel sheet rolled on a hot rolling mill; can be further processed. Includes use in the following sectors: structural steels, shipbuilding, pipes, pressure vessels, boilers, heavy metal structures, offshore structures etc. Typical thickness between 2 to 20 mm. The maximum width is 1860 mm.
Hot rolled coil	Steel coil rolled on a hot-strip mill; can be further processed. Applications in virtually all sectors of industry: transport, construction, shipbuilding, gas containers, pressure vessels, energy pipelines, etc. Typical thickness between 2 - 7 mm. Typical width between 600 - 2100 mm
Pickled hot rolled coil	Hot rolled steel from which the iron oxides present at the surface have been removed in a pickling process; can be further processed. Applications in virtually all sectors of industry: transport, construction, shipbuilding, gas containers, pressure vessels, energy pipelines, etc. Typical thickness between 2 - 7 mm. Typical width between 600 - 2100 mm
Cold rolled coil	Obtained by a further thickness reduction of a pickled hot rolled coil. This step is achieved at low temperature in a cold-reduction mill; can be further processed. Used as primary material for finished cold rolled coils and coated coils. Typical thickness between 0.15 - 3 mm. Typical width between 600 - 2100 mm
Finished cold rolled coil	Obtained by heat treatment (annealing) and strain-hardening of cold rolled steel in a way to achieve final mechanical properties making the steel suitable for further uses (forming and bending); can be further processed. Classified into the following: formable steels, high strength formable steels, weathering structural steels, structural steels, hardenable steels. They have excellent forming properties, electromagnetic properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, automotive applications, lighting fixtures, electrical components (stators, rotors) and various kinds of sections roofing applications, profiled sheets, wall elements, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.
Hot-dip galvanized steel	Obtained by passing cold rolled coil through a molten zinc bath, in order to coat the steel with a thin layer of zinc to provide corrosion resistance; can be further processed. They have excellent forming properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, building applications (e.g. wall elements, roofing applications), automotive applications (e.g. body in white for vehicles underbody auto parts), lighting fixtures, drums and various kinds of sections applications, profiled sheets, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.
Electrogalvanized steel	Obtained by electro plating finished cold rolled steel with a thin layer of zinc or zinc-nickel to provide corrosion resistance; can be further processed. They have excellent forming properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, building applications (e.g. wall elements, roofing applications), automotive applications (e.g. body in white for vehicles underbody auto parts), lighting fixtures, drums and various kinds of sections applications, profiled sheets, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.
Rebar	A steel reinforcing bar is rolled on a hot rolling mill; can be further processed. This product is used to strengthen concrete in highway and building construction also as primary product for the wire rod process.
Engineering steel (Tool steel)	Engineering Steel is rolled on a Hot Rolling mill. It can be found on the market and is further processed into finished products by the manufacturers This steel is used in the manufacture of tools, dies, components for engines, drives, equipment, transmissions, etc.
Sections	A steel section rolled on a hot rolling mill. Steel Sections include I-beams, H-beams, wide-flange beams, and sheet piling. This product is used in construction, multi-story buildings, industrial buildings, bridge trusses, vertical highway supports, and riverbank reinforcement.

Welded pipe	A flat plate steel coil that is bended and welded into a tube. It can be found on the market for final use. A heavy-wall pipe is technically used to transport fluids (e.g. oil, gases, water, chemicals).
Seamless Pipe	The seamless pipe is manufactured using a process called “extrusion”. During this process a solid steel bar is pierced though the centre using a die, turning the solid steel into a tube which is processed into the correct shape and dimensions. They have an advantage in aggressive environments as there is no weld.
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 December 2019 are listed below:

Acciaierie Bertoli Safau	Kyoei Steel
Aichi Steel	Liberty Steel
ArcelorMittal	Nippon Steel
BlueScope	Osaka Steel (part of Nippon Steel)
British Steel	Sanyo Special Steel
China Steel Corporation	Severstal
Daido Steel	Shimizu Steel Tomakomai
Erdemir	SSAB
Sidenor	Sahaviriya Steel Industries (SSI)
Godo Steel	Tata Steel Europe
Hadeed	Tata Steel India
HBIS	Tenaris
Isdemir (part of Erdemir Group)	Ternium
Itoh Ironworks Corp	Tokyo Kohtetsu
JFE Steel	Tokyotekko
JSW	Topy Industries
Kobe Steel	voestalpine

APPENDIX 4: EXAMPLE DATA COLLECTION QUESTIONNAIRE

Fiscal period	2017				
Site	Example BF, 2017				
Questionnaire	(H) Hot Strip Mill (new)				
Tab	Input				
Name	**Unit**	**Value**	**Quality of data**	**Source**	**Year**
Flows	-	-	-	-	-
Production residues in life cycle	-	-	-	-	-
Waste for recovery	-	-	-	-	-
Scarfing dust	kg		n.a.	Factory	
Used oil	kg		n.a.	Factory	
Waste water treatment sludge	kg		n.a.	Factory	
Resources	-	-	-	-	-
Material resources	-	-	-	-	-
Renewable resources	-	-	-	-	-
Water	-	-	-	-	-
Fresh water	kg		n.a.	Factory	
Sea water	kg		n.a.	Factory	
Water (softened, deionized)	kg		n.a.	Factory	
Water Cooling fresh	kg		n.a.	Factory	
Water Cooling sea	kg		n.a.	Factory	
Valuable substances	-	-	-	-	-
Energy carrier	-	-	-	-	-
Electric power	-	-	-	-	-
Electricity	MJ		n.a.	Factory	
Fuels	-	-	-	-	-
Crude oil products	-	-	-	-	-
Heavy fuel oil	kg		n.a.	Factory	
Liquefied petroleum gas	kg		n.a.	Factory	
Refinery products	-	-	-	-	-
Light fuel oil	kg		n.a.	Factory	
Natural gas products	-	-	-	-	-
Natural gas, at production	-	-	-	-	-
Natural gas	kg		n.a.	Factory	
Other fuels	-	-	-	-	-
Basic Oxygen Furnace Gas (MJ) (Copy)	MJ		n.a.	Factory	
Blast furnace gas (MJ)	MJ		n.a.	Factory	
Coke oven gas (MJ) (Copy)	MJ		n.a.	Factory	
Mechanical energy	-	-	-	-	-
Compressed air for process	m^3		n.a.	Factory	
Thermal energy	-	-	-	-	-
Hot water (MJ)	MJ		n.a.	Factory	
steam	-	-	-	-	-
Steam (MJ)	MJ		n.a.	Factory	
Materials	-	-	-	-	-
Intermediate products	-	-	-	-	-
Inorganic intermediate products	-	-	-	-	-
Ferric chloride	kg		n.a.	Factory	
Nitrogen gaseous	kg		n.a.	Factory	
Oxygen gaseous	kg		n.a.	Factory	
Sodium hydroxide (100%; caustic	kg		n.a.	Factory	
Sulphuric acid (100%)	kg		n.a.	Factory	
Organic intermediate products	-	-	-	-	-
Lubricant	kg		n.a.	Factory	
Propane	kg		n.a.	Factory	
Metals	-	-	-	-	-
Cold rolled coil (from DSP)	kg		n.a.	Factory	
Slab (from BOF)	kg		n.a.	Factory	
Slab (from EAF)	kg		n.a.	Factory	
Slab (from external supply)	kg		n.a.	Factory	
Steel strap	kg		n.a.	Factory	
Minerals	-	-	-	-	-
Lime quicklime (lumpy)	kg		n.a.	Factory	
Refractories (magnesia, alumina,	kg		n.a.	Factory	
Refractories (silica, alumina)	kg		n.a.	Factory	
Operating materials	-	-	-	-	-
Grease	kg		n.a.	Factory	
Water for industrial use	kg		n.a.	Factory	

Date	2018-02-20T07:46:45				
Fiscal period	2017				
Site	Example BF, 2017				
Questionnaire	(H) Hot Strip Mill (new)				
Tab	Output				
Name	**Unit**	**Value**	**Quality of data**	**Source**	**Year**
Flows	-	-	-	-	-
Emissions to air	-	-	-	-	-
Heavy metals to air	-	-	-	-	-
Arsenic (+V)	kg		n.a.	Factory	
Copper	kg		n.a.	Factory	
Iron	kg		n.a.	Factory	
Zinc	kg		n.a.	Factory	
Inorganic emissions to air	-	-	-	-	-
Ammonia	kg		n.a.	Factory	
Carbon dioxide	kg		n.a.	Factory	
Carbon monoxide	kg		n.a.	Factory	
Nitrogen oxides	kg		n.a.	Factory	
Sulphur oxides (as SO2)	kg		n.a.	Factory	
Organic emissions to air (group VOC)	-	-	-	-	-
Group NMVOC to air	-	-	-	-	-
Group PAH to air	-	-	-	-	-
Polycyclic aromatic hydrocarbons	kg		n.a.	Factory	
Halogenated organic emissions to air	-	-	-	-	-
Dioxins (unspec.)	kg		n.a.	Factory	
Methane	kg		n.a.	Factory	
VOC (unspecified)	kg		n.a.	Factory	
Particles to air	-	-	-	-	-
Dust (PM10)	kg		n.a.	Factory	
Dust (unspecified)	kg		n.a.	Factory	
Emissions to fresh water	-	-	-	-	-
Analytical measures to fresh water	-	-	-	-	-
Biological oxygen demand (BOD)	kg		n.a.	Factory	
Heavy metals to fresh water	-	-	-	-	-
Arsenic (+V)	kg		n.a.	Factory	
Cadmium	kg		n.a.	Factory	
Iron	kg		n.a.	Factory	
Tin	kg		n.a.	Factory	
Zinc	kg		n.a.	Factory	
Inorganic emissions to fresh water	-	-	-	-	-
Acid (calculated as H+)	kg		n.a.	Factory	
Aluminium	kg		n.a.	Factory	
Ammonia (NH4+, NH3, as N)	kg		n.a.	Factory	
Barium	kg		n.a.	Factory	
Nitrogen dioxide	kg		n.a.	Factory	
Organic emissions to fresh water	-	-	-	-	-
Carbon, organically bound	kg		n.a.	Factory	
Hydrocarbons to fresh water	-	-	-	-	-
Oil (unspecified)	kg		n.a.	Factory	
Phenol (hydroxy benzene)	kg		n.a.	Factory	
Thiocyanates (CNS-)	kg		n.a.	Factory	
Other emissions to fresh water	-	-	-	-	-
Waste water	kg		n.a.	Factory	
Particles to fresh water	-	-	-	-	-
Solids (suspended)	kg		n.a.	Factory	
Emissions to sea water	-	-	-	-	-
Analytical measures to sea water	-	-	-	-	-
Biological oxygen demand (BOD)	kg		n.a.	Factory	
Chemical oxygen demand (COD)	kg		n.a.	Factory	
Heavy metals to sea water	-	-	-	-	-
Copper	kg		n.a.	Factory	
Iron	kg		n.a.	Factory	
Manganese	kg		n.a.	Factory	
Zinc	kg		n.a.	Factory	
Production residues in life cycle	-	-	-	-	-
Hazardous waste for disposal	-	-	-	-	-
Hazardous non organic waste for	-	-	-	-	-
Hazardous Waste	kg		n.a.	Factory	
Hot Rolling Sludge	kg		n.a.	Factory	
Refractories (silica, alumina)	kg		n.a.	Factory	
Scale internal	kg		n.a.	Factory	
Waste from steel works	kg		n.a.	Factory	
Hazardous organic waste for disposal	-	-	-	-	-
Waste water treatment sludge	kg		n.a.	Factory	
Waste for disposal	-	-	-	-	-
Non hazardous non organic waste for	-	-	-	-	-
Hot Rolling Sludge	kg		n.a.	Factory	
Scale internal	kg		n.a.	Factory	
Waste from steel works	kg		n.a.	Factory	
Non hazardous organic waste for	-	-	-	-	-
Waste water treatment sludge	kg		n.a.	Factory	
Waste for recovery	-	-	-	-	-
Refractories	kg		n.a.	Factory	
Scales internal (Copy)	kg		n.a.	Factory	
Steel scrap (external supply)	kg		n.a.	Factory	
Steel scrap (Home scrap)	kg		n.a.	Factory	
Used oil	kg		n.a.	Factory	
Waste water treatment sludge	kg		n.a.	Factory	
Resources	-	-	-	-	-
Material resources	-	-	-	-	-
Renewable resources	-	-	-	-	-
Water	-	-	-	-	-
Fresh water	kg		n.a.	Factory	
Sea water	kg		n.a.	Factory	
Valuable substances	-	-	-	-	-
Energy carrier	-	-	-	-	-
Thermal energy	-	-	-	-	-
Hot water from process stages (MJ)	MJ		n.a.	Factory	
Steam (from process stages, in MJ)	MJ		n.a.	Factory	
Materials	-	-	-	-	-
Metals	-	-	-	-	-
Steel hot rolled coil	kg		n.a.	Factory	
Operating materials	-	-	-	-	-
Water for industrial use	kg		n.a.	Factory	

APPENDIX 5: LIST OF UPSTREAM INPUTS AND THEIR DATA SOURCES

Item	Process Information	Country	Year	Source
Acetylene	Ethine (acetylene), SACHSSE-BARTHOLOME process	DE	2018	thinkstep
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	2018	thinkstep
Aluminium	Cradle-to-gate, Aluminium ingot production based on data from the International Aluminium Institute (IAI).	GLO	2013	IAI
Aluminium chloride	Aluminium chloride hexahydrate	DE	2018	thinkstep
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	2018	thinkstep
Aluminium sulphate	Aluminium sulphate	DE	2018	thinkstep
Ammonia	Ammonia is produced almost exclusively by the well-known HABER-BOSCH process.	EU-28	2018	thinkstep
Ammonium sulphate	Ammonium sulphate mix (by-product)	DE	2018	thinkstep
Anthracite	Country specific data, based on hard coal mix for each country	Country specific	2016	thinkstep
Argon	Gaseous, LINDE process	DE	2018	thinkstep
Bauxite	Opencast and underground mining	EU-28	2018	thinkstep
Benzene	technology mix, from pyrolysis gasoline, reformate and toluene dealkylation	EU-28	2018	thinkstep
BOF slab	1kg global BOF slab, weighted average	GLO	2019	worldsteel
Calcium chloride	(from epichlorohydrine synthesis)	DE	2018	thinkstep
Carbon dioxide	From HABER-BOSCH process (ammonia synthesis, NH3/CO2)	DE	2018	thinkstep
Catalyst	Ethylene glycol	EU-28	2018	thinkstep
Cement	Cement (CEM I 42.5) (EN15804 A1-A3)	EU-28	2018	thinkstep
Charcoal	Site data for production	GLO	2015	worldsteel
Coal	Country specific data, based on hard coal mix for each country	Country specific	2016	thinkstep
Coal for coke making	Coking coal global consumption mix including transport to border of country of production	GLO	2015	thinkstep
Coal for injection	Country specific data, based on hard coal mix for each country	Country specific	2016	thinkstep
Coke	1kg global coke, weighted average	GLO	2019	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	2018	thinkstep
Corrugated board	EU-27: Corrugated board incl. paper production, average composition 2015 ts/FEFCO	EU-27	2018	thinkstep

Item	Process Information	Country	Year	Source
Diesel	Country/region specific	Country/region specific	2016	thinkstep
Diesel (high Sulphur)	Country/region specific	Country/region specific	2016	thinkstep
Diesel (low Sulphur)	Country/region specific	Country/region specific	2016	thinkstep
Direct Reduced Iron	1kg global DRI, weighted average	GLO	2019	worldsteel
Dolomite	Decarboxylation process by burning mined dolomite	EU-28	2018	thinkstep
Dolomite (crude)	Dolomite extraction	DE	2018	thinkstep
EAF Slab	1kg global EAF slab, weighted average	GLO	2019	worldsteel
Electricity	See Appendix 6 – Country specific	Country specific	2016	thinkstep
Electrode	baking petrol coke, pitch and hard coal tar	ZA	2018	thinkstep
Embankment	Gravel (Grain size 2/32) (EN15804 A1-A3)	DE	2018	thinkstep
Ferric chloride	direct chlorination of iron scrap	DE	2018	thinkstep
Ferro chrome	Ferro Chromium (high carbon)	GLO	2018	thinkstep
Ferro manganese	Production of ferro-manganese (77% Mn) with high carbon content.	ZA	2018	thinkstep
Ferro molybdenum	Ferro molybdenum (67% Mo)	GLO	2016	thinkstep
Ferro nickel	Ferro nickel (29% Ni)	GLO	2018	thinkstep
Ferro silicum	Ferro silicon mix (91%)	GLO	2018	thinkstep
Ferro vanadium	Ferro vanadium (FeV 80%)	ZA	2018	thinkstep
Ferrous sulphate	Iron (II) sulphate	EU-28	2018	thinkstep
Gasket (seal)	EPDM gaskets for aluminium profile (EN15804 A1-A3)	DE	2018	thinkstep
Gasoline	from crude oil and bio components	EU-28	2016	thinkstep
Glass wool	For glass wool production, the pure mineral primary glass is melted in a melting vat at approx. 1400°C	EU-28	2018	thinkstep
Glue	Mixer of Methylenediphenyl diisocyanate ((p)MDI) and Aromatic Polyester Polyols (APP) production mix	EU-28	2014	thinkstep
Heavy fuel oil	Country/region specific	Country/region specific	2016	thinkstep
Hot metal	1kg global hot metal, weighted average	GLO	2019	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	2018	thinkstep
Hydrogen	Steam reforming - natural gas	EU-28	2018	thinkstep
Hydrogen peroxide	50% H2O2. Anthraquinone process	DE	2018	thinkstep
Iron Ore	worldsteel production mix of 4 thinkstep datasets	GLO	2019	thinkstep
Kerosene	From crude oil	EU-28	2016	thinkstep

Item	Process Information	Country	Year	Source
Lead	Lead (99.995%), primary lead produced on the traditional process route. Does not include lead and zinc recovery.	RNA	2018	thinkstep
Light fuel oil	Country/region specific	Country/region specific	2016	thinkstep
Lime	Calcination of limestone	DE	2018	thinkstep
Limestone	Mining and beneficiation	DE	2018	thinkstep
Liquefied petroleum	Liquefied gas (LPG; 70% Propane; 30% Butane), refining process	DE	2016	thinkstep
Lubricants	The data set covers the entire supply chain of the refinery products.	EU-28	2016	thinkstep
Magnesium	Magnesium Pidgeon process	CN	2018	thinkstep
Manganese	South Africa and Australia cover 90% of the world manganese production (International Manganese Institute).	ZA	2018	thinkstep
	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%.			
MDI (Isocyanate)	Phosgenation of methylenedianiline	DE	2018	thinkstep
Mineral rock wool	Rock wool flat roof plate (120 mm)	DE	2018	thinkstep
Natural gas	Country specific data, based on natural gas mix for each country	Country specific	2016	thinkstep
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	2018	thinkstep
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	2018	thinkstep
Nitrogen	Air and power to produce gaseous nitrogen, country specific	-	2007	thinkstep
Olivine	Silica sand (Excavation and processing)	DE	2018	thinkstep
Oxygen	Air, cooling water and power to produce gaseous oxygen, country specific		2007	thinkstep
Paint (epoxy, melamine)	Mix of three powder coating upstreams, red, black and white	DE	2018	thinkstep
Paint (epoxy, phenolic)	Mix of three powder coating upstreams, red, black and white	DE	2018	thinkstep
Paint (polyester, melamine)	Mix of three powder coating upstreams, red, black and white	DE	2018	thinkstep
Paint (polyurethane)	Mix of water and solvent based primer	DE	2018	thinkstep
Paint (polyvinyl chloride)	Underbody protection PVC	DE	2018	thinkstep
Item	Process Information	Country	Year	Source
Paint (silicon modified polyester)	Mix of Coating water-based red, black and white	DE	2018	thinkstep
Paint (PVDF, acrylic)	Mix of Coating solvent-based red, black and white	DE	2018	thinkstep

Item	Process Information	Country	Year	Source
Pellet	1kg global pellet, weighted average	GLO	2019	worldsteel
Pentane	estimated via Butane	EU-28	2018	thinkstep
Petroleum coke	Country / region specific data, based on hard coal mix for each country	Country / region specific	2016	thinkstep
Phosphoric acid	100%, wet process	DE	2018	thinkstep
PMDI	Methylenediphenyl diisocyanate ((p)MDI)	EU-28	2010	thinkstep
Polyethylene	Polyethylene low density granulate (PE-LD)	EU-28	2018	thinkstep
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	2018	thinkstep
Propane	Regional specific	Region specific	2016	thinkstep
Protection Foil (PE-LD)	Polyethylene Film (PE-LD) without additives	EU-28	2018	thinkstep
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	2018	thinkstep
Refractories (all)	Sand-lime insulation brick	EU-28	2018	thinkstep
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	2018	thinkstep
Serpentine	Mined, as kaolin, normally together with silica sand and feldspar using bucket excavators or bucket chain dredgers.	DE	2018	thinkstep
Silicon mix	Purified, electric arc furnace process, from quartz sand	GLO	2018	thinkstep
Sinter	1kg global sinter, weighted average	GLO	2019	worldsteel
Sinter/pellet fines	1kg global sinter, weighted average	GLO	2019	worldsteel
Sodium carbonate	Soda (Na2CO3), produced by the Solvay process	DE	2018	thinkstep
Sodium chloride	Rock salt is obtained from salt mines by use of machines or leaching techniques.	EU-28	2018	thinkstep
Sodium hydroxide	100% caustic soda from brine extraction, electrolysis and purification	EU-28	2018	thinkstep
Sodium hypochlorite	50% solution	DE	2018	thinkstep
Sodium sulphate	Sodium sulfate is a by-product in the production of boric acid.	GLO	2018	thinkstep
Steam	Process steam from natural gas 85%	EU-28	2016	thinkstep
Steel scrap	See section 3.6.2.	GLO	2019	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	2019	worldsteel
Item	Process Information	Country	Year	Source
Sulphur	From Crude Oil	EU-28	2016	thinkstep
Sulphur dioxide	Sulphur dioxide estimation from oxygen and sulphur production	GLO	2013	thinkstep
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	2018	thinkstep

Item	Process Information	Country	Year	Source
Surface cleaning agent	Non-ionic surfactant (fatty acid derivative)	GLO	2018	thinkstep
Synthetic gas	Synthesis gas (H2: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	2018	thinkstep
Tar	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	EU-28	2016	thinkstep
Thermal energy	Mix of thermal energy from peat and biomass	FI	2016	thinkstep
Timber	Timber pine (12% moisture; 10.7% H2O content) (EN15804 A1-A3)	DE	2018	thinkstep
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	2018	thinkstep
Titanium dioxide	Chloride process	EU-28	2018	thinkstep
Varnish	Clear coat solvent-based (2K)	DE	2018	thinkstep
Zinc	Special high grade zinc	GLO	2019	IZA

APPENDIX 6: ELECTRICITY GRID MIX INFORMATION

The power grid mix that is used for each site is relevant to the location of each steelmaking site, by country. All data has been taken from the GaBi 9.2 SP39 software and is listed in more detail below. The data is a cradle-to-gate inventory and is in compliance with ISO 14040: 2006 and 14044: 2006.

Country	Age	Grid
Argentina	2015	49.32% Natural gas, 26.49% Hydro,15.37% Heavy fuel oil, 4.91% Nuclear, 1.72% Hard coal, 1.47% Biomass, 0.41% Wind, 0.3% Coal gases, 0.01% Photovoltaic.
Australia	2015	42.65% Hard coal, 20.79% Natural gas, 20.2% Lignite, 5.33% Hydro, 4.54% Wind, 2.69% Heavy fuel oil, 2.36% Photovoltaic, 0.84% Biomass, 0.59% Biogas.
Austria	2015	62.18% Hydro, 11.92% Natural gas, 7.41% Wind, 5.36% Biomass, 4.56% Hard Coal, 3.22% Coal gases, 1.64% Waste, 1.44% Photovoltaic, 1.32% Heavy fuel oil, 0.96% Biogas.
Belgium	2015	37.19% Nuclear, 32.5% Natural gas, 7.94% Wind, 5.06% Biomass, 4.37% Photovoltaic, 3.15% Hard coal, 3.02% Waste, 2.9% Coal gases, 2.02% Hydro, 1.55% Biogas, 0.3% 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	2015	61.89% Hydro, 13.68% Natural gas, 8.28% Biomass, 5.05% Heavy fuel oil, 3.72% Wind, 2.53% Nuclear, 1.95% Hard coal, 1.43% Coal gases, 1.34% Lignite, 0.12% Biogas, 0.01% Photovoltaic.
Canada	2015	57.2% Hydro, 15.24% Nuclear, 10.09% Natural gas, 8.63% Lignite, 3.97% Wind, 1.73% Biomass, 1.28% Hard coal, 1.22% Heavy fuel oil, 0.43% Photovoltaic, 0.15% Biogas, 0.04% Waste, 0.01% Coal gases.
China	2015	68.8% Hard coal, 19.29% Hydro, 3.17% Wind, 2.91% Nuclear, 2.48% Natural gas, 1.32% Coal gases, 0.90% Biomass, 0.77% Photovoltaic, 0.19% Waste, 0.17% Heavy fuel oil.
Czech	2015	42.34% Lignite, 32.03% Nuclear, 6.74% Hard coal, 5.08% Natural gas, 3.66% Hydro, 3.12% Biogas, 2.7% Photovoltaic, 2.5% Biomass, 0.83% Coal gases, 0.68% Wind, 0.2% Waste, 0.11% Heavy fuel oil.
Finland	2015	34.01% Nuclear, 24.54% Hydro, 15.49% Biomass, 7.6% Natural gas, 7.49% Hard coal, 4.52% Peat, 3.4% Wind, 1.25% Waste, 0.84% Coal gases, 0.53% Biogas, 0.31% Heavy fuel oil, 0.01% Photovoltaic.
France	2015	77.00% Nuclear, 10.54% Hydro, 3.74% Wind, 3.48% Natural gas, 1.7% Hard coal, 1.28% Photovoltaic, 0.75% Waste, 0.44% Coal gases, 0.38% Biomass, 0.38% Heavy fuel oil, 0.31% Biogas.
Germany	2015	23.95% Lignite, 18.25% Hard coal, 14.23% Nuclear, 12.28% Wind, 9.77% Natural gas, 6.00% Photovoltaic, 5.2% Biogas, 3.86% Hydro, 1.99% Waste, 1.78% Coal gases, 1.71% Biomass, 0.96% Heavy fuel oil, 0.02% Geothermal.
India	2015	63.88% Hard coal, 11.29% Lignite, 9.98% Hydro, 4.92% Natural gas, 3.09% Wind, 2.71% Nuclear, 1.73% Biomass, 1.66% Heavy fuel oil, 0.41% Photovoltaic, 0.13% Coal gases, 0.12% Waste, 0.07% Biogas.

Italy	2015	39.26% Natural gas, 16.63% Hydro, 15.00% Hard coal, 8.12% Photovoltaic, 5.26% Wind, 4.74% Heavy fuel oil, 4.64% Biogas, 2.19% Geothermal, 1.69% Waste, 1.4% Biomass, 0.77% Coal gases, 0.3% Lignite.
Japan	2015	39.36% Natural gas, 29.29% Hard coal, 9.85% Heavy fuel oil, 8.76% Hydro, 3.67% Coal gases, 3.44% Photovoltaic, 3.32% Biomass, 0.91% Nuclear, 0.66% Waste, 0.50% Wind, 0.25% Geothermal.
Luxembourg	2015	55.39% Hydro, 30.2% Natural gas, 3.84% Waste, 3.77% Photovoltaic, 3.69% Wind, 2.24% Biogas, 0.87% Biomass.
Mexico	2015	59.86% Natural gas, 10.76% Hard coal, 10.15% Heavy fuel oil, 9.9% Hydro, 3.72% Nuclear, 2.81% Wind, 2.03% Geothermal, 0.51% Biomass, 0.1% Coal gases, 0.08% Photovoltaic, 0.05% Biogas, 0.01% 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.
Netherlands	2015	42.34% Natural gas, 36.11% Hard coal, 6.87% Wind, 3.71% Nuclear, 3.3% Waste, 2.59% Coal gases, 1.73% Biomass, 1.3% Heavy fuel oil, 1.02% Photovoltaic, 0.94% Biogas, 0.08% Hydro.
Poland	2015	47.14% Hard coal, 32.05% Lignite, 6.59% Wind, 5.48% Biomass, 3.87% Natural gas, 1.48% Coal gases, 1.48% Hydro, 1.28% Heavy fuel oil, 0.55% Biogas, 0.05% Waste, 0.03% Photovoltaic.
Russia	2015	49.65% Natural gas, 18.32% Nuclear, 15.92% Hydro, 8.59% Hard coal, 5.74% Lignite, 0.95% Heavy fuel oil, 0.47% Coal gases, 0.26% Waste, 0.06% Peat, 0.03% Photovoltaic, 0.01% Wind.
Saudi Arabia	2015	55.8% Natural gas, 44.2% Heavy fuel oil.
Spain	2015	20.41% Nuclear, 18.7% Natural gas, 17.57% Wind, 17.14% Hard coal, 11.17% Hydro, 6.14% Heavy fuel oil, 2.94% Photovoltaic, 1.99% Solar thermal, 1.43% Biomass, 1.15% Lignite, 0.55% Waste, 0.47% Coal gases, 0.35% Biogas.
Sweden	2015	46.55% Hydro, 34.77% Nuclear, 10.04% Wind, 5.54% Biomass, 1.82% Waste, 0.43% Coal gases, 0.26% Natural gas, 0.24% Hard coal, 0.16% Heavy fuel oil, 0.11% Peat, 0.06% Photovoltaic, 0.02% Biogas.
Taiwan	2015	37.6% Hard coal, 29.5% Natural gas, 14.13% Nuclear, 6.72% Lignite, 4.92% Heavy fuel oil, 2.91% Hydro, 1.82% Coal gases, 1.28% Waste, 0.59% Wind, 0.34% Photovoltaic, 0.18% Biomass, 0.01% Biogas.
Thailand	2015	71.44% Natural gas, 10.94% Hard coal, 8.51% Lignite, 3.69% Biomass, 2.67% Hydro, 1.34% Photovoltaic, 0.57% Heavy fuel oil, 0.36% Biogas, 0.29% Waste, 0.19% Wind.
Turkey	2015	37.99% Natural gas, 25.71% Hydro, 15.99% Hard coal, 12.41% Lignite, 4.46% Wind, 1.31% Geothermal, 0.85% Heavy fuel oil, 0.76% Coal gases, 0.46% Biogas, 0.04% Waste, 0.01% Biomass.
United Kingdom	2015	29.5% Natural gas, 22.3% Hard coal, 20.74% Nuclear, 11.89% Wind, 5.73% Biomass, 2.66% Hydro, 2.23% Photovoltaic, 2.12% Biogas, 1.88% Waste, 0.63% Heavy fuel oil, 0.32% Coal gases.
United States of America	2015	32.05% Hard coal, 31.83% Natural gas, 19.26% Nuclear, 6.29% Hydro, 4.48% Wind, 1.97% Lignite, 1.11% Biomass, 0.90% Heavy fuel oil, 0.74% Photovoltaic, 0.44% Waste, 0.43% Geothermal, 0.32% Biogas, 0.09% Coal gases, 0.08% Solar thermal.

Full documentation for GaBi 9.2 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 9.2 software and are distributed from a web-based platform via rtf format to enable ease of use of the data. Data can also be provided in the GaBi format and are available in some LCA software tools.

The GaBi Envision reports contain the following information:

7.1 LCI flows

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

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

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

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 is generally small). When the recycling credits and burdens are included, the scrap input is not listed as the associated upstream burden has been included instead.
Ferrous scrap includes:

- Scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internally generated scrap.
- Home scrap is considered when the scrap comes from a process which occurs on the steelmaking site, but does not contribute to any of the production stages of the product for which the LCI is provided.

7.4 Water consumption

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

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

The quantity of salt water used by the steel plants is recorded within the GaBi model as sea water (though not reported specifically in the Envision report as part of the water footprint). 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, incinerated, flared etc. are classified as waste. In order to comply with ILCD[7], 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.

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 other primary energy sources, such as hydropower and biomass.

A full breakdown of energy is available on request.

7.10 Life cycle impacts

Four Life Cycle Impact Assessment Indicators from the CML2001 – Jan. 2016 impact assessment suite are reported for informational purposes only. 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. Concerning the air and water emissions, all 'accounted' emissions (see Section 4.3.) are reported in the data sheets.

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

APPENDIX 8: SYSTEM EXPANSION ASSUMPTIONS

Steel co-product	Co-product function	Avoided production	Data Source
Blast furnace slag, basic oxygen furnace slag, electric arc furnace slag	Cement or clinker production	1 tonne per tonne of cement. Portland cement (CEM I)	GaBi 9.2 (EU-28)
	Aggregate or roadstone	Gravel production	GaBi 9.2 (DE)
	Fertiliser	Lime production	GaBi 9.2 (DE)
Process gas (coke oven, blast furnace, basic oxygen furnace, off gas)	Heat production for internal or external use	Coal, heavy fuel oil, light fuel oil or natural gas	GaBi 9.2 (Country specific)
	Electricity production	1MJ gas = 0.365 MJ electricity	GaBi 9.2 (Country specific)
Electric arc furnace dust	Zinc production	1 kg dust = 0.5 kg Zinc	GaBi 9.2 (IZA)
Electricity from energy recovery	Electricity production	Electricity production	GaBi 9.2 (Country specific)
Steam from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 9.2 (EU-28)
Hot water from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 9.2 (EU-28)
Ammonia	Any ammonia application	Ammonia production	GaBi 9.2 (EU-28)
Ammonium sulphate	Any ammonium sulphate application	Ammonium sulphate production	GaBi 9.2 (DE)
Benzene	Any benzene application	Benzene production based on different technologies	GaBi 9.2 (EU-28)
BTX	Any BTX application	Benzene production based on different technologies	GaBi 9.2 (EU-28)
Scales	Metallurgical input to steelmaking	Iron ore extraction	worldsteel (2019)
Sulphuric acid	Any sulphuric acid application	Sulphuric acid production	GaBi 9.2 (EU-28)
Tar	Any tar application	Bitumen production	GaBi 9.2 (EU-28)
Used oil	Heat generation	Coal, heavy fuel oil, light fuel oil or natural gas	GaBi 9.2 (Country specific)
Zinc	Any zinc application	Zinc production	GaBi 9.2 (IZA)
Zinc dust	Any zinc application	Zinc production	GaBi 9.2 (IZA)
Electrode	Electrode making	Electrode mix	GaBi 9.2 (ZA)

APPENDIX 9: UPDATES FROM THE 2018 STUDY REPORT

This study report covers an update of the global steel industry LCI data and follows the 2017 LCI methodology report. During this 2019 update, a number of changes and updates have been made (compared to the 2018 study), and for ease of comparison, these differences are summarised here. Further information can be found in relevant sections of the report.

- The modelling software used for this update is GaBi 9.2 SP39. All upstream data which have not been collected by worldsteel from industry associations are based on GaBi 9.2 upstream data. The previous study used an earlier version of GaBi 8.7.
- Due to naming issues of some emission flows in GaBi 4, they were not picked up by impact assessment methodologies in GaBi. These have been corrected to ensure that all emission flows are correctly named. Currently this is done through a manual process using a flow name modification plan.
- To ensure the data is ILCD compliant, recovered material and wastes that had no final fate have now been modelled to be landfilled which will result in impacts that are higher than reality but is a conservative approach.
- Global iron ore upstream data is calculated using a 4-region-specific mix of iron ore production for 2017.
- Zinc upstream processes have been replaced with an interim process adapted from the International Zinc Association (IZA) dataset in coordination with IZA. The previous dataset was found not to represent the global Zinc production.
- New companies and sites have been added to the database and sites with data older than 5 years have been removed from the database and thus from the average product LCI calculations.
- Within the worldsteel modelling system, there is a separate Coke Oven model used to calculate the upstream Coke Oven impacts for sites that do not produce their own Coke. The Coke Oven model has been modified to use proxy energy impacts (natural gas) for BF Gas and BOF Gas consumption rather than relying on the system expansion process gas modelling. This is implemented so that the model replicates the impacts of the Coke Oven and its products more accurately. Therefore, the impact of producing coke (which is used in this model for imported coke only) has increased, specifically for GWP, by 84%. However, as the use of imported coke by the sites in this data collection is relatively low, the overall impact on the product LCIs is also quite low with an increase of GWP of around 1.6%.
- A new Internal Transport Combustion model has been introduced to the steel production model to include the impacts of the combustion of fuel used by the transport which is utilised internally within the steelmaking sites. Previously, only the impacts of the manufacture of the fuels utilised were included in the product LCIs. The overall increase in impacts is very small (at around 0.2 grams GWP per kg product) but helps to ensure that the steel industry looks at all potential sources of impacts that it generates.
- New transport modelling has been introduced to reduce the size of the models for unused repeated transport models. When the worldsteel steel production model was first created in GaBi, in order to be as complete as possible, the possibility was given for each site to provide transport information for all raw materials coming onto a site, as well as semi-finished products being transferred from one site to another for further processing (known within the model as split routes). Over the years, it has become evident that the majority of these transport flows are not required yet slow down the functioning of the model. The new system has removed all of these repeated transport plans and a single transport plan has been introduced when the spilt route system is constructed.
- In the co-product methodology one of the system expansion credits for BF slag and BOF slag was the replacement of Portland cement, but applied with a reduced credit of 90%. This has been reviewed by the LCA Expert Group, comparing the properties of the cement manufactured using BF Slag and the properties of Portland cement. It is found that the cement made from GGBS is of an equivalent if not better quality than the normal cement being produced, so this 90% factor has been removed, assuming that 1 tonne of GGBS replaces 1 tonne of cement.

APPENDIX 10: LIST OF ALL AVAILABLE QUESTIONNAIRES FOR DATA COLLECTION

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

APPENDIX 11: MATRIX OF USES OF STEEL PRODUCTS

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[2] and study reports[8].[9]

REFERENCES

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