worldsteel ASSOCIATION

LIFE CYCLE ASSESSMENT METHODOLOGY REPORT

Methodology report

Life cycle inventory study for steel products

Life cycle assessment methodology report

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Acronyms

AP	Acidification potential
BF	Blast furnace
BF Gas	Process gas produced in the blast furnace
BOF	Basic oxygen furnace
BOF Gas	Process gas produced in the basic oxygen furnace
CO Gas	Process gas produced in the coke ovens
CRP	Critical review panel
DRI	Direct reduced iron
EAF	Electric arc furnace
ECCS	Electrolytic chrome-coated steel (tin-free steel)
ELCD	European Reference Life Cycle Database
EP	Eutrophication potential
GWP	Global warming potential
HDG	Hot-dip galvanized steel
HRC	Hot-rolled coil
ILCD	International Reference Life Cycle Data System
ISO	International Organization for Standarization
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. Executive summary

1.1 Introduction

Selecting the most appropriate materials for any application depends on the consideration of a range of technical and economic factors including, for example, functionality, durability and cost. A further and increasingly important factor for material specifiers, in a world where sustainable development is a key issue, is the associated environmental performance of material applications from the perspective of manufacturing and product performance.

Among the tools available to evaluate environmental performance, life cycle assessment (LCA) provides a holistic approach to evaluate environmental performance by considering the potential impacts from all stages of manufacture, product use and end-of-life stages. This is referred to as the cradle-to-grave approach.

LCA generally comprises four major components:

- Goal and scope definition;
- Life cycle inventory (LCI) – data collection and calculation of an inventory of materials, energy and emissions related to the system being studied;
- Life cycle impact assessment (LCIA) – analysis of data to evaluate contributions to various environmental impact categories; and
- Interpretation - where data are analysed in the context of the methodology, scope and study goals and where the quality of any study conclusions is assessed.

The World Steel Association (worldsteel) has carried out an LCI study, the third of its kind in the steel industry, to quantify resources use, energy and environmental emissions associated with the processing of 15 steel industry products from the extraction of raw materials in the ground through to the steel factory gate.

The previous studies were carried out in 1995/6 and 2000/1. It is not intended that the previous data collections are used to show a time series of steel product profiles; the sites and companies used in each study are not all the same.

Data from 2000/1 was used to help make checks of the new data. This study began in 2006 and was led by worldsteel with technical assistance from the industry LCA Expert Group. Data were collected from worldsteel member companies, based on a year of production between 2005 and 2008. LCI data were then calculated for steel industry intermediate products derived via the blast furnace/basic oxygen furnace route (based on iron ore and steel scrap) and the electric arc furnace route (mainly based on steel scrap).

Downstream processing into manufactured products and their use has not been included in the inventory. The steel products have also been modelled including the end-of-life process of recycling. Therefore, the results can either be presented as a 'cradle-to-gate' study, or as a 'cradle-to-gate including end-of-life recycling' study. This latter term can also be referred to as a 'cradle to cradle' study. For the worldsteel study, this excludes further processing of the steel beyond the works gate and the use phase, as well as the processing of the steel scrap (e.g. collection, shredding and baling).

The boundaries of the study can be extended past the steel factory gate to include downstream activities, particularly in collaboration with customers who are applying LCAs to their own product systems, and the use phase of their product.

1.2 Goals

The primary goals of the study are to update the steel industry's worldwide LCI database and improve the already rigorous LCI methodology for steel products in accordance with ISO 14040:2006[1] and 14044:2006[2] standards, to provide reliable and up-to-date data to meet requests from customers and external studies.

The model, methodology and data collection have been updated. Improvements include moving to a weighted average dataset (product average calculated based on site production volume) and improving data quality. Further goals were to promote steel's environmental credentials and to further develop steel industry expertise in the subject.

1.3 Scope

The 15 products included in the study are the main finished products of the steel industry: plate, hot-rolled coil, pickled hot-rolled coil, cold-rolled coil, finished cold-rolled coil, hot-dip galvanized steel, electrogalvanized steel, organic coated steel, tinplated steel, electrolytic chrome coated steel (tin-free steel), UO pipe, welded pipe, sections, rebar and wire rod. Engineering steel has not yet been updated but will be completed in due course.

The products are of general relevance to a wide range of downstream applications including those in the construction, automotive and packaging sectors. The annual production figures are published in the worldsteel Steel Statistical Yearbook[3], available from worldsteel.org.

Stainless steel products are not included in this study. The results of a recent European stainless steel study are available now from Eurofer[4]. Global stainless steel data is available from the International Stainless Steel Forum[5].

In total, 49 sites operated by 15 companies, including 24 blast furnace operations and 12 electric arc furnace operations participated in the study. The companies contributing data to the LCI study account for over 25% of global crude steel production.

Companies in Europe (Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, the Netherlands, Norway, Spain, Sweden, and the UK) and Asia (China, India and Japan) are well represented and a typical range of operating configurations included. North America is included in the global average datasets and significant effort is being undertaken to enable a North American average dataset to be developed.

New sites and companies will be added to the average datasets once their data have been submitted and verified. This level of coverage maintains the worldsteel LCI study as the most representative LCI study for steel and thus provides a sound basis for LCA studies including steel products.

1.4 Methodology

The quality and relevance of LCA/LCI results, and the extent to which they can be applied and interpreted, depends critically upon the methodology used. It is important, therefore, that the methodology is transparent and well documented. International Organization for Standardization (ISO) standards have been developed to provide guidance on methodological choices and to set down rules for transparency and reporting. The relevant ISO standards are:

- ISO 14040: 2006 – Environmental management – Life cycle assessment – Principles and framework
- ISO 14044: 2006 – Environmental management – Life cycle assessment – Requirements and guidelines.

The goal of collecting and developing worldsteel LCI datasets is to facilitate the range of emerging impact assessment methods in future studies.

The worldsteel LCI study has been undertaken in accordance with ISO 14040 and ISO 14044. The previous data collection and methodology underwent a critical review from an independent critical review panel (CRP) of LCA specialists. This approach improved the integrity of the study and helped to guide the development of the methodology. The full CRP report is included in the methodology report of 2002, 'World Steel Life Cycle Inventory Methodology Report 1999 – 2000'[6].

The new data collection, released in February 2010, is based on the same methodology, with only a few modifications, which are detailed in this report. These modifications include:

- taking a weighted average approach (product average calculated based on site production volume) to determine product specific LCIs,
- utilising updated and more specific (e.g. country specific) upstream data with more complete coverage and
- including end-of-life recycling.

A summary of the main changes from the 2002 methodology report is in Appendix 11. It is not the intention of this report to make a comparison between the old and new worldsteel steel product LCIs, but to provide an overview of the methodology adopted by the steel industry. Where data is referred to, it is done so for illustrative purposes.

The LCI study is a project of the worldsteel Life Cycle Assessment Expert Group.

2 Project context

This report presents a summary of the third global worldsteel LCI study. It provides an explanation 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 and as part of worldsteel's ongoing commitment to improving data quality, it has now been updated for 2005-2008 data.

The main goal of the study is to update the LCI data for steel products on a global and regional basis. Currently, the only regional data that is available is European data but this will be expanded to include Asian and North American data. It is believed that other datasets on steel have been derived with limited accuracy or representation and/or contain out of date information. The worldsteel data contains data on process operations from 2005 to 2008 collected at individual sites with a universally applied methodology for data collection and LCI calculation.

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 the report aims to describe the details of the LCI methodology, further details on the steel industry production processes are available from other publications (available via the worldsteel website worldsteel.org and steeluniversity.org).

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

The worldsteel LCI study has been undertaken in accordance with ISO14040:2006 and 14044:2006, and has been critically reviewed by an independent panel of specialists, the CRP, to comment on the updated methodology and reporting of the study. This approach has improved the integrity of the study and helps to establish transparency. The final CRP report is included in Appendix 14 of this report.

In addition, the data itself has undergone a review in relation to the European Commission's International Reference Life Cycle Data System (ILCD) guidelines[7]. These guidelines build on the ISO 14040:2006 and 14044:2006 standards, providing technical guidance for detailed LCA studies while assuring quality and consistency of life cycle data, methods and assessments.

3 Goal of the study

LCA continues to be a topic of growing interest to the steel industry, as well as other industries. Several steel companies and regional steel associations have conducted independent LCA studies, mostly relating to packaging, construction and automotive applications. As these studies were different in purpose, system boundary and methodology, in 1996 the Board of Directors of worldsteel initiated the original global 'LCI on Steel Industry Products' to avoid inconsistency and duplicated effort. The update for 1999/2000 data and this update of data released in 2010 follows the same criteria. Both updates were carried out to get more up-to-date data for the global steel industry.

The goals of the project are to:

- Develop the common worldwide methodology for steel product LCIs from the original and updated study for this 2010 update study.
- 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.
- Support communication with industry stakeholders.
- Assist industry benchmarking and environmental improvement programmes.

For each data collection project, a methodology report was produced and underwent critical review to ensure compliance with the ISO standards relating to LCA.

The target audience of the study includes worldsteel 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 people, including customers of the steel industry, policy makers, LCA practitioners and academia. The data will also be made available in public and proprietary databases.

This LCI data is the basis for full LCAs, including LCIA, across broader boundaries and complete product life cycles. In addition, this data can be used to address single issues such as carbon footprinting of products.

The results of the study are not intended to be used in comparative assertions disclosed to the public. However, the data can be used in studies where comparative assertions are made and where a separate review of that study will be carried out.

The data can also be used for other purposes including:

- eco-design/design for recycling applications
- benchmarking of specific products
- procurement and supply chain decisions

- inclusion in Type I Ecolabel criteria for products
- inclusion in life cycle based Type III environmental product declarations for specific products
- the analysis of specific indicators, e.g. carbon footprints or primary energy consumption.

No comparison has been made with the previous data collection exercises, but it is intended that this will be carried out at a later date.

The overall magnitude of the results is on the same level as previous steel LCI data and there have been changes both increasing and decreasing the specific LCI values. The changes that have been made to the model and methodology have been made to improve the quality and representativeness of the data. Where appropriate, a conservative approach has been taken.

4 Scope of the study

4.1 System 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 functions, functional unit, system boundary and cut-off criteria of the study. These are outlined in the following sections.

4.2 Functional unit

Within the scope of this study, the functional unit is the production of 1 kg of a steel product at the factory gate. As upstream impacts are included in addition to the steel production, the data provided is called 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 section 4.6.1.

Fifteen steel products (see Table 1 below) were included in the study. These products were chosen because they cover the vast majority of steel products (>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 depending on 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 ranges.

Engineering steel data are not yet included in the list as there were not a sufficient number of sites providing data. Data collection is ongoing for this and other steel products.

The study focused on carbon and low-alloy steels (with alloy content lower than 2%). Notably stainless steels (with at least 12% chromium) were outside the study scope, but form the basis of another study[5].

Product category	Manufacturing route	List of products
Long products	Blast furnace route and electric arc furnace route	Sections Rebar* Wire rod*
Flat products	Blast furnace route	Plate Hot-rolled coil Cold-rolled coil Pickled hot-rolled coil Finished cold-rolled coil Electrogalvanized* Hot-dip galvanized Tin-free steel Tinplated products Organic coated flats Welded pipes UO pipes

* only global data is currently available

Table 1: List of products covered by the study

4.3 System boundaries

The study is a cradle-to-gate LCI study with and without the end-of-life recycling of the steel (see Figures 1 and 2 below). That is, it covers all of the production steps from raw materials in 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 associated with recycling the steel from the final products at the end-of-life (end-of-life scrap). It does not include the manufacture of the downstream final products or their use.

Steel is used in many different applications and as a consequence, the use phase has to be modelled by the downstream user of the steel products based on the cradle-to-gate datasets provided by worldsteel. 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.

In addition, cradle-to-gate (with and without recycling) inventories do not include the following, based on materiality: R&D, business travel, production and decommissioning, repair and maintenance, cleaning and legal services, marketing, operation of administration offices, etc.

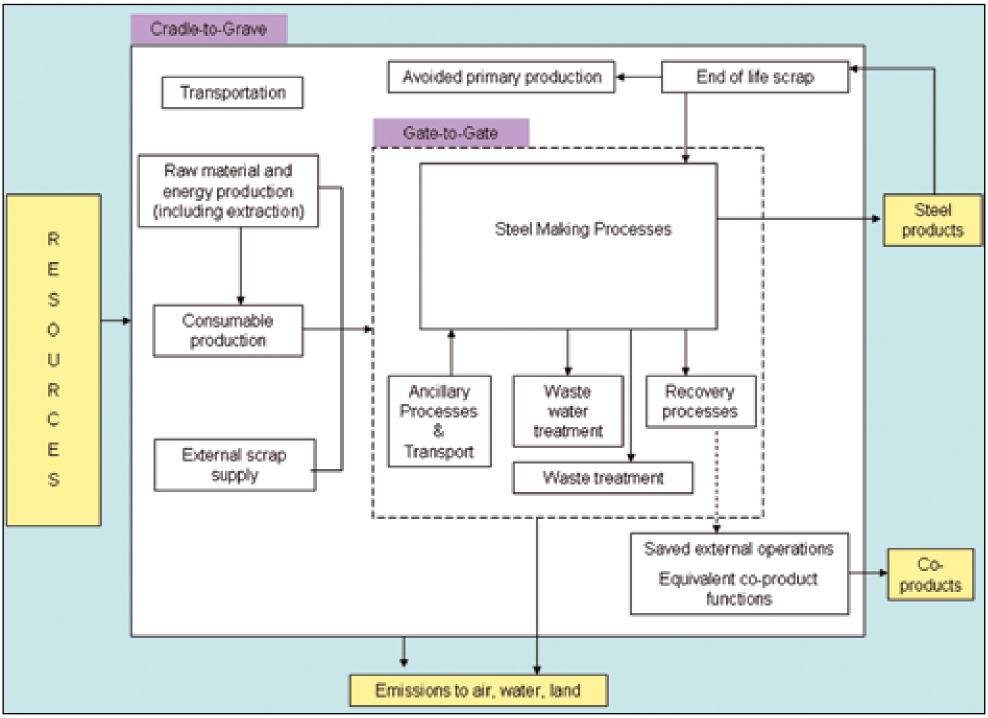


Figure 1: System overview, with end-of-life recycling

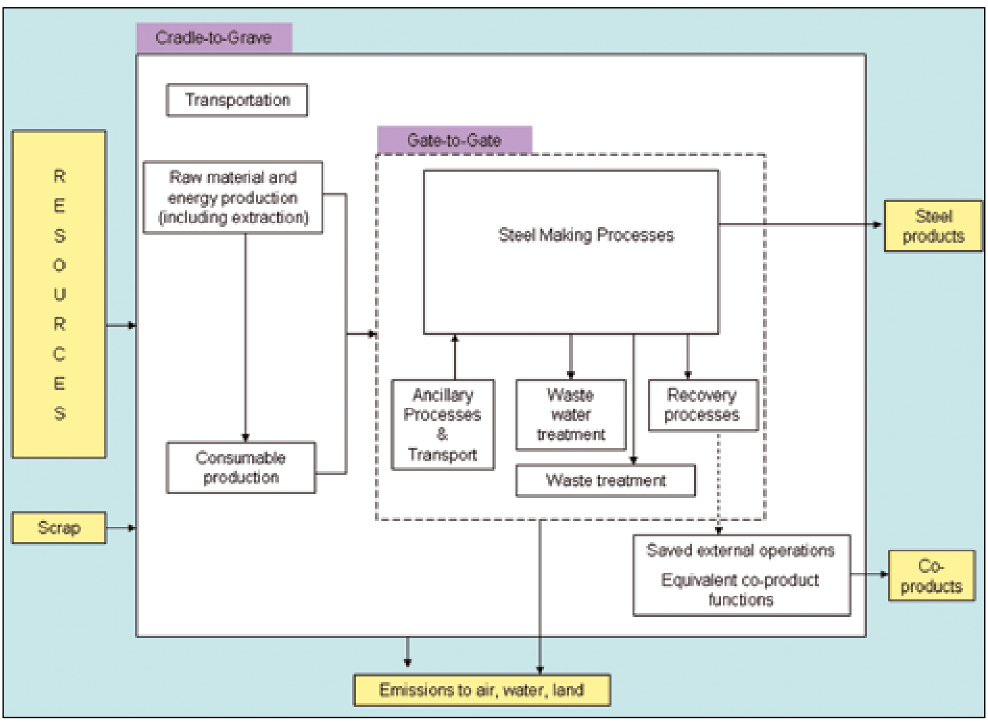


Figure 2: System overview, without end-of-life recycling

As shown in Figures 1 and 2, the system boundaries for the LCI for steel products encompass the activities of the steel manufacturing sites and the production and transport of raw material inputs, energy sources and other consumables (diesel for internal transport, oxygen, nitrogen, etc.) used in the steelworks.

In addition the recovery and use of steel industry co-products outside of the steelworks are taken into account using the method of system expansion as described in Section 4.6.1. Externally supplied scrap is sourced from merchants, other steel production facilities and municipal facilities. As indicated in Figure 1, for cradle-to-gate data including end-of-life recycling, the upstream burdens from using ferrous scrap are included in the methodology and scope of this data collection, as are the credits for recycling steel scrap at the end of the final products life. The methodology for calculating this burden and credit are included in section 4.6.2.

Terminology for the various system components is as follows. 'Route' refers to the full cradle-to-gate system including upstream supplies, transport and co-product credits. 'Site' refers to the steelworks boundaries. 'Processes' are the component unit processes within the 'site' and the 'route'. This can refer to either the main process stages and the associated ancillary workshops (e.g. coke oven or blast furnace), or to a common utility on the site (e.g. a power plant producing electricity or steam). For each of these processes, all relevant input and output flows have been identified for which the sites participating in the study needed to provide data. A representation of the basic oxygen furnace module is given in Appendix 2.

Utilising the individual processes, e.g. the sinter plant, an average dataset can be generated for intermediate materials produced on the steelworks – this is a weighted average based on the production volume of each of the specific processes. This is necessary for those sites that import such materials (e.g. coke, sinter, hot metal).

Analysis of the individual processes can also be used to facilitate data/error analysis. It can also help with the potential application of results for benchmarking and environmental improvement.

Process stage	No. of processes	Process Stage	No. of processes
Cokemaking	21	Electrogalvanizing	5
Sintermaking	22	Hot-dip galvanizing	17
Pellet plant	4	Tin-free mill (ECCS)	4
Blast furnace	24	Tinplate mill	11
Direct reduced iron	1	Organic coating line	9
Basic oxygen furnace	24	Section mill	8
Electric arc furnace	12	Heavy plate mill	7
Hot strip mill	19	Rebar	6
Pickling plant	20	UO pipe	4
Cold-rolling mill	20	Welded pipe	4
Annealing and tempering mill	19	Wire rod	8
Total processes			269

Table 2: Number of process stages represented in the study

Primary data were collected for 22 separate steelmaking process steps (Table 2 shows the break down), plus boilers, compressors, water intake, effluents, stockpile emissions, transport, and the NCV, iron and carbon content of specific flows. Data were also collected regarding the use of steel industry co-products such as process gases and slags.

The steel product manufacturing flow diagrams via the blast furnace route and the electric arc furnace route are shown in Appendix 3.

4.3.1 Technology coverage

Steel is produced predominantly by two process routes; the blast furnace/basic oxygen furnace route and the electric arc furnace route (the BOF and EAF routes respectively).

The BOF route is primary ore-based which generally uses up to 35% scrap input[8]. The steelmaking stage of this route is carried out using the basic oxygen furnace. The EAF route is predominantly a 100% scrap-based steelmaking process. Both routes continuously cast products that feed into hot and cold rolling processes. Cold-rolling together with coating and finishing processes for flat products are termed here the 'cold-rolling route'.

In principle, all products can be produced via both process routes. For example, steel sections that are often produced from the EAF process are produced in both the EAF and BOF routes at Tata Steel; steel sheet that is commonly thought of as a BOF product is produced in the EAF route at Nucor.

Flat products are often produced by the BOF route whilst long products are produced from both the EAF and BOF routes. Both of these routes are represented in this data update and the number of sites contributing data for each process is specified in Table 2.

Steelmaking technologies such as the open-hearth process and ingot cast steel products were not included. Open-hearth steelmaking and ingot casting technologies are declining for economic and environmental reasons and tend to be used mainly in the CIS and in India (see section 4.5.8).

4.3.2 Geographic coverage

The companies participating in the study account for over 25% of global steel production and the contributing sites (which cover 10% of global steel production) are among the largest of the principal producer countries. The highest represented region is Europe: the sites participating represent over 30% of European steel production. The list of participating companies is shown in Appendix 5.

A total of 49 sites located in 17 countries participated in the study. Although this data accounts for just over 10% of the global crude steel production, the major steel producing countries and regions are included: China, India, Japan, North and South America and Europe.

Although the datasets have been published and made available, any new company or site wishing to provide data will be included in future updates to this dataset. Data collection is ongoing in many more companies and this data will be added to the average datasets, increasing the representativeness of the data.

The groups currently defined for reporting of regional statistics include Global and European data. Asian and North American data will soon be available. Global and regional LCI averages are considered more appropriate than country-specific data since steel products are traded mainly at the regional or global level.

4.3.3 Time coverage

The data collection is related to one year of operation and the year of the data is indicated in the questionnaire for each data point. The majority of data were derived from the period 2005 to 2008 and is believed to be representative of global steel production during this time frame. Although improvements are continually being sought for the steelmaking processes, this is more of a gradual process than any major global change.

4.4 Example selection of 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 could consider a range of impact categories. The methodological aspects for key data categories are discussed in section 4.5.

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 provide impact category information with the LCI profiles, except for the Global Warming Potential, which is given for information purposes only. However, the worldsteel LCI profiles provided to users will be used to calculate LCIA results, applying selected impact methodologies. Therefore a selection of LCIA results has been included in this report for illustrative purposes only and is included in further detail in Chapter 7. The impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University, CML 2001 – Dec.07[9].

The following LCIA categories, which have been chosen as examples, will be applied to the LCI data:

- Global warming potential (GWP 100 years): an impact assessment level with global effect; GWP is mainly caused from CO_2 and CH_4 emissions which account for over 98% of GHG emissions from the steel industry. In exploratory impact assessments, other GHGs account for less than 2% of the steel industry GHG emissions, on a CO_2 equivalent basis.

- Acidification potential (AP): an impact assessment level with local effect; 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 from 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 from carbon monoxide emissions.

For a full assessment, there are other impact categories that need to be considered, for example human toxicity, ecotoxicity, ozone depletion potential, etc.

4.5 Data collection

The worldsteel LCI model was created in GaBi 4. It is based on the previous steel industry model used in the two previous data collection studies which was created in TEAM LCA modelling software. The model was created by a team of experts including the worldsteel LCA Manager, PE International and the worldsteel members and represents the steel production process.

Site data are collected using the internet-based GaBi Web Questionnaire, known as SoFi. The LCA software system GaBi 4 communicates with the web-based questionnaire platform via a specific interface. 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, an example of which is shown in Appendix 4, as well as for ancillary utilities such as boilers/power plants, compressors, alternators, etc. Each questionnaire contains a list of input and output flows in the following categories: material and energy inputs, air and water emissions, wastes, products and co-products, and recovered material.

Further information such as transport data and flow property information (e.g. net calorific value and iron or carbon contents) is also provided in the questionnaires. The central allocation of access rights by an administrator ensures the confidentiality of all collected data.

Details of the upstream inputs to the steelmaking process are detailed in Appendix 6.

A training manual for the GaBi Web Questionnaire is available. The following features in the questionnaire also facilitate data collection:

- The GaBi 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 questionnaire 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 are collected by worldsteel member companies, i.e. the steel-producing companies, on a site-by-site and process-by-process basis, ensuring a high quality dataset. The data represents normal or abnormal operation, but excluding accidents, spills and similar events.

Once the data are provided in the GaBi Web Questionnaire, basic checks are carried out on the carbon, mass and energy balances for each site. Then the data are exported from the GaBi Web Questionnaire using the export function to create an XML file that can be directly imported into the worldsteel GaBi model. Using this function is very beneficial as it removes any potential errors in data transfer between the data collection tool (GaBi Web Questionnaire) and the data modelling tool (GaBi).

4.5.1 Transport

The environmental burden of internal transport is very small. A review of a sample of sites in the original study showed an average of 0.001 litres of diesel was consumed (for internal transport) per kg of crude steel produced, corresponding to about 0.03MJ fuel energy/kg of steel product. However, the combustion of diesel consumption for on-site vehicles has nevertheless been included and is conservatively considered to be the same for each company participating in the study.

For external transport, the means of transport and distances for the shipment of the main raw materials (in terms of tonnage) to the steelworks were recorded by the companies in the questionnaires and included: rail (electricity and diesel powered), road, sea and river.

The models for these transport options come from the GaBi 4 database and consist of an average fuel supply, based on EU15 data for diesel and EU25 data for heavy fuel oil, light fuel oil and electricity.

The functional unit for all transport models is kg.km. Transport was included for iron ore, pellet, coal, scrap, limestone, lime and dolomite as well as steel intermediate products. These raw materials represent more than 95% (w/w) of the total tonnage of inputs (except water which is not transported).

Transport of the steel product and other co-products from the steelworks gate has not been included in the LCI.

4.5.2 Fuels and energy – upstream data

For all energy inputs (e.g. electricity, heating fuels, diesel for internal transport), the country/region-specific upstream inventories have been taken into account. All upstream data have been updated. For electricity and coal, further detail is provided in the following sections as significant changes have been made since the previous data collection exercise.

4.5.2.1 Electricity

The grid electricity production associated with individual sites can have a significant effect on the LCI, particularly with regard to CO_2 emissions. Therefore, this was customised for each country. For each site contributing data, the country specific electricity grid mix is used, as defined in the GaBi 4 database.

The LCI profiles for electricity taken from the GaBi 4 database quantify the related environmental burden on the basis of the consumption mix analysis for the related cradle-to-gate system. This includes domestic production and the most important imports for a certain country. Appendix 7 gives more information on grid electricity mix used for this study.

4.5.2.2 Coal

The data for coal have been significantly improved since the previous study. The average global coking coal mix that has been used is developed from data from 2006 from different countries, according to the 2006 International Energy Agency coking coal production mix, with a specific adaption by lower heating value from average hard coal to coking coal (using a lower heating value of global average coking coal of 29.02 MJ/kg). The average coking coal mix was used as coal is often sourced from many different suppliers and this information is not provided by the steel producers to worldsteel.

The transport of the coal product by rail and/or inland vessel from the coal mine to the harbour or country border is included. International transport from production country to consumer country is excluded from the coking coal dataset; this information has been provided by each of the steel producers using coal on their site in the LCI data collection questionnaire.

The dataset considers the whole supply chain from coal mining to coal upgrading as well as the transport to the coal terminal of the production country. All relevant process steps and technologies are covered: the data is representative of deep coal mining (approximately 67%) and open cast mining (approximately 33%). The inventory is mainly based on secondary and literature data.

Regarding methane emissions, the net value is provided (occurring mine methane emissions minus the use of the mine methane emissions). Data for mine methane emissions has been taken from the International Energy Agency[10], the German Federal Institute for Geosciences and Natural Resources (BGR)[11] and the United Nations Framework Convention on Climate Change (UNFCCC)[12]. Mine methane emissions contribute 62.2% to the GWP, with reference to the supply chain of the global coking coal mix.

4.5.3 Raw and process materials – upstream data

Data for processes outside the steel industry, e.g. upstream raw material production, were obtained for use in the study. To ensure a high level of data quality, worldsteel acquired data for those upstream processes that were judged to have a significant contribution to the global LCI results, either directly from the different industries, or from industry associations.

Where possible, data were taken directly from the material associations for their LCI data. Otherwise, data were taken from the GaBi 4 Professional database. The methodology for the derivation of these datasets is out of the scope of the worldsteel project but the major methodological and data quality aspects are consistent with the worldsteel methodology.

Upstream data were also required for those products being made within the steel industry (e.g. coke, sinter, hot metal), but which are not always produced on-site by each company. This is described further in section 4.5.3.3.

4.5.3.1 Iron ore

Iron ore is delivered to the steelmaking plants either in the form of iron ore fines or in the form of pellet. This depends on the quality of the original ore material and on the operational practices at the steelmaking plants. Pelletising is performed on very fine ores to ensure satisfactory gas permeability in the blast furnace. Similarly, iron ore fines are sintered to obtain an agglomerated product, called "graded sinter", of suitable size, porosity and strength for charging into a blast furnace.

Whilst sintering always takes place on the steelmaking plants, pelletising is done either by the mining companies or by the steel producers. Upstream pelletising data used within the worldsteel LCA model are based on the pelletising operations within the steelworks. As pelletising plants within a steelworks generally use process gases for their operation, their environmental impact, in terms of GWP, is generally higher as the process gases are more carbon intensive than the electricity grid mix that would be used at standalone plants.

The upstream model for iron ore mining used within the LCI Study has been updated. The LCI data are primary industry data and are collected for the mining of iron ore from 2008. The data cover seven iron ore mines representing nearly 250 million tonnes of iron ore production. Global iron ore production in 2008 was 2.18 billion tonnes.

4.5.3.2 Ferrous scrap

No upstream data for scrap collection, sorting and processing (e.g. shredding) has yet been included in the study. This will be incorporated in the next update to the data. However, for scrap coming from an external supply, the environmental burdens associated with the transport from the scrap merchant, municipal facilities or other factories to the steelworks is included, although this is generally negligible.

When considering the recyclability of steel at the end of a final products' life, a burden, which describes the value of the scrap (see appendix 10), is applied to the scrap input to the steelmaking process and a credit for the steel that will be recycled when the final product reaches the end of its life. This enables the practitioner to utilise the steel product LCI data as cradle-to-grave data, excluding final product manufacture and use phase. The allocation procedure for calculating this burden and credit is detailed in section 4.6.3.

Scrap input to the steelmaking process is defined in one of three ways:

1. Internal scrap: steel scrap from the BOF or EAF that is put back into the same BOF or EAF.

2. Home scrap: steel scrap from a steelworks process (not BOF or EAF) that is put back into the BOF or EAF process.

3. External scrap: steel scrap from external supply, outside the boundary of the steelworks site.

4.5.3.3 Intermediate products from external supply

Semi-finished products (continuously cast products at the steelmaking stage) are sometimes imported to the sites from external supply. Where the site is known (this is generally the case), the two sites are linked within the GaBi model so that the upstream data of the intermediate product are connected to the downstream processing site. Where the source of semi-finished products is not known, the global average value for the products is used.

Coke, graded sinter, pellet, direct reduced iron and hot metal can also be sourced from external supply. Since these can be substantial quantities, they were assigned the global study LCI average data, including appropriate transport, as they are all globally traded.

4.5.4 Emissions to air, water and soil

A list of all known air and water emissions was defined and drawn up for each process stage and included in the site questionnaires for data collection. Because techniques of measurement are more advanced for some sites than others, the total list of flows used in the questionnaire is more extensive than the typical emission monitoring data collected routinely at any one site. However, the long list enables all sites to provide their specific emissions data.

The availability of data was sometimes limited from certain sites and emission values were unknown. There are a number of emission flows for both air and water which are known to occur from certain steelmaking processes and these have been defined as 'accounted emissions' and are listed below.

Where sites are not able to provide the data for such flows, and to avoid artificially reducing the average values for these flows (as the value for sites that do not know the data is zero), average data are assigned to the sites with 'missing data'. This average value is calculated based on those sites that have submitted data for each of the accounted flows below and is based on a global average value, where a minimum of three sites have provided data. Carbon dioxide has been provided by all sites. For the other flows, the sites not providing data for the accounted emissions ranges from 5% to 85%.

Accounted emission		Flows
Air	Greenhouse gases	CO_2, CH_4, N_2O
	Acidification gases	NO_X, SO_X as SO_2, HCl, H_2S
	Organic emissions	Dioxins VOCs (excluding methane)
	Metals	Cd, Cr, Pb, Zn
	Others	CO, Particulates (Total)
Water	Metals	Cr, Fe, Zn, Pb, Ni, Cd
	Others	N (except ammonia), P compounds, Ammonia, COD, Suspended matter

Table 3: List of accounted air and water emissions

The list in Table 3 includes the significant emissions for global warming, air acidification and eutrophication indices, a number of metals, and some additional emissions to water. Further explanation of the air and water articles can be found in Appendix 8.

All other non-accounted emissions are still considered to be important emissions and are included in the data when it has been provided in the data collection. These are generally emissions that are not present in all steelworks, but only emitted from certain plants, depending on their production process and raw material inputs. Average values are therefore not assigned to all sites with missing data.

Fugitive emissions have been combined with particulate/dust emissions.

Regarding water emissions specifically, when recorded in the questionnaires, the pollutant amounts in the intake were subtracted from the pollutant amounts in the water released after waste water treatment because they are not attributable to the steelmaking processes. For some sites downstream of urban and industrial areas, the outflow water is purer than the intake. However, the quality of this ("polluted") water entering the site is often not provided. Therefore, the values of waterborne emissions are potentially overestimated in terms of net emissions.

Where data were not available for specific steelmaking processes, aggregated data were collected for the site's waste water treatment and these environmental burdens were allocated directly to the crude steel. This means that the data were collected and submitted in either the BOF or the EAF questionnaires.

Material disposed of in landfills, both internal and external to the steel works, and incinerated materials have been classified as waste.

4.5.5 Waste for recovery

Materials which were recovered within the site were specified as an output from the process in which it was produced and as an input for the process where it was then re-used. The net balance of each material was then calculated in the model for each steel product. With the exception of scrap and process gases, the net balance of these internally recycled materials is generally small.

Finally, materials exported from the site for external applications have been classified as co-products (or waste for recovery).

Some materials are partly waste and partly co-products. In such cases, the figures were included separately in the questionnaires for site data collection. For material recovered, the application of the recovered material was also included. Allocation procedures were applied only to the co-products.

4.5.6 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 must be very high. To achieve this, industry data collected directly from the producers were used wherever possible. For all other data, primary data were used where possible, e.g. ferro alloy compounds, and finally upstream LCA data from the GaBi professional database. For this latter case, the GaBi data were customised for the worldsteel data collection project.

4.5.7 Flares

Process gases are sometimes sent to flare stacks and combusted rather than being used elsewhere. This is due to variations in gas supply and demand and to the availability of gas collection facilities. As the combusted gases disperse without containment, measurement of these emissions is difficult.

Estimates of emission data for flares were either supplied by sites in questionnaires or, alternatively, default data were used, based on the average emissions data supplied by other sites. Some sites included their flaring data in the process data and so it is not possible to disaggregate this information from the process emissions.

About eight sites provided emissions data for the flaring of their process gases. The average CO_2 emissions have been calculated and used for those sites that did not include their flaring emissions in their data as CO_2 is the only commonly reported emission figure.

Overall, air emissions due to flaring are often quite low compared to the process stage air emissions, but are still included in the data. No manufacturing or economic benefits are realised from flaring, and the associated emissions were allocated entirely to the functional unit of the respective gas source module (e.g. coke oven gas and BOF gas).

4.5.8 Exceptions

In 2010, 98.7% of crude steel production was produced either via the BOF or EAF route. Open hearth production and ingot cast steel production, accounting for approximately 1.3% of global steel production, was not included. No other exceptions to the scope of this study on carbon steel products are given.

4.6 Methodological details

4.6.1 Co-product allocation

With any multi-product system, allocation rules are defined to relate the system inputs and outputs to each of the products. This is particularly important in the case of the blast furnace route, which generates important quantities of valuable co-products (also known as by-products), but it also applies to slag produced in the EAF route.

Several methods are documented in ISO 14040:2006 and ISO Technical Report 14049. The main co-products for the coke ovens, BF, BOF and EAF are listed in Table 4, together with the allocation method chosen. System expansion has been chosen by the steel industry as the approach used to incorporate co-products within the methodology and is described in further detail below.

Production process	Main co-products	Allocation method
Coke oven	CO gas	System expansion
	Coke Benzene Tar Toluene Xylene Sulphur	System expansion
Blast furnace	Blast furnace gas Hot metal Slag	System expansion
Basic oxygen furnace (BOF)	BOF gas Crude steel Slag	System expansion
EAF	Crude steel Slag	System expansion

Table 4: Steelmaking co-products

4.6.1.1 The system expansion method

This is the preferred method of the steel industry as it provides the most consistent solution to avoid many of the problems of other approaches. For example, allocation rules are avoided by attributing all system inputs/outputs to the main system function (to produce hot metal) but credits are given to the production of process gases and slags because their production replaces alternative production of similar functional products.

To some extent, this method can be seen as an "open loop recycling procedure". Where process gases are consumed in modules within the system, the burdens of alternative products are then added to the system, offsetting the credits. Where all generated gases are consumed on-site, values of inputs/outputs and emissions equate to the real site values.

The method is cited in section 4.3.4 of ISO 14044:2006. It is described as one of the preferred methods since it 'avoids' allocation. The challenge, however, is in the choice and functional equivalence of the alternative systems selected and great care has been taken to ensure that those selected are consistent with actual practice. For example, blast furnace gas is a fuel with no equivalent means of generation. It is used as a fuel for upstream and downstream processes and can be exported to systems external to the steel production system. Therefore, an assumption has to be made regarding the fuels potentially replaced. On average, 4.8 MJ of blast furnace gas is generated per kg of hot metal, excluding the small quantities that are flared without energy recovery (see section 4.5.7).

The selection of alternative fuels was the subject of sensitivity analyses described in the original study. The decision was taken to assume that energetic gases generated in steel production such as blast furnace gas, coke oven gas and BOF gas, replace the energy needed to produce the equivalent thermal energy or the national grid electricity applicable to the respective country. For example, if the steel is produced in Japan and the process gases are exported to replace electricity, the Japanese electricity grid mix will be used.

Surplus gas that is not used on site but that is exported beyond the system boundaries is also used to replace thermal energy or is supplied to local power stations to generate electricity. Generally, the alternative fuel to these gases would be coal, fuel oil or natural gas with usually coal predominant.

The system expansion takes account of both the production and the combustion of the fuels compared to coal, heavy fuel oil, light fuel oil or natural gas, and also considers the efforts to combust the process gases. In terms of fuel quality and air emissions, the exported gases are not always as good as the fuels that they replace (e.g. natural gas) and in these cases, the system expansion approach can result in an increase to some of the flows in the inventory of the steel products being assessed.

The selected replaced fuel or electricity is determined by the site, who reports this to worldsteel as part of the data collection process, and the national grid mix for the country of location.

In the same way, significant material co-products such as slags, which are sold to known destinations, are assumed to replace functionally similar products. For example, BF 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, 0.3 kg of BF slag is generated per kg of hot metal. The generation rate, which depends on the raw materials used, can be as high as 0.35 kg in some cases. On the sample of participating sites, approximately 95% of the total amount of BF slag produced is recovered and over 80% is used for cement making. Some slag is not exported, and is used for such things as on-site construction.

Details on the use of slags, for the data collected, is provided in Table 5. 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.

	Total recovered	Cement	Roadstone	Fertiliser
BF slag	>94%	82%	17%	<1%
BOF slag	>95%	9%	83%	8%
EAF slag	100%	9%	91%	0%

Table 5: Slag recovery rates and usages

This method allows discriminating between alternative recycling routes of steel co-products from an environmental perspective as different “credits” are given for recycling based on the end use of the co-product. This reinforces the environmental value of recycling in the industry.

Allocation scenarios do not integrate the actual use of co-products. For example, allocation applied to BF slags would not consider the actual proportions of slags used in cement making and aggregates. The environmental benefits of saving cement is much higher, in terms of energy resources and air emissions at least, than those associated to aggregates.

System expansion is also used for the allocation of dusts, scales, oils, etc. that are produced in the steel making processes. Details of the assumptions made for all recovered material are included in Appendix 9.

With system expansion, the initial (actual) inventories of the process units are preserved in the results displaying their individual contribution to the overall LCI at the route level.

4.6.1.2 Partitioning

Within the worldsteel methodology, energy partitioning is used for allocation to the various products (electricity, hot water, steam, compressed air and blast air) at power plants within the steel sites. These data categories were collected through the site questionnaires.

Partitioning is an allocation process that is used where a system generates material products of similar function. Where systems generate energetic products, such as fuels, allocation can be based upon the relative energy values of the products. This is termed energy partitioning.

4.6.1.3 The EAF route

System expansion is applied to the EAF co-products, including the slag, dusts, scales, oils, etc. in the same way as is done for the BOF route co-products. One notable difference between the BOF route and the EAF route is that the co-product credit/debit for the latter is much lower.

4.6.1.4 Summary

Each relevant plant defined the proportion of the process gas (coke oven, BF and BOF gases) used for electricity generation, and that used for heat generation. The quantity of process gas used for electricity generation is assumed to displace the average national grid electricity. Similarly, the quantity used for heat production is assumed to displace the appropriate fossil fuel(s) used at the facility.

It could also be considered that the choice of the replaced energy depends on the goal of the study and particularly to its time scale. For example, marginal means of electricity production would be preferentially applied in the case of (short-term) descriptive studies. In contrast, average 'construction' models would be preferred for (long-term) prospective studies.

The construction of the system expansion method in the GaBi worldsteel LCI model provides the flexibility to specify different scenarios for each co-product in question. For example, slags can replace cement, fertiliser or aggregate/roadstone; process gases can be used internally or externally and can replace different heat or energy sources. This information was provided by the member companies. Where this is not possible, the model will apply default scenarios corresponding to:

- the use of slag to replace aggregate/roadstone
- the use of process gases to replace natural gas used for thermal energy.

In both these cases a conservative approach was taken as these default values of aggregate/roadstone and natural gas give the lowest credit to the system. All sites provided information on the destination of their slags and process gases. For any recovered gases or slags not accounted for by the sites, the default scenario applies.

In conclusion, the system expansion method was selected for multi-functional systems since it closely represents the real interactions of steel production routes with the environment and avoids unsound theoretical scenarios. Most importantly, it does not result in favourable LCI results for the steel industry.

The construction of the system expansion method in the worldsteel LCI model provides flexibility to analyse and, if necessary, switch off each system expansion scenario and/or replace it with alternative functional systems. This facility allows sensitivity analysis of different system expansion scenarios and will facilitate studies into alternative uses of wastes that may in future be treated to replace functionally similar products.

4.6.2 Capital goods

The aspect of capital goods was addressed in the previous study and it was decided not to include it. Capital goods have not been included in the present study.

4.6.3 The end-of-life phase

Steel is completely recyclable. Therefore, it is important to consider recycling in LCA studies involving steel, namely the steel scrap that is recycled from a final product at the end of its life. In addition, steel is a vital input to the steelmaking process, and this input of steel scrap should also be considered in LCA studies.

The worldsteel methodology considers both of these factors. There is a growing market for steel products and there are no changes to the inherent properties of the steel when it is recycled and steel can be recycled over and over again.

Due to the maturity of the steel recycling system that has developed across the world, steelmakers and scrap merchants have harmonised the use of the steel scrap for relevant products to minimise the costs in treatment of scrap for use in the new steel products. With selection of various scrap grades, some products are recycled into lower quality products, in the same way that some scrap steel is recycled into higher quality products such as aerospace steels. Should the need arise, further segregation of steel from contaminants and processing could be carried out.

A closed loop approach can therefore be applied for the recycling of steel; this follows ISO 14044:2006 section 4.3.4.3, which describes the allocation procedures for closed loop material recycling. The Declaration by the Metals Industry on Recycling Principles[13] provides further interpretation of recycling as described in ISO 14044:2006.

The general life cycle equation for this "closed material loop recycling methodology" is applied as shown by the equation below:

$$\text{LCI for 1 kg of steel product including recycling} = X - (RR - S)\, Y(X_{pr} - X_{re})$$

Where:

X is the cradle-to-gate LCI of the steel product

(RR – S) is the net amount of scrap produced from the system:

RR is the end-of-life recycling rate of the steel product

S is the scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internal 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.

$Y(X_{pr} - X_{re})$ is the LCI value of steel scrap:

Y is the process yield of the EAF (i.e. >1kg scrap is required to produce 1kg steel)

X_{pr} is the LCI for 100% primary metal production. This is a theoretical value of steel slab made in the BOF route, assuming 0% scrap input.

X_{re} is the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.

Further explanation is provided in Appendix 10.

It is intended that the upstream data for scrap collection, sorting and processing (e.g. shredding) will be incorporated into the model in the future. In this case, these impacts will be assigned to the steel scrap that is used as an input to the steelmaking process, i.e. S in the above equation. Any scrap processing that occurs on the steelworks site is currently incorporated in the dataset.

4.6.4 Cut-off criteria

Criteria were set out in the original study for the recording of material flows and to avoid the need to pursue trivial inputs/outputs in the system. These are outlined below:

1. All energetic inputs to the process stages were recorded, including heating fuels, electricity, steam and compressed air.

2. The sum of the excluded material flows must not exceed 5% of mass, energy or environmental relevance. However, in reality at least 99.9% of material inputs to each process stage were included.

3. Wastes representing less than 1% of total waste tonnage for given process stages were not recorded unless treated outside of the site.

Criterion 2 was attainable because site input tonnages are weighed by relatively few inputs such as iron ore, pellets, limestone, scrap, dolomite, olivine, serpentine, metallic additions, refractories, coke, sinter, hot metal, and intermediate steel products which account for >99% of material inputs to each process stage.

4.6.5 Averaging

In contrast to the previous data collection, averages have been calculated using a weighted average (product average calculated based on site production volume), based on the contribution according to the production tonnage of each site to a particular product. The earlier decision to use an arithmetic average was a political decision and moving to a weighted average is a more robust, scientific approach.

The LCIs are still calculated vertically, i.e. the LCIs are calculated for each site (vertical aggregation) and the resulting values averaged across the contributing sites, see Figure 3. For benchmarking and interpretation of the data, the straight average approach was used: each site was treated with an equal weighting.

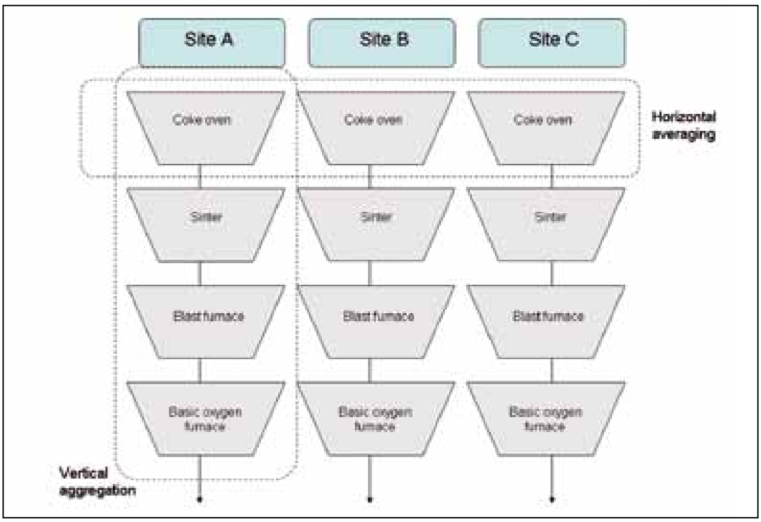


Figure 3: Horizontal averaging and vertical aggregation

4.7 Software and database

The LCA model for steel production was made using the GaBi 4 software system for life cycle engineering, developed by PE International GmbH (version 4.3, 2008)[14]. In conjunction with the model, the GaBi Web Questionnaire was used for the data collection exercise. Once the data had been collected as described in section 4.5, it was imported into GaBi where the modelling was carried out. The GaBi 4 Professional database was used for many upstream inputs as described in section 4.5.3.

The worldsteel model will be updated as new versions of GaBi software become available.

4.8 Interpretation

The results of the LCI/LCIA are interpreted according to the goal and scope. The interpretation addresses the following topics:

- Identification of significant findings such as the main contributors to the overall results or certain impact categories, see Chapter 8.
- Evaluation of completeness and sensitivity to justify the inclusion or exclusion of data from the system boundary or methodological choices, see section 8.2.2.
- Conclusions, limitations and recommendations of the appropriateness of the definitions of the system function, functional unit and system boundaries, see section 8.3.

4.9 Critical review

To ensure that this methodology correctly follows the methodology for LCA according to ISO 14044:2006, a critical review was conducted. This revision of the worldsteel LCI data collection project is based on the previous methodology developed by worldsteel. A few changes have been made to the methodology and it is these changes which are one of the main subjects of the critical review. A summary of these deviations from the previous methodology are noted in Appendix 11. The critical review report is included in Appendix 14.

In addition, the data has also undergone a review, in relation to the European Commission's ILCD guidelines.

5 Data quality

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. ferro compounds, from industry associations or producers
- Primary gate-to-gate data, plus background system from the GaBi 4 Professional database.

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 data are collected directly from the steel producers themselves, enabling a thorough analysis and exchange with these producers.

The steel industry strives to improve the quality of its own data and upstream data used in the model. Figure 4 below shows an overview of the organisation of the data collection exercise.

Project leader: worldsteel LCA Manager

Data provision: worldsteel member companies

Support:
- worldsteel LCA Expert Group
- PE International

Review:
- worldsteel LCA Expert Group
- PE International
- Critical review panel (4 international LCA experts)

Figure 4: Organisation of the worldsteel data collection

To ensure that the primary, gate-to-gate data collected from worldsteel member companies were of highest quality, each member company was provided with a data collection user guide and was given training on how to use the GaBi Web Questionnaire. The worldsteel LCA Manager was available for web meetings or calls to answer specific questions relating to the data collection exercise.

Gate-to-gate data

All data on steel production and processing were collected on a site-by-site basis using the GaBi Web Questionnaire. All data submitted were checked many times for plausibility of inputs and outputs and benchmarked against other data collected.

Upstream GaBi data

All data from the GaBi Professional database were created with consistent system boundaries and upstream data. Expert judgement and advice were used to select 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/.

5.1 Data quality check

The GaBi Web Questionnaires were based on the worldsteel LCA model that had been set up between worldsteel and PE International. 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 in kg, MJ, GJ, Nm^3, kWh, etc.

The SoFi data collection tool allowed users to carry out an iron, carbon and mass balance across individual processes. This data could be extracted by worldsteel for analysis. In addition to the worldsteel LCA Manager, further work was conducted by steel experts who were given access to individual datasets, to examine processes to ensure no errors in data collection had occurred. This was carried out by examining the individual processes for all sites and comparing the inputs and outputs. The experts applied their knowledge of the steelmaking processes to ensure the data was consistent with known steelmaking practices.

5.1.1 Raw data

All completed GaBi Web Questionnaires submitted by the sites were checked individually and systematically by worldsteel. General plausibility checks were applied (e.g. carbon checks) as well as benchmarking checks as offered by the GaBi system, for example for horizontal benchmarking, see Figure 3. Initial checks were done by the sites entering the data, using the balance facility available in the GaBi Web Questionnaire (energy, mass, carbon, and iron balance).

Suspected out-of-range data and important missing information were detected following visual inspection and analysis of the data, and requested from the companies. The questionnaires were imported directly into the GaBi software; an update function is also available that allows the import of intermediate data as data quality checks are made and data is updated. No manual import was necessary, which avoided errors in conversion or typing mistakes. Further checks were made of the data, by benchmarking processes for each site. This was done using a horizontal average approach, by comparing the same process across each site (see Figure 3).

Where data were missing or suspected to be erroneous clarification was sought with the site, until all necessary data were of the desired quality.

5.1.2 Process, site and route data

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

- carbon and iron balance per kg of product for each process
- energy consumption per process, including the boilers
- emissions to air and water
- yields between different process steps and scrap produced/consumed
- LCIA level checks.

Data checking was an iterative process, with continual communication with the data providers to clarify any queries or inconsistencies about the data.

The product LCIs were then 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 3), i.e. calculating the LCI for product A from site X and averaging with product A from site Y, based on the weighted average (product average calculated based on site production volume) of the production volume of product A.

The final product specific LCI results were then distributed to the worldsteel LCA experts in order to check them for accuracy to ensure that the final LCI results were accurate and robust.

5.2 Data gaps

Where there were gaps in the data, the data collector was asked 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 accounted air and water emissions, this average approach was taken. This is detailed in section 4.5.4.

Where data were missing for energy and material inputs, the sites were requested to provide this missing information.

6 worldsteel life cycle model description

The worldsteel LCA model has been set up in a hierarchical structure:

- process chain, i.e. the steelmaking processes only
- gate-to-gate, process chain plus utilities
- cradle-to-gate level, including up-stream data, substitution
- cradle-to-gate including recycling.

The gate-to-gate level model consists of all the steelmaking processes (process chain) as well as any additional on-site ancillary services that are required. This includes boilers, compressors, waste water treatment, etc. The cradle-to-gate level then includes this gate-to-gate level as well as all related upstream processes (raw material inputs) and substitution, waste treatment, etc. This is shown in Figure 2.

The highest level, cradle-to-gate including recycling (see Figure 1), considers the cradle-to-gate level as well as the impacts of using steel scrap in the steelmaking process and the end-of-life recycling of the steel from the final product when it reaches the end of its life. The methodology for including these recycling aspects is described in section 4.6.3.

Each site is a standalone model, which considers the complete production chain of steel product manufacturing. However, in some cases, the production of the steel products does not take place on only one site. For example, one company produces steel slab on site A and then transports the slab to site B for processing into tinplate. This situation is referred to as a split route and the two sites are linked within the worldsteel model in order to calculate the product LCI. Nevertheless, the environmental impacts of sites A and B can still be determined separately.

6.1 Steel manufacturing

Steel production involves several processing stages including ironmaking, primary and secondary steelmaking, casting and hot rolling. These are followed by some of the following fabrication processes: cold rolling, annealing, tempering, coating and/or heat treatment.

Steels can be made either from raw materials (e.g. iron ore, coal and limestone) or by recycling steel scrap. The two main process routes are:

- EAF using predominantly steel scrap as well as pig iron or direct reduced iron
- the integrated route, often referred to as the BF or BOF route, using mainly raw materials and a lower steel scrap input.

These complex processes, particularly the integrated route, produce a wide variety of steel compositions, in many different shapes and sizes, each tailored closely to the requirements of the use of the steel. These are not two distinct process routes and neither route is solely a 'primary' steelmaking or 'secondary' steelmaking route; the EAF can often contain primary material (pig iron or DRI) and the BOF contains scrap.

A representation of the steel production routes that have been modelled in the GaBi 4 software is shown in Appendix 3 and further details can be found on steeluniversity.org.

6.2 Life cycle inventory modelling

The LCA model for steel production has been set up in the GaBi 4 LCA software tool and reflects all possible steel production routes, with the exception of open hearth furnace steel production, thus allowing over 98% of steel production sites to participate. The complexity of the steelmaking process is reflected in the complexity of the worldsteel model.

A generic model has been created that can be used by all sites participating in the data collection process. This ensures consistency and allows for calculations to be made at all levels, from the individual processes and process chains to the cradle-to-gate level and including end-of-life recycling. The model also enables calculations to be carried out on a horizontal and vertical level (see Figure 3), which is extremely useful for benchmarking and data analysis.

Data collection was carried out using the GaBi Web Questionnaires, which contained all necessary inputs and outputs per process, including materials, energy carriers, emissions, wastes and co-products. An overview of all relevant questionnaires is provided in Appendix 12. Once data collection was completed, all checks were carried out as described in section 5.1 prior to importing into the worldsteel GaBi LCA model for calculation of steel product LCIs. Each company had access to their password-protected questionnaires to ensure confidentiality of company data.

The worldsteel LCA model in GaBi is 'parameterised'. This means that, by using the global parameter function (meaning global to the model) in GaBi 4:

- the specific product being calculated can be chosen – the model is tailored so that only one product can be produced/modelled at a time
- results can be calculated including/excluding system expansion
- results can be calculated with or without upstream data
- data can be calculated using a vertical or horizontal approach (see Figure 3)
- the end-of-life recycling rate can be modified to reflect any end-of-life recycling rate.

Also, considerations such as region/country specific upstream data are handled via parameters.

The route, or cradle-to-gate, level plan for each site creating a specific product was used to create a vertically aggregated, weighted average (product average calculated based on site production volume) of each product, where a minimum of three sites contributed data. This respects the confidentiality agreement with the data providers and increases representiveness of the product LCI.

7 LCA results and analysis

This chapter does not provide an impact assessment of the steel products considered in this study. They are considered here as plausibility checks and for illustrative purposes only.

LCI data for 15 steel products are available for free from worldsteel, upon request via worldsteel.org. The data are provided using the GaBi i-report function, by which the data is easily generated directly from the GaBi 4 software. This reduces the likelihood of errors in generating datasets. The data provided are LCI data and are typically cradle-to-gate including end-of-life recycling. A description of the data provided can be found in Appendix 8.

Table 6 shows typical impacts for three steel industry products: steel sections, hot-rolled coil and hot-dip galvanized steel. For this analysis, three products have been selected to cover a wide range of steel products. Steel sections are produced both in the EAF and in the BOF route. Hot-rolled coil is one of the first products from the BOF route. The third product, hot-dip galvanized steel, is a product that has undergone many additional processes such as cold rolling, pickling, annealing, tempering and galvanizing.

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. Typical rates for the automotive sector are above 95%, for construction around 85% and for packaging around 70%[15]. These values are based on the judgement of the worldsteel LCA experts. There are no public sources available for these references, they are intended as guidance only. Work is ongoing to gather more robust data for the end-of-life recycling rates of steel products.

In addition, the values mentioned above are used as guidance only for those requesting data and are believed to be conservative values as recycling of products will improve in the future. When a request for data is received and a different end-of-life recycling rate is specified, this specified value can be used.

7.1 Energy demand and environmental impact categories

The impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University[9] and include the following LCIA categories:

- GWP 100 years: an impact assessment level with global effect; GWP is mainly caused from CO_2 and CH_4 emissions which account for around 98% of GHG emissions from the steel industry. In exploratory impact assessments, other GHGs account for less than 2% of the steel industry GHG emissions, on a CO_2 equivalent basis.

- AP: an impact assessment level with local effect; AP is mainly caused by SO_2 and NO_x.
- EP: an impact assessment level with local effect; within the steel industry, EP is mainly caused from NO_x emissions.
- POCP: an impact assessment level with local effect; within the steel industry, POCP, also known as summer smog, is mainly caused from carbon monoxide emissions.

Primary energy demand (PED) 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. For the most up-to-date LCI data for all steel products on a regional or global level, visit worldsteel.org.

		PED MJ	GWP kg CO_2e	AP kg SO_2e	EP kg phosphate e	POCP kg ethene e
Sections, 1 kg	Cradle-to-gate	19.6	1.6	0.0045	0.00036	0.0008
	Including recycling	16.4	1.2	0.0037	0.00034	0.0006
	Recycling benefit	-3.2	-0.4	-0.0008	-0.00002	-0.0002
Hot-rolled coil, 1 kg	Cradle-to-gate	21.6	2.0	0.0052	0.00035	0.00094
	Including recycling	11.9	0.9	0.0025	0.000282	0.00035
	Recycling benefit	-9.7	-1.1	-0.0027	-6.8E-05	-0.00059
Hot-dip galvanized steel, 1 kg	Cradle-to-gate	27.5	2.5	0.0074	0.00048	0.0012
	Including recycling	17.5	1.3	0.0047	0.00041	0.00061
	Recycling benefit	-10.0	-1.2	-0.0027	-0.00007	-0.00059

Table 6: Life cycle impact assessment results of steel products

The three products selected in Table 6 above are typical steel products, but have different production requirements and uses. 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. Steel sections are rolled on a hot-rolling mill and include I-beams, H-beams, wide flange beams and sheet piling. They are are often found on the market for direct use.

The data for the steel sections comes from both the EAF and the BOF route. Based on the latest worldsteel LCI data, the scrap content is typically around 0.6 tonnes per tonne steel section. Hot-rolled coil and hot-dip galvanized steel are generally produced in the BOF route so the amount of scrap consumption is generally a lot lower, around 0.1 to 0.15 tonnes per tonne steel product.

7.1.1 Primary energy demand

PED for the three products described above is shown in Figure 5.

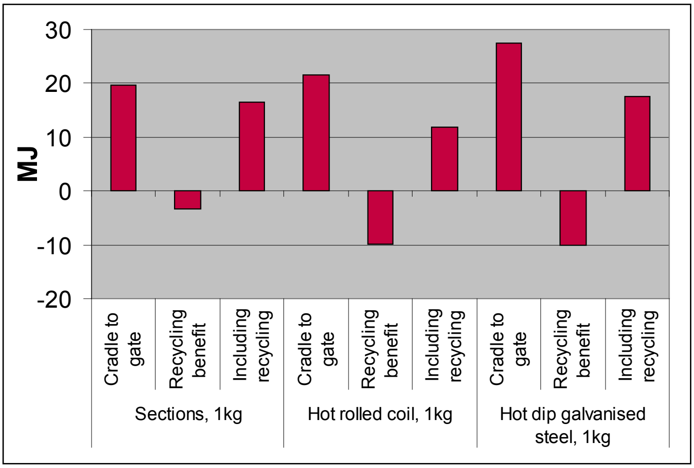


Figure 5: Primary energy demand (MJ) of steel products

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, more than 97% of the demand is from non-renewable resources, with the majority being attributable to hard coal consumption, see Figure 6 below. The consumption of uranium is only associated with the upstream profiles of electricity consumption.

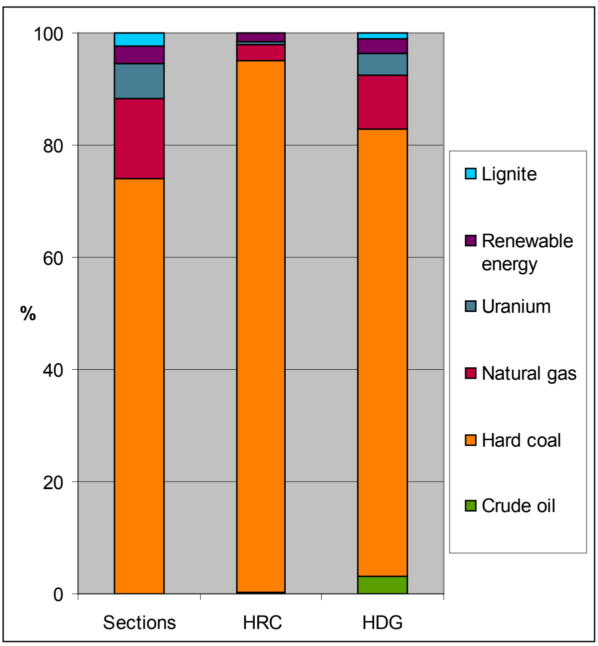


Figure 6: Contributions to primary energy demand of steel products

7.1.2 Global warming potential

The GWP for the three products described above is shown in Figure 7.

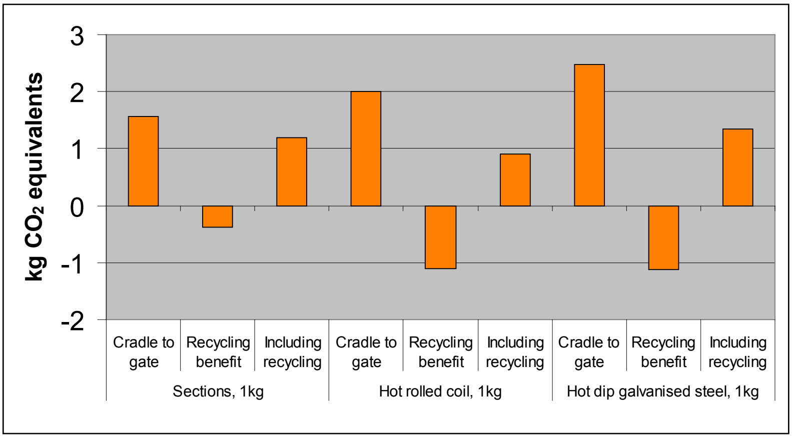


Figure 7: Global warming potential (CO_2e) of steel products

The GWP for steel products is dominated by CO_2 and methane emissions, which account for over 98% of all GHG emissions for the steel industry. Methane emissions come predominantly from the coal that is used within the process and for cokemaking. Figure 8 shows the contributions to the GWP, with the category 'others' including nitrous oxide, sulphur hexafluoride, NMVOCs and hydrocarbons.

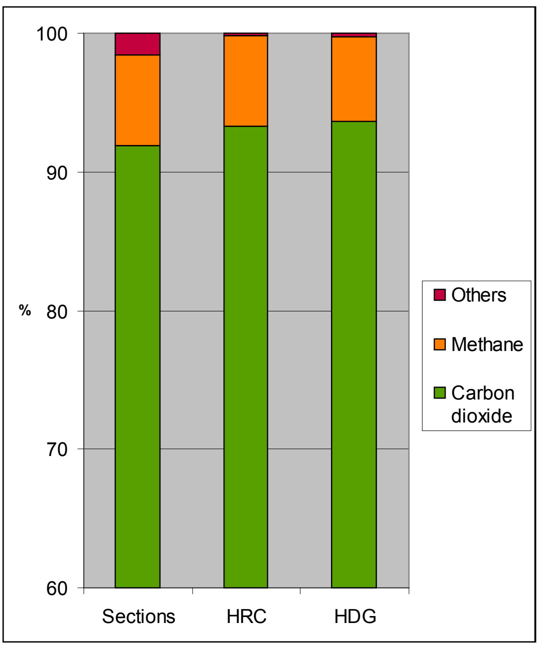


Figure 8: Contributions to global warming potential of steel products

7.1.3 Acidification potential

The AP for the three products described above is shown in Figure 9.

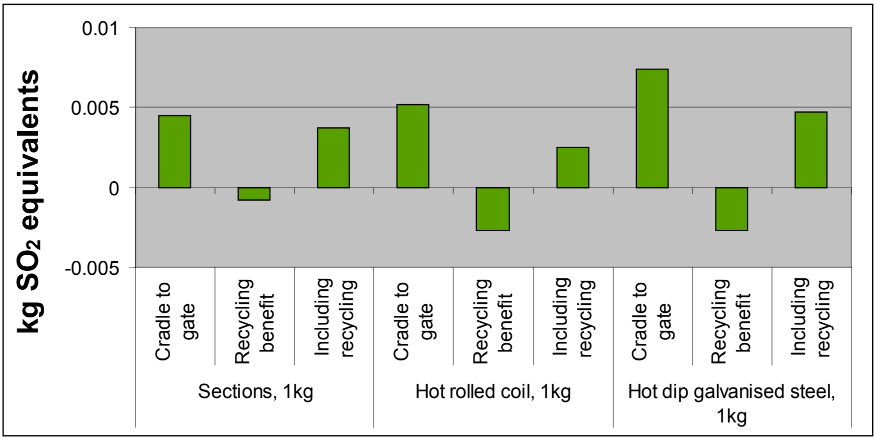


Figure 9: Acidification potential (SO_2e) of steel products

The AP for steel products is dominated by emissions to air, which contribute over 97% to this impact. The main contributors are sulphur dioxide and nitrogen oxides, as shown in Figure 10.

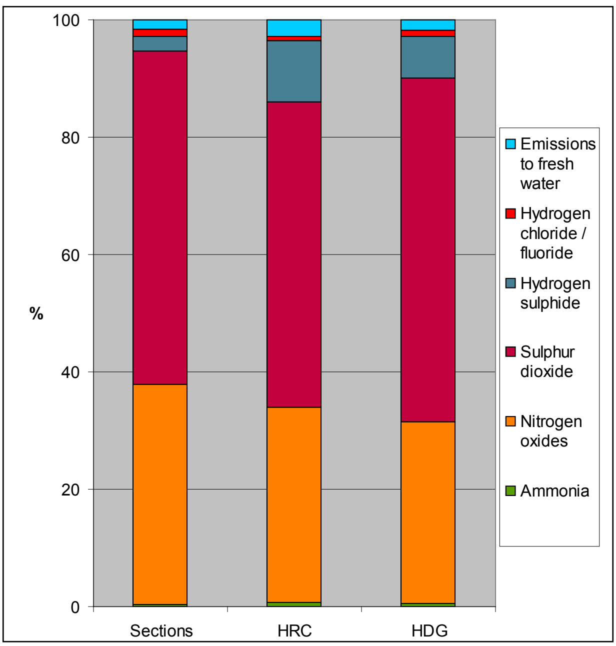


Figure 10: Contributions to acidification potential of steel products

7.1.4 Eutrophication potential

The EP for the three products described above is shown in Figure 11.

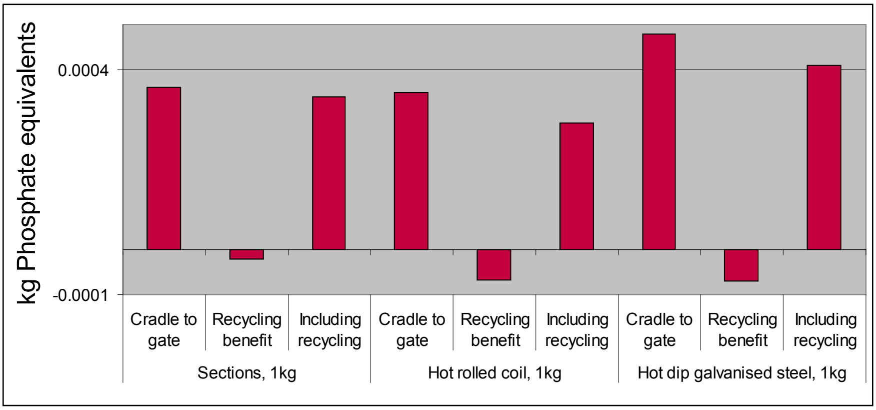


Figure 11: Eutrophication potential (PO_4^{3-} e) of steel products

The EP for steel products is dominated by emissions to air, which contribute over 94% 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 12.

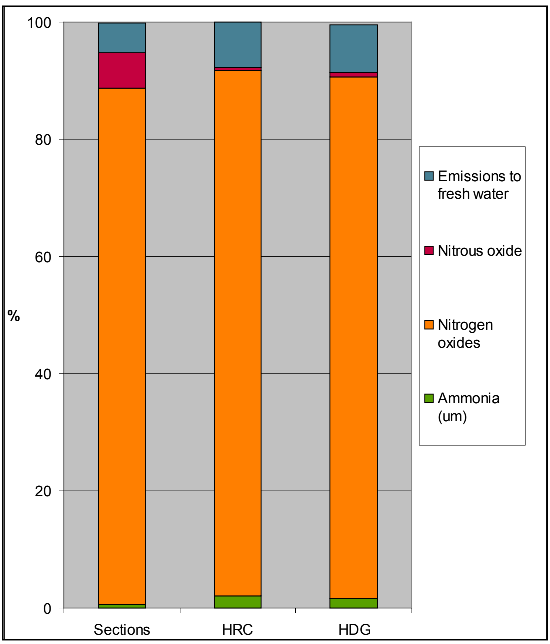


Figure 12: Contributions to eutrophication potential of steel products

7.1.5 Photochemical ozone creation potential

The POCP for the three products described above is shown in Figure 13.

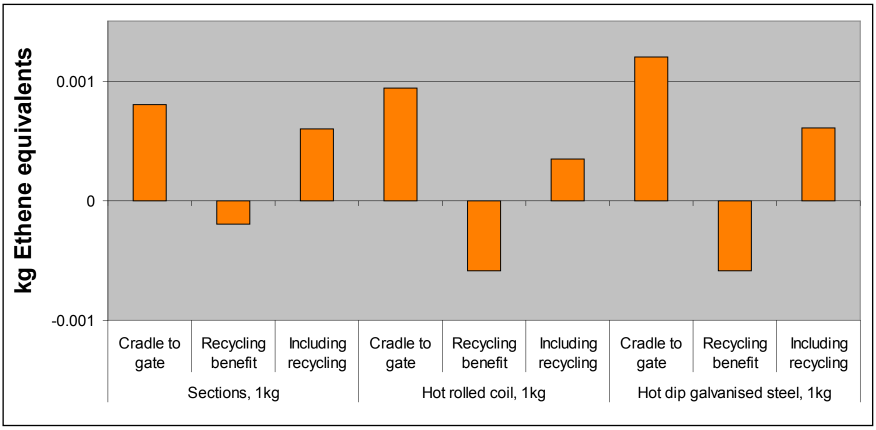


Figure 13: Photochemical ozone creation potential ($C_2H_{4-}e$) of steel products

The photochemical ozone creation potential for steel products is dominated by carbon monoxide, which accounts for over 60% of the contribution to this impact. All other major substances contributing to the POCP are shown in Figure 14.

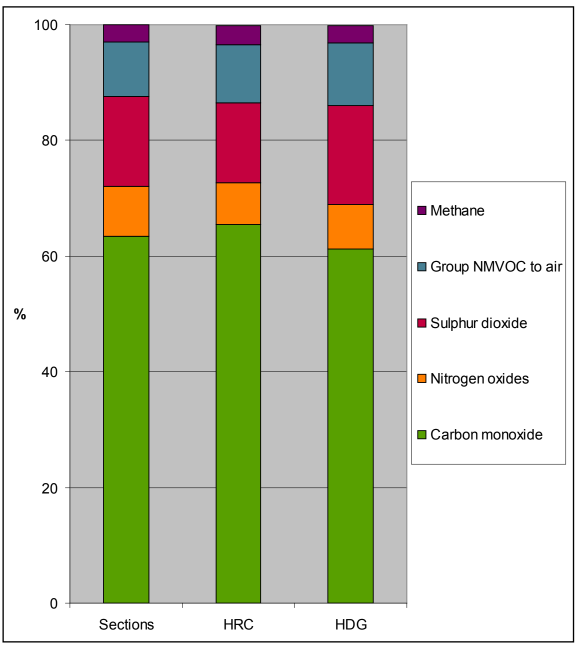


Figure 14: Contributions to photochemical ozone creation potential of steel products

7.2 LCI value of steel scrap

The methodology for determining the LCI for steel scrap has been described in section 4.6.3 and further discussed in Appendix 10. A credit is given for the net scrap that is produced at the end of a final products life. This net scrap is determined as follows:

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

where the end-of-life recycling rate should be expressed as x tonnes of steel recycled per tonne of steel in the final product.

This is commonly also expressed as a percentage. Scrap input should also be expressed as x tonnes of steel scrap input per tonne of steel produced. Using this equation, the LCI for future steel scrap being made available for recycling is considered to be the same as the scrap consumed today.

In this case the scrap input generally refers to the net scrap input, i.e. it does not consider the recirculating, internal or home scrap that is generated in the processes that are being studied, i.e. scrap from the hot rolling process that goes back into the BOF is not included as an external scrap input for hot-rolled coil. Thus, the scrap input is often considered to be post-consumer scrap, or scrap produced in processes downstream of the product in question.

The results provided in section 7.1 include this net credit for scrap recycling. The impact of recycling 1 kg steel scrap is shown in Table 7; this has been calculated using the equation and method in section 4.6.3. The results are illustrative only.

Impact category	LCI for 1 kg steel scrap
PED, MJ	13.4
GWP (100 years) kg CO_2-e	1.51
AP, kg SO_2-e	0.0037
EP, kg Phosphate-e	9.97E-5
POCP, kg Ethene-e	0.00081

Table 7: Example impact categories and PED for 1 kg of steel scrap

Thus, for every 1 kg scrap consumed in the steelmaking process, and every 1 kg of steel recycled from a final product at the end of its life, the data displayed in Table 7 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.

8 Life cycle interpretation

The primary goals of the study were to update the steel industry's worldwide LCI database and improve the already rigorous LCI methodology for steel products in accordance with ISO 14040:2006 and 14044:2006 standards, to provide reliable and up-to-date data to meet requests from customers and external studies.

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

8.1 Identification of significant issues

Chapter 7 indicates 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, AP, EP, and POCP.

Figures 15 to 17 below show contributions to PED and the four impact categories mentioned above, for the different life cycle stages and using the cradle-to-gate LCI values as the (100%) reference values. The PED is dominated by the upstream contribution, whereas the other four impact categories have a greater influence from the on-site, gate-to-gate activities. The exception is AP for sections and hot-dip galvanized steel where the upstream contribution is the main contributor.

Credits for co-product allocation (system expansion) and end-of-life recycling modify the overall impact of the products as shown.

Figure 15 shows the life cycle contributions to the PED and the four impact categories discussed above, for global steel sections. 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 for the inputs to the steelmaking process, and the contribution from the co-product allocation. Following this, the net end-of-life recycling credits are shown (negative value), followed by the overall value which is the cradle-to-gate including end-of-life recycling.

For the sake of 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, RR.

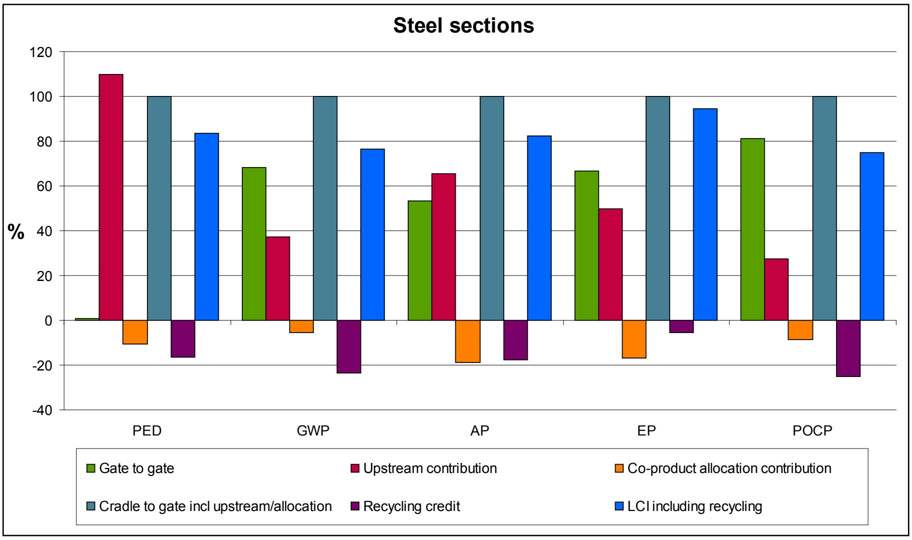


Figure 15: Life cycle contributions to PED and impact categories for steel sections

Following the same description for steel sections above, Figure 16 shows the life cycle contributions to the PED and the four impact categories for global hot-rolled coil.

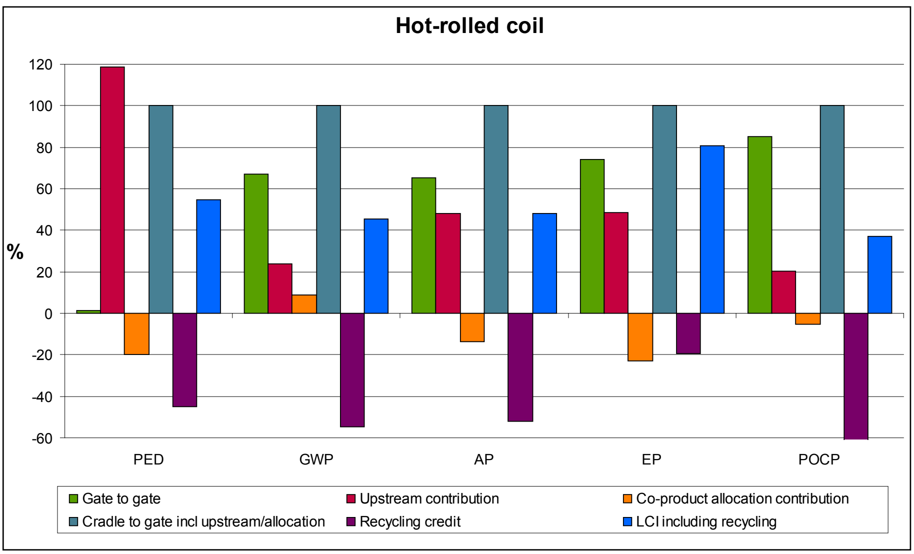


Figure 16: Life cycle contributions to PED and impact categories for HRC

And finally, Figure 17 shows the life cycle contributions to the PED and the four impact categories for global hot-dip galvanized steel.

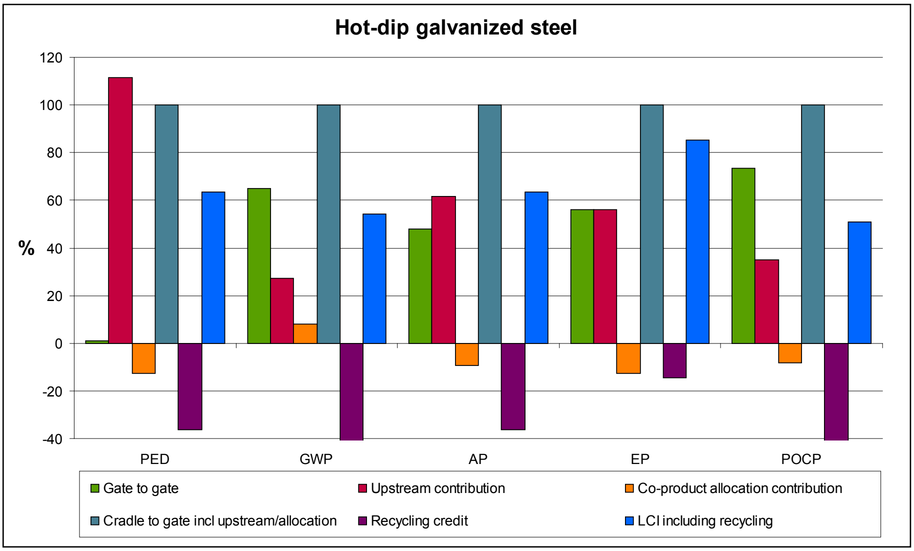


Figure 17: Life cycle contributions to PED and impact categories for HDG steel

Table 8 summarises the main contributors to each of the impact categories and PED. Steel production is an energy-intensive industry. The consumption of energy and electricity are one of the main contributors to the environmental impact of the steelmaking process. Therefore, its influence on the LCIA of the product is obviously very much dependent on the location of the steel works, which will often determine the source of electricity and energy consumption.

Impact category	Main input/output	Main phase	Main processes
PED	Hard coal (75 – 95%) Natural gas (0 – 15%)	Upstream (~ 100%)	Upstream energy: electricity and fuels
GWP (100 years)	Carbon dioxide (90 – 95%) Methane (~ 6%)	Gate-to-gate (> 60%) Upstream (20 – 30%)	
AP	Sulphur dioxide (50 – 60%) Nitrogen oxides (30 – 40%) Hydrogen sulphide (< 10%)	Gate-to-gate (40 – 60%) Upstream (40 – 60%)	
EP	Nitrogen oxides (>90%) Nitrous oxide (~ 2%) Ammonia (~ 2%) Chemical Oxygen Demand (~ 2%)	Gate-to-gate (55 - 75%) Upstream (~ 50%)	Gate-to-gate: steel production processes up to slab production
POCP	Carbon monoxide (60 – 70%) Sulphur dioxide (10 – 20 %) NMVOCs (<10%) Nitrogen oxides (<10%)	Gate-to-gate (> 80%) Upstream (~ 20%)	

Table 8: Life cycle significant flows, phases and processes (excluding the end-of-life phase)

Including the-end-of-life recyclability of the steel products within the LCI gives the overall impact of a steel-containing product or service. The values shown in Figures 15 to 17 above are for the net scrap arising, i.e. amount of steel recycled at the end of the product's life (end-of-life recycling rate) – scrap input to the steelmaking process.

Thus, for products with a higher scrap input, for example steel sections, the overall net credit for end-of-life recycling is lower than for a product with a lower scrap consumption, based on the same end-of-life recycling rate.

8.2 Completeness, sensitivity and consistency checks

8.2.1 Completeness

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

- the completeness of 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.

8.2.2 Sensitivity

In any LCA 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 and is described below. These three aspects have been chosen:

- 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 diesel consumption is included for the sensitivity analysis
- packaging: packaging materials are excluded from the study.

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 Chapters 7 and 8. The recycling methodology is discussed in more detail in Appendix 10.

For this analysis, three representative products have been selected. Steel sections are produced both in the EAF and in the BOF route. Hot-rolled coil is one of the first products from the BOF route. The third product, hot-dip galvanized steel, is a product that has undergone many additional processes such as cold rolling, pickling, annealing, tempering and galvanizing.

8.2.2.1 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 4.6.1 and the impact on the PED and GWP of choosing this methodology is shown in section 7.1, using global average data.

		PED MJ	GWP kg CO_2e
Sections, 1 kg	Excluding system expansion	21.75	1.65
	Including system expansion	19.64	1.56
	% Difference	-9.7%	-5.7%
Hot-rolled coil, 1 kg	Excluding system expansion	25.96	1.83
	Including system expansion	21.64	2.01
	% Difference	-16.6%	9.8%
Hot-dip galvanized steel, 1 kg	Excluding system expansion	31.61	2.35
	Including system expansion	27.59	2.47
	% Difference	-12.7%	5.1%

Table 9: Sensitivity analysis of system expansion

Table 9 shows the influence that system expansion has on the worldsteel LCI data. It demonstrates that the steel industry co-products are valuable, whether in the form of replacing raw materials for cement, road-stone, fertiliser etc., or as a replacement for energy sources both within or external to the steelmaking site, or for electricity.

The contribution of the system expansion to the GWP is +/- 5% to 10%. Steel sections are made from both the EAF and BOF route; the EAF route does not produce (but might use) process gases which are used to replace other forms of energy supply, either on site or replacing energy and electricity off-site.

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 contribution of the system expansion to the PED ranges between 10% and 17%. 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. Steel sections see a lower benefit to PED as the product is made in both the BOF and the EAF, where there are no process gases being generated and thus recovered.

PED and GWP are both important aspects for steelmaking. Other impact categories that are often considered in LCA studies include AP, POCP and EP, but these are not as relevant for the steel industry. These impact categories have been considered further in Chapter 7.

8.2.2.2 Sensitivity Analysis on Internal Transport

The environmental burden of internal transportation is very small. A study on a sample of sites in the original study showed an average of 0.001litres of diesel per kg crude steel was used, corresponding to about 0.03MJ fuel energy/kg of steel product. However, the combustion of diesel consumption for on-site vehicles has been included.

8.2.2.3 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 steel works 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.

8.2.3 Consistency checks

To check the consistency of the data provided by each of the member companies, iron, carbon and energy balances were carried out on a process level, for each site. In addition, benchmarking checks were made of the data, on a horizontal level, for example by comparing all coke ovens or all blast furnaces (see Figure 3). This was also carried out at a gate-to-gate and cradle-to-gate level.

8.3 Conclusions, limiations and recommendations

A critical review has been carried out to ensure that the changes made to the methodology are compliant with ISO 14040:2006 and ISO 14044:2006.

This study is representative of over 98% of steel technologies worldwide and covers over 25% of the steel production by company on a global basis.

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

8.3.1 Conclusions

This study provides LCI data for 15 steel industry products on a global level, of which 12 products are represented on an EU level (see Table 1). The addition of new sites is an ongoing process, to increase the geographical spread and representativeness of the data.

In an LCA study, end-of-life scenarios should always be considered. The worldsteel methodology includes the end-of-life recycling of steel products and this approach is recommended.

8.3.2 Limitations

The data provided by the steel producers ranges from 2005 to 2008. With continuing measures to improve the environmental performance of these companies, it should be noted that improvements will occur over the coming years and these will need to be incorporated into the steel product LCI data.

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

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

The data should not be used for stainless steel products.

8.3.3 Recommendations for use of data

When an LCA study is to be conducted using steel LCI data, it is preferable that the practitioner contact 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. A matrix of possible uses for each product is provided in Appendix 13. 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 specified.

The results from the study reflect global steel production from 2005 to 2008 and new sites continue to join the worldsteel data collection project. It will therefore be necessary to update the worldsteel steel LCI datasets on a timely basis, which may contribute changes to the data. It may be appropriate, therefore, to contact the worldsteel LCA Manager if it is felt that such changes may have occurred.

worldsteel endeavours to provide the datasets to LCA software tools and databases so that they can be used as easily as possible. Care should be taken to ensure that the correct steel product is selected and the methodology is fully understood.

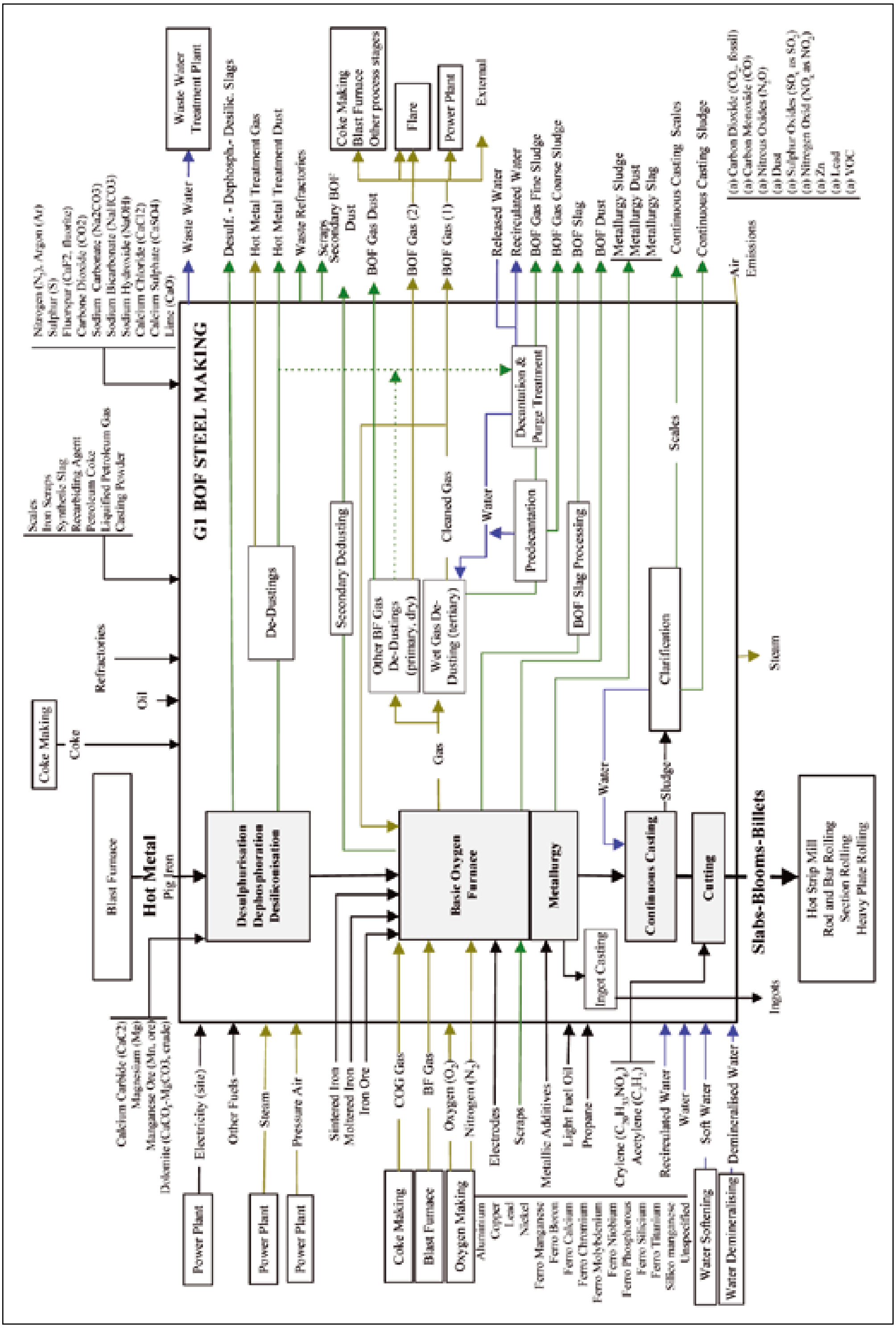
Appendices

Appendix 1: Description of steel products

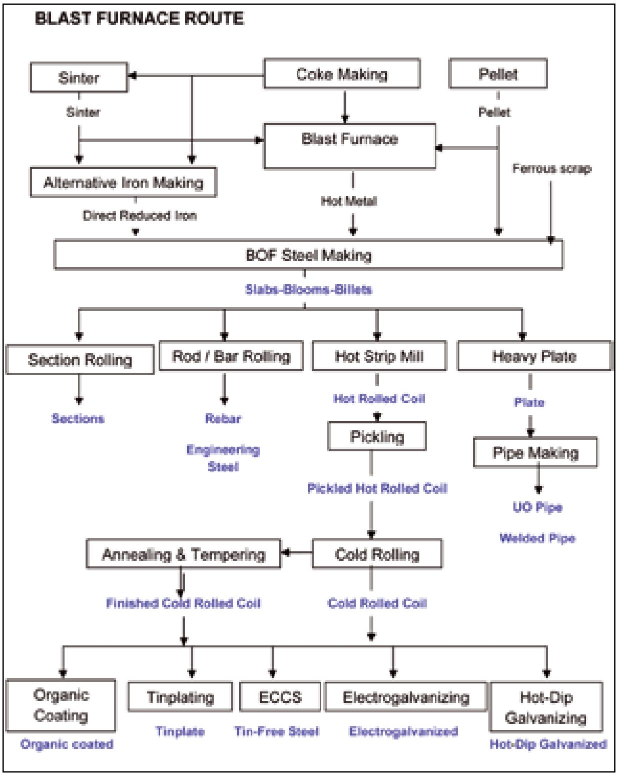
Product	Product description
Plate	A flat steel sheet rolled on a hot-rolling mill; can be further processed. Includes use in the following sectors: structural steels, shipbuilding, pipes, pressure vessels, boilers, heavy metal structures, offshore structures, etc. Typical thickness between 2 and 20 mm. Maximum width is 1,860 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 and 7 mm. Typical width between 600 and 2,100 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 and 7 mm. Typical width between 600 and 2,100 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 and 3 mm. Typical width between 600 and 2,100 mm.
Finished cold-rolled coil	Obtained by heat treatment (annealing) and strain-hardening of cold-rolled steel 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 roofing applications, profiled sheets, wall elements, etc. Typical thickness between 0.3 and 3 mm. Typical width between 600 and 2,100 mm.
Hot-dip galvanized steel	Obtained by passing cold-rolled coil through a molten zinc bath, to coat the steel with a thin layer of zinc to provide corrosion resistance; can be further processed. Has excellent forming properties, paintability, weldability, and is 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 and 3 mm. Typical width between 600 and 2,100 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. Has 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 and 3 mm. Typical width between 600 and 2,100 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.

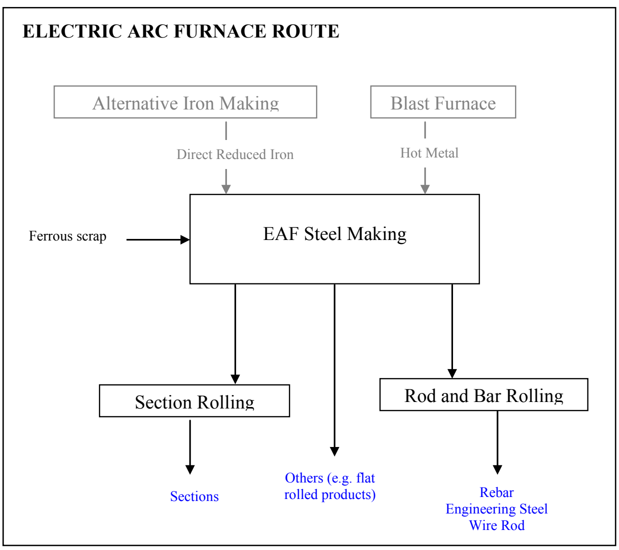
Sections	A steel section rolled on a hot-rolling mill. Steel sections include I-beams, H-beams, wide-flange beams, and sheet piling. This product is used in construction, multi-story buildings, industrial buildings, bridge trusses, vertical highway supports, and riverbank reinforcement.
UO pipe	UO pipe is usually large in diameter and produced one piece at a time by forming plates. The plate is first pressed into a U shape by the U-press, and then into an O shape by the O-press. Relatively thick material is used for making UO pipes, so submerged arc welding is used for joining. UO pipe is mainly used as line pipe for transporting petroleum and natural gas in large quantities and over long distances.
Welded pipe	A flat plate steel coil that is bent 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).
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 and 0.49 mm. Typical width between 600 and 1,100 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 and 0.49 mm. Typical width between 600 and 1,100 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, VCR & DVD casings, etc.) and packaging. Typical thickness between 0.15 and 1.5 mm. Typical width between 600 and 1,300 mm.

Appendix 2: Representation of the BOF module



Appendix 3: Steel product manufacturing flow diagrams via the BOF and EAF routes





Typical representation of steelmaking processes. Process routes can vary; not all routes are included. Steel products highlighted in blue.

Appendix 4: Example data collection questionnaire

Fiscal period: 2008

Site: Steel Site 1, Steel Company

Questionnaire: Hot strip mill

Tab: Inputs

Name	Unit	Value	Quality of data	Source	Year
Flows	-	-	-	-	-
Production residues in life cycle	-	-	-	-	-
Waste for recovery	-	-	-	-	-
Hot rolling sludge	kg	150	Measured	Factory	2008
Oxycutting slag	kg		Calculated	Literature	
Scales internal	kg		Estimated	Other	
Scarfing dust	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	-	-	-	-	-
Water (fresh water)	kg		n.a.	Factory	
Water (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	-	-	-	-	-
Power	MJ		n.a.	Factory	
Fuels	-	-	-	-	-
Crude oil products	-	-	-	-	-
Heavy fuel oil	kg		n.a.	Factory	
Light fuel oil	kg		n.a.	Factory	
Liquefied petroleum gas	kg		n.a.	Factory	
Natural gas products	-	-	-	-	-
Natural gas	kg		n.a.	Factory	

Name	Unit	Value	Quality of data	Source	Year
Other fuels	-	-	-	-	-
Basic Oxygen Furnace Gas (MJ)	MJ		n.a.	Factory	
Blast furnace gas (MJ)	MJ		n.a.	Factory	
Coke oven gas (external supply, in MJ)	MJ		n.a.	Factory	
Coke oven gas (MJ)	MJ		n.a.	Factory	
Smelting furnace gas (MJ)	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 (MJ)	MJ		n.a.	Factory	
Materials	-	-	-	-	-
Intermediate products	-	-	-	-	-
Inorganic intermediate products	-	-	-	-	-
Ferric chloride	kg		n.a.	Factory	
Ferrous sulphate (FeSO4)	kg		n.a.	Factory	
Hydrochloric acid (100%)	kg		n.a.	Factory	
Nitrogen gaseous	kg		n.a.	Factory	
Oxygen gaseous	kg		n.a.	Factory	
Sodium hydroxide (100%; caustic soda)	kg		n.a.	Factory	
Sodium hypochlorite	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, chromic oxide)	kg		n.a.	Factory	
Refractories (silica, alumina)	kg		n.a.	Factory	

Name	Unit	Value	Quality of data	Source	Year
Operating materials	-	-	-	-	-
Anticorroding Agent (unspecified)	kg		n.a.	Factory	
Antifur Agent (unspecified)	kg		n.a.	Factory	
Detergent	kg		n.a.	Factory	
Grease	kg		n.a.	Factory	
Water for industrial use	kg		n.a.	Factory	
Waste water treatment	-	-	-	-	-
Aluminum sulfate	kg		n.a.	Factory	
anticorroding agent	kg		n.a.	Factory	
Antifoaming Agent (unspecified)	kg		n.a.	Factory	
Antifur Agent (unspecified)	kg		n.a.	Factory	
Carbon dioxide	kg		n.a.	Factory	
Citric acid ($C_6H_8O_7$)	kg		n.a.	Factory	
Coagulation agent	kg		n.a.	Factory	
Compressed air	m^3		n.a.	Factory	
Ferric chloride	kg		n.a.	Factory	
Flocculating agent	kg		n.a.	Factory	
Hydrochloric acid (100%)	kg		n.a.	Factory	
Hydrogen peroxide (H_2O_2)	kg		n.a.	Factory	
Lime quicklime (lumpy)	kg		n.a.	Factory	
Natural gas	kg		n.a.	Factory	
Nitric acid	kg		n.a.	Factory	
Oxygen gaseous	kg		n.a.	Factory	
Phosphoric acid	kg		n.a.	Factory	
Polyelectrolyte	kg		n.a.	Factory	
Power	MJ		n.a.	Factory	
Soda (sodium carbonate)	kg		n.a.	Factory	
Sodium bisulphite	kg		n.a.	Factory	
Sodium chloride (rock salt)	kg		n.a.	Factory	
Sodium hydrosulfite ($Na_2O_4S_2$)	kg		n.a.	Factory	
Sodium hydroxide (100%; caustic soda)	kg		n.a.	Factory	
Sodium hypochlorite	kg		n.a.	Factory	
Sodium nitrite	kg		n.a.	Factory	
Steam	MJ		n.a.	Factory	
Sulphuric acid (100%)	kg		n.a.	Factory	
Water (fresh water)	kg		n.a.	Factory	
Water (sea water)	kg		n.a.	Factory	
Water for industrial use	kg		n.a.	Factory	

Appendix 5: List of participating companies

The following companies contributed to the LCI released in February 2010.

ArcelorMittal

Baosteel

CELSA

Gerdau

JFE

JSW

Kobe Steel

Nippon Steel

Nisshin

Ruukki

SAIL

SSAB

Sumitomometal

Tata Steel Europe

ThyssenKrupp Steel

voestalpine

Appendix 6: List of upstream inputs and their sources

Item	Process Information	Country	Year	Source
Acetylene	Ethine (acetylene), SACHSSE-BARTHOLOME process	DE (Germany)	2005	PE
Activated carbon	–	DE	2005	PE
Aluminium	The common raw material for aluminium production, bauxite is composed primarily of one or more aluminium hydroxide compounds, plus silica, iron and titanium oxides as the main impurities. It is used to produce aluminium oxide through the Bayer chemical process and subsequently aluminium through the Hall-Heroult electrolytic process.	RER (Europe)	2002	PE
Aluminium chloride	Aluminium chloride hexahydrate	DE	2005	PE
Aluminium sulphate	Aluminium sulphate	DE	2005	PE
Ammonia	Ammonia is produced almost exclusively by the HABER-BOSCH process. First, synthesis gas has to be produced. It is a mixture of nitrogen and hydrogen (not to be mistaken for the more common CO/H_2 synthesis gas). Nitrogen is gained from air by fractionation, hydrogen from natural gas by steam reforming. The latter process produces CO and CO_2, which can either be converted to methane or oxidised entirely to CO_2 for sale. The final conversion of synthesis gas to ammonia is a carefully trimmed equilibrium reaction which runs at high temperature and pressure. The product then undergoes multiple stages of purification.	RER	2002	PE
Ammonium sulphate	Ammonium sulphate mix (by-product)	DE	2005	PE
Anthracite	Country specific data, based on hard coal mix for each country	Country specific	2002	PE
Argon	Gaseous, LINDE process	DE	2005	PE
Bauxite	Opencase and underground mining	RER	2004	PE
Benzene	Benzene produced from reformate gasoline, pyrolysis gasoline or from toluene dealkylation, consisting of the distribution of technologies used for the production of benzene, representing the respective country / region. The technology shares were taken from national statistics.	RER	2005	PE
BOF slab	1kg global slab, weighted average	GLO (Global)	2010	worldsteel
Calcium chloride	(from epichlorohydrine synthesis)	DE	2005	PE
Carbon dioxide	From HABER-BOSCH process (ammonia synthesis, NH_3/CO_2)	DE	2005	PE

Item	Process Information	Country	Year	Source
Cement	CEM I 32.5 (39.6%) CEM I 42.5 (36.5%) CEM I 52.5 (7.6%) CEM III 32.5 (16.3%) The main processes in cement production consist of raw material extraction, production of clinker, and cement grinding. The extraction of the main raw material from the quarry normally takes place in the immediate area of the cement works. Portland cement (CEM I) is primarily made up of finely ground clinker cement and a smaller amount of ground materials. Other cements may also include constituents such as slag sand (CEM III), natural puzzolan such as trass (CEM IV), fly ash, oil shale burn-out or limestone. The most important agent is the blast furnace cement (CEM III).	DE	2001	PE
Coal	Country specific data, based on hard coal mix for each country	Country specific	2002	PE
Coal for coke making	Coking coal production mix - see section 4.5.2.2	GLO	2006	PE
Coal for injection	Country specific data, based on hard coal mix for each country	Country specific	2002	PE
Coke	1 kg global coke, weighted average	GLO	2010	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	2002	PE
Diesel	Three regional LCIs for diesel, based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER, Japan, USA	2003	EU: ELCD[20] and PE USA and Japan: PE
Direct reduced iron	1kg global DRI, weighted average	GLO	2010	worldsteel
Dolomite	Burned dolomite	DE	2005	PE
Dolomite (crude)	Dolomite extraction	DE	2005	PE
Electricity	See Appendix 7	Country specific	2002	PE
Electrode	Electrode mix	GLO	2005	PE
Ferric chloride	Ferric (III) chloride (hexahydrate)	DE	2005	PE
Ferro chrome	Ferro Chromium (high carbon)	GLO	2005	ICDA

Appendix 6: continued

Item	Process Information	Country	Year	Source
Ferro manganese	Production of ferro-manganese (77% Mn) with high carbon content. The direct process chain includes the mining and the beneficiation of the ore (South African specific and mining and beneficiation are at the same operation site), a sinter and melting process (electric furnace), the transport to the port of transhipment (Rotterdam) and the subsequent 300 km transport to the German trade market.	ZA (South Africa)	2000	PE
Ferro molybdenum	Ferro molybdenum (67% Mo)	NA	2008	Molybdenum Association
Ferro nickel	Ferro Nickel (32% Ni)	NA	2008	PE
Ferro silicum	Ferro silicon mix (90%)	DE	2000	PE
Ferro vanadium	Ferro Vanadium (FeV 80%)	ZA	2005	PE
Ferrous sulphate	Ferrous (II) sulphate	DE	2005	PE
Gasoline	Three regional LCIs for gasoline, based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER	2003	PE
Heavy fuel oil	Three regional LCIs for heavy fuel oil, based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER, Japan, USA	2003	EU: ELCD and PE USA and Japan: PE
Hot metal	1 kg global hot metal, weighted average	GLO	2010	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	2005	PE
Hydrogen	Electrolysis of water and hydrocracking of hydrocarbons, steam reforming of natural gas or heavy fuel oil for the industrial scale production of hydrogen.	RER	2005	PE
Hydrogen peroxide	50%; H_2O_2. Anthraquinone process	DE	2005	PE
Iron ore	See section 4.5.3.1	GLO	2008	worldsteel
Kerosene	Three regional LCIs for kerosene, based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER	2003	PE

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	2000	PE
Light fuel oil	Three regional LCIs for light fuel oil, based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes.	RER, Japan, USA	2003	EU: ELCD and PE USA and Japan: PE
Lime	CaO; quicklime lumpy, manufactured technically by deacidifying limestone (CaCO3) at temperatures over 900°C. This leads on average to the production of 7.58 kg CO2/t quick lime. These emissions are physically determined and they dominate the CO2 balance of the lime burning process.	DE	2000	PE
Limestone	$CaCO_3$; washed	DE	2005	PE
Liquefied petroleum	Liquefied gas (LPG; 70% Propane; 30% Butane), refining process	GLO	2003	PE
Lubricants	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes.	RER	2003	PE
Magnesium	Magnesium Pidgeon process	CN	2004	PE
Manganese	South Africa and Australia cover 90% of world manganese production (International Manganese Institute). 80% of the mining takes place underground and 20% in open cast operations. The beneficiation is done at the mining site. The manganese ore is crushed and processed. The concentrate is then reduced by intense heating in a calcination process. Manganese metal is produced during electrolysis by addition of ammonia and sulphuric acid. The end product is manganese 99%.	ZA	2002	PE
Natural gas	Country specific data, based on natural gas mix for each country	Country specific	2002	PE and IEA
Nickel	Global Nickel mix. The nickel ore is mined, milled and in-situ concentrated by flotation. Then, the heading is transported to a nickel works where it is roasted and smelted. The nickel matte remains after separation of the cinder. From this product, the high-purity nickel is extracted in a refinery.	GLO	2002	PE
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	2005	PE
Nitrogen	Air and power to produce gaseous nitrogen	NA	2007	PE
Olivine	Silica sand (excavation and extracting)	RER	2005	PE

Appendix 6: continued

Item	Process Information	Country	Year	Source
Oxygen	Air, cooling water and power to produce gaseous oxygen	NA	2007	PE
Pellet	1 kg global pellet, weighted average	GLO	2010	worldsteel
Petroleum coke	Three regional LCIs for petrol coke at refinery	RER, Japan, USA	2003	PE
Phosphoric acid	100%, wet process	DE	2005	PE
Polyethylene	Polyethylene low density granulate (PE-LD)	RER	2005	PlasticsEurope
Polyvinyl chloride	Polyvinyl Chloride granulate (bulk, B-PVC)	RER	2005	PlasticsEurope
Propane	Three regional LCIs for propane free refinery	RER, Japan, USA	2003	PE
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	2005	PE
Refractories (all)	Insulation brick (high in alumina)	DE	2005	PE
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	2005	PE
Scrap	See section 7.2			worldsteel
Serpentine	Kaolin: mined, as kaolin, normally together with silica sand and feldspar using bucket excavators or bucket chain dredgers.	DE	2005	PE
Silicon mix	Usually, silicon metal and ferro-silicon are commonly produced in low-shaft three phase submerged electric arc furnaces (open or semi-closed type). The furnace rotates in intervals which homogenises the molten metal and because of this saves 5-10% electric energy. The silicon metal production under examination is calculated with the import mix from 2003. The following import countries of silicon to the German market are considered: USA 42%, United Kingdom 19%, Japan 17% and Russia 12% (around 90% of the import mix to Germany).	DE	2000	PE
Sinter	1 kg global sinter, weighted average	GLO	2010	worldsteel
Sinter/pellet fines	1 kg global sinter, weighted average	GLO	2010	worldsteel
Sodium carbonate	Soda (Na_2CO_3), produced by the Solvay process	DE	2005	PE

Item	Process Information	Country	Year	Source
Sodium chloride	Rock salt is obtained from salt mines by use of machines or leaching techniques.	RER	2005	PE
Sodium hydroxide	100% caustic soda from brine extraction, electrolysis and purification	RER	2005	PlasticsEurope
Sodium hypochlorite	50% solution	DE	2007	PE
Sodium sulphate	Sodium sulphate production and refining	GLO	2005	PE
Steam	Steam (mp)	RER	2005	PlasticsEurope
Steel strap	Hot-rolled coil	GLO	2010	worldsteel
Sulphur	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER	2003	PE
Sulphur trioxide	SO_3 from evaporation of sulphuric acid	DE	2005	PE
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.	RER	2005	PE
Surface cleaning agent	Non-ionic surfactant (fatty acid derivative)	-	2005	PE
Synthetic gas	Synthesis gas (H_2:CO = 3:1). Produced from water (steam) and methane (natural gas). The latter can be replaced with other hydrocarbons and mixtures thereof, e.g. naphtha or fuel oils.	DE	2005	PE
Tar	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	RER	2003	PE
Tin	Indonesia is one of the biggest tin producers in the world beside Peru. The mining operation of the tin sand considered in this data set is considered with the dredging technology (off shore). The mined tin sand (approx. 25% Sn) is transported to the beneficiation plant by using conveyer belts.	ID	2000	PE
Titanium dioxide	Chloride process	RER	2005	PE
Zinc	Global zinc mix	GLO	2005	PE

Appendix 7: 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 4 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	Original data sources	Grid
Argentina	2002	GaBi 4 based on national statistics, IEA etc.	46% natural gas, 43% hydro, 7% nuclear, 2% heavy fuel oil, 1% solid biomass, 1% blast furnace gas
Australia	2002	GaBi 4 based on national statistics, IEA etc.	52% hard coal, 25% brown coal, 12% natural gas, 7% hydro, 2% heavy fuel oil, 1% blast furnace gas, 1% solid biomass
Austria	2002	GaBi 4 based on European Commission's ELCD	67% hydro, 15% natural gas, 8% hard coal, 3% heavy fuel oil, 2% brown coal, 2% solid biomass, 1% blast furnace gas, 1% waste
Belgium	2002	GaBi 4 based on European Commission's ELCD	58% nuclear, 22% natural gas, 12% hard coal, 3% blast furnace gas
Brazil	2002	GaBi 4 based on national statistics, IEA etc.	83% hydro, 4% nuclear, 4% natural gas, 4% heavy fuel oil, 3% solid biomass, 1% hard coal, 1% blast furnace gas
Canada	2002	GaBi 4 based on national statistics, IEA etc.	58% hydro, 13% nuclear, 11% brown coal, 8% hard coal, 6% natural gas, 2% heavy fuel oil, 1% solid biomass
China	2002	GaBi 4 based on national statistics, IEA etc.	77% hard coal, 18% hydro, 3% heavy fuel oil, 1.5% nuclear
Finland	2002	GaBi 4 based on European Commission's ELCD	30% nuclear, 17% hard coal, 15% natural gas, 14% hydro, 13% solid biomass, 8% peat, 1% blast furnace gas, 1% heavy fuel oil
France	2002	GaBi 4 based on European Commission's ELCD	78% nuclear, 12% hydro, 4% natural gas, 4% hard coal
Germany	2002	GaBi 4 based on European Commission's ELCD	29% nuclear, 26% brown coal,, 23% hard coal, 9% natural gas, 5% hydro, 3% wind, 2% waste, 1% blast furnace gas, 1% heavy fuel oil
India	2002	GaBi 4 based on national statistics, IEA etc.	64% hard coal, 11% hydro, 11% natural gas, 5% heavy fuel oil, 5% brown coal, 3% nuclear
Italy	2002	GaBi 4 based on European Commission's ELCD	35% natural gas, 31% heavy fuel oil, 16% hydro, 12% hard coal, 2% blast furnace gas, 2% geothermal, 1% waste
Japan	2002	GaBi 4 based on national statistics, IEA etc.	27% nuclear, 22% natural gas, 22% hard coal, 13% heavy fuel oil, 8% hydro, 5% blast furnace gas, 1% solid biomass, 1% gaseous biomass
Korea	2002	GaBi 4 based on national statistics, IEA etc.	36% nuclear, 36% hard coal, 13% natural gas, 9% heavy fuel oil, 4% blast furnace gas, 2% hydro
Luxembourg	2002	GaBi 4 based on European Commission's ELCD	71% natural gas, 27% hydro, 1% waste, 1% wind

Country	Age	Original data sources	Grid
Netherlands	2002	GaBi 4 based on European Commission's ELCD	59% natural gas, 25% hard coal, 4% nuclear, 3% blast furnace gas, 3% heavy fuel oil, 3% waste, 1% solid biomass, 1% wind
Norway	2002	GaBi 4 based on European Commission's ELCD	99% hydro (plus blast furnace gas, natural gas, solid biomass and waste)
Singapore	2002	GaBi 4 based on national statistics, IEA etc.	38% nuclear, 33% brown coal, 23% hydro, 3% hard coal, 2% natural gas
Spain	2002	GaBi 4 based on European Commission's ELCD	28% hard coal, 25% nuclear, 13% natural gas, 11% heavy fuel oil, 11% hydro, 5% brown coal, 3% wind, 1% solid biomass
Sweden	2002	GaBi 4 based on European Commission's ELCD	46% nuclear, 46% hydro, 3% solid biomass, 2% heavy fuel oil, 2% hard coal, 1% blast furnace gas
United Kingdom	2002	GaBi 4 based on European Commission's ELCD	39% natural gas, 32% hard coal, 23% nuclear, 2% hydro, 2% heavy fuel oil, 1% gaseous biomass
United States of America	2002	GaBi 4 based on national statistics, IEA etc.	48% hard coal, 20% nuclear, 18% natural gas, 6% hydro, 3% heavy fuel oil, 2% brown coal, 1% solid biomass, 1% waste

Full documentation can be found at:
http://database-documentation.gabi-software.com/index.php?id=6689

Appendix 8: Steel LCI data explanation

This appendix explains some of the main features of the datasets and clarifies potential ambiguities. Datasets have been developed for all products both globally and regionally (currently the only regional datasets available are for Europe) 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 which has been generated using the GaBi 4 software. They are distributed in RTF format to enable ease of use of the data. The reports contain the following information:

8.1 Data provision information

The name and company for whom the data have been prepared is indicated on the front page of the report together with the details of the person who has provided the data on behalf of worldsteel and the date on which the data has been provided. Due to the vast amount of data contained in the worldsteel LCI data, updates may occur following corrections or adjustments to improve methodology, but this will be done on a timely basis.

8.2 LCI flows

This section gives additional clarification about some of the flows included in the worldsteel i-reports for LCI data. The data are generally 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.

Only major flows are shown in the data sheets, namely the major raw materials and the 'accounted' emissions (see section 4.5.4). 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.

Information on other flows is also available.

8.2.1 Iron (ore)

The mass of iron ore in the ground is reported in kg of iron oxides (mainly FeO, Fe_3O_4, Fe_2O_3) and excludes the mass of overburden.

8.2.2 Ferrous scrap (net)

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 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 from external supply (scrap merchants, municipal facilities or other factories),
- 'Circulating' scrap from within the steelworks but outside the manufacturing system for the steel product route. Thus for intermediate stages (e.g. hot-rolled coil) net scrap input may be elevated owing to inputs from downstream stages (e.g. cold rolling). This scrap component tends to decrease with additional process stages. Scrap generated and reused within the manufacturing system is not included as this flow is internal to the system.

8.2.3 Water consumption

The net water consumption per kg of steel product is listed in the datasets. In addition to the water used directly on site, the water used in the upstream processes is also included. In contrast to the previous study, the water used in coal mining is also included.

The quantity of salt water used by the steel plants is recorded. It is mainly used for indirect cooling and therefore it is not contaminated with pollutants coming from the processes.

Fresh water used by the steel plants has several origins: surface water (river and lake), deep water (e.g. mine water) or 'technosphere' sources (other industrial plants, waste water treatment plants, etc.).

8.2.4 Water emissions

Obtaining accurate LCI results for water usage and water emissions is a difficult task, partly because rain water and evaporation influence the balance. There is sometimes a lack of metering, and the water networks within industrial plants are complex. Effluents from different process units are mixed, intensively recycled between process units to minimise the intake from the environment, and finally often treated in common waste water treatment plants. This makes it difficult to allocate the water usage and water emissions between individual process units.

Regarding water emissions specifically, when recorded in the questionnaires, the pollutant amounts in the intake were subtracted from the pollutant amounts in the discharged waste water because they are not attributable to the steelmaking processes. For some sites located downstream of urban and industrial areas, the outflow water is purer than the intake. However, there are many gaps for this category of data for which it is not possible to calculate an estimate. Therefore, the values of waterborne emissions are potentially overestimated in terms of net emissions.

These aspects account for the variability of data regarding water usage and water emissions. Better metering and monitoring will help to reduce this in future.

8.2.5 Carbon dioxide

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 commonly requested indicators.

8.2.6 Particulates to air

This flow includes all types of airborne particulate emission, including PM 10 and PM 2.5.

In the extended list of flows, the emission of particles to air is split into a number of sources including PM 10, PM 2.5, fugitive emissions, etc. However, as the data are not always reported in the same format, this split is not always complete.

8.2.7 Waste

The full list of waste flows is available and covers the different wastes for disposal and recovery. Overburden materials were recorded separately as deposited material.

In steelmaking, process metallurgy (BF, BOF, metallurgy) slags are used as the steelmakers' tool for the important roles of separating iron from the other constituents in the ore, and to remove any unwanted elements from the steel and incorporate them in a stable slag structure. When the liquid iron or steel is removed from the process, the slag accompanies it.

By carefully controlling the separation and treatment of this slag, the steel maker generates a slag product that can be sold in certain markets, of which the main ones are aggregate and cement. Other smaller markets exist, such as sandblasting and agriculture. If there is a lack of demand in these markets, the steel maker might not process the slag in this way, and therefore it must go to landfill. Only in these circumstances does slag become waste.

8.2.8 Primary energy demand

The primary components of an LCI are the material inputs and outputs that are taken from or are emitted to earth. 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.

8.2.9 Global warming potential

In the same way, GWP is also listed in addition to the main input / output flows. Again, this is not in addition to the other flows mentioned in the results table, but serves as an indicator of one of the most sought-after environmental indicators.

8.2.10 Other articles 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 4.5.4) are reported in the data sheets.

The full list of flows is available. 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 quantity 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.

In addition, tin is used as the coating material for tinplated coil (an average of 3.5 g of tin per kg of tinplated coil according to the study). Some chromium compounds, mainly chromic acid, are also used either for pre-coating treatments (passivation) and /or as a coating material for electrolytic chrome coated steel (tin-free steel).

Appendix 9: 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	0.9 tonne per tonne of cement	GaBi 4 average of 4 cement types: CEM I (32.5, 42.5, 52.5) and CEM III (32.5) (DE)
	Aggregate or roadstone	Gravel production	GaBi 4 (DE)
	Fertiliser	Lime production	GaBi 4 (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 4 (Country specific)
	Electricity production	Electricity production	GaBi 4 (Country specific)
Electric arc furnace dust	Zinc production	Zinc production	GaBi 4 (Global)
Electricity from energy recovery	Electricity production	Electricity production	GaBi 4 (Country specific)
Steam from energy recovery	Heat generation	Steam production	GaBi 4 (EU: PlasticsEurope)
Hot water from energy recovery	Heat generation	Steam production	GaBi 4 (EU: PlasticsEurope)
Ammonia	Any ammonia application	Ammonia production	GaBi 4 (EU)
Ammonium sulphate	Any ammonium sulphate application	Ammonium sulphate production	GaBi 4 (DE)
Benzene	Any benzene application	Benzene production based on different technologies	GaBi 4 (EU)
BTX	Any BTX application	Benzene production based on different technologies	GaBi 4 (EU)
Scales	Metallurgical input to steelmaking	Iron ore extraction	worldsteel
Sulphuric acid	Any sulphuric acid application	Sulphuric acid production	GaBi 4 (EU)
Tar	Any tar application	Tar production	GaBi 4 (EU)
Used oil	Heat generation	Coal, heavy fuel oil, light fuel oil or natural gas	GaBi 4 (Country specific)
Zinc	Any zinc application	Zinc production	GaBi 4 (Global)
Zinc dust	Any zinc application	Zinc production	GaBi 4 (Global
Electrode	Electrode making	Electrode mix	GaBi 4 (Global)

Appendix 10: Recycling methodology

10.1 Introduction

worldsteel has developed an LCI database of steel products which accounts for end-of-life recycling, to aid LCA practitioners modelling steel products in full crade-to-grave LCAs. This appendix explains how the closed material loop recycling methodology employed by worldsteel has been used to generate these LCIs. The guidance given in this appendix is only advisory; other alternative methods may be valid depending upon the goals and scope of the LCA study.

10.2 Rationale for the chosen recycling approach

The worldsteel LCI data collection methodology considers a cradle-to-gate approach, and also takes account of recycling in the following ways:

- allocation for scrap inputs to the steelmaking process and
- allocation for steel scrap outputs from whole product systems (e.g. scrap arising from an end-of-life building or automobile).

Where systems have both scrap inputs and outputs, it is necessary to apply consistent allocation procedures to each and therefore the abovementioned inputs and outputs of steel scrap can be treated symmetrically. This is assumed to be the case for the worldsteel methodology.

In formulating this methodology, worldsteel has followed ISO 14044: 2006, which sets out allocation procedures for reuse and recycling. Within this standard a distinction is made between open and closed loop recycling. Open loop recycling is used to describe product systems where material is recycled into a new different product or where inherent material properties change. Closed loop recycling applies to products that are recycled to produce the same product type or where the inherent material properties do not change. Where inherent material properties do not change, this is also known as closed material loop recycling.

The vast majority of steel recycling involves re-melting scrap to produce new steels with no change in the inherent properties of the basic steel material and therefore steel recycling can be regarded as closed loop. In this situation ISO 14044:2006 states that 'in such cases the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials'. This guidance provides the basis for the 'closed material loop' recycling methodology employed by worldsteel, which is used to deal with scrap inputs and outputs.

The worldsteel recycling approach, outlined in this appendix, is the approach that is advised for all LCA studies. However, worldsteel will also provide cradle-to-gate data on request.

10.3 Recycling approaches

There are many ongoing discussions about different ways in which recycling can be considered and there are a number of standards or methodologies that consider recycling in different ways. Some examples of such publications are:

- World Resources Institute/World Business Council for Sustainable Development standards developed under the GHG Protocol Initiative[16]
- PAS 2050 (Publicly Available Specification 2050: Specification for the assessment of the life cycle greenhouse as emissions of goods and services), British Standards Institute, Carbon Trust, DEFRA[17]
- CEN TC 350: Sustainability of construction works (draft)[18]
- ISO 14067: Carbon footprint of products (draft)[19]
- ILCD: The European Commission's International Reference Life Cycle Data System Handbook[7]

The two main approaches to recycling which form the basis for many of discussions are the cut-off approach and the end-of-life approach.

Cut-off approach (100-0)

The cut-off approach considers the impacts and/or benefits of recycling that only occur within the product system being studied. There is no crediting or assignment of environmental impacts between different product systems and metal scrap at the point of discard is considered to have no upstream environmental impacts beyond re-melting. This is also known as the recycled content method because the benefits of metals recycling are only taken into account on the input side (considered as being 'free') and recycling at end-of-life is neglected regardless of recycling rate.

From a policy perspective, this method leads to a focus on increasing the percentage of recycled materials in the product. Figure 10-1 shows how the cut-off approach would be applied for each stage of the life cycle; the impacts from the disposal of steel, if any, are negligible.

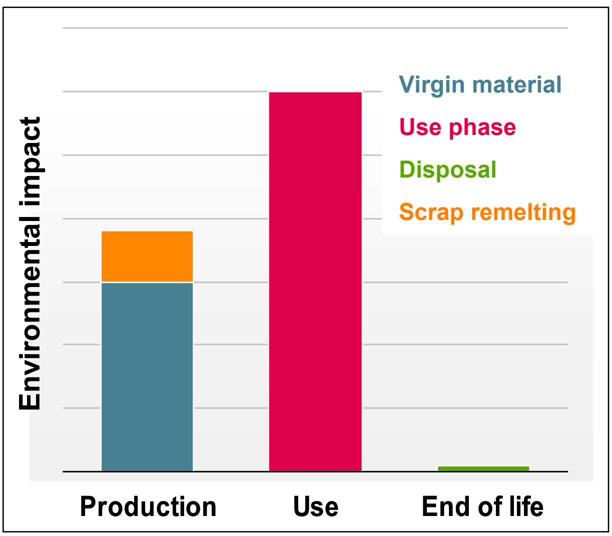


Figure 10.1: Cut-off approach for a product system that uses both primary and recycled steel inputs

End-of-life approach (0-100)

The end-of-life approach takes an overall approach to recycling as it considers the assignment of environmental impacts and credits between different product systems across different life cycles and the environmental impact of the product system is dependent on the recycling rate at end-of-life.

Another way of thinking about this method is in terms of system expansion where the boundary of the study is extended to include another product system. Where a material is recycled at end of life the product system is credited with an avoided burden based on the reduced requirement for virgin material production in the next life cycle. Equally, any recycled content adds the same burden to the product system in order to share the burden with the previous life cycle. This method is also known as the closed material loop method because recycling saves the production of virgin material with the same properties. The approach is particularly relevant for metals such as steel (Section 10-5) where recycling rates of end-of-life products are known.

From a policy perspective, this method leads to a focus on recycling at end of life. Figure 10.2 shows how the end-of-life approach would be applied for each stage of the life cycle; the impacts from the disposal of steel, if any, are negligible.

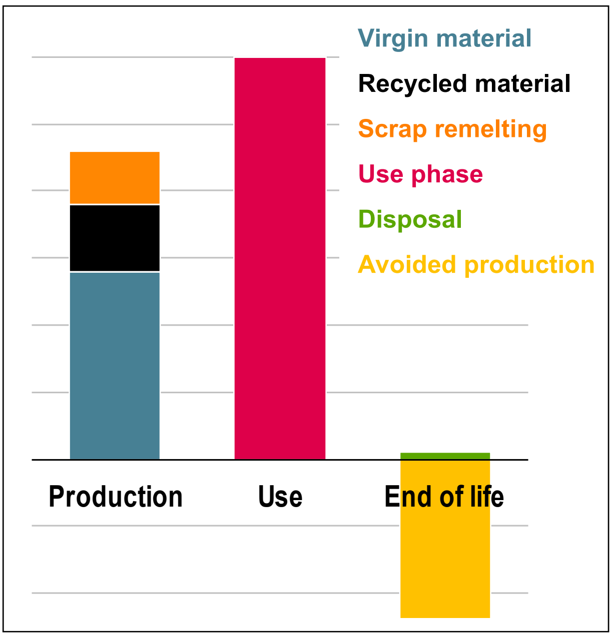


Figure 10.2: End-of-life approach for a product system that uses both primary and recycled steel inputs

A compromise approach is sometimes offered, referred to as the 50-50 method. This position represents the arbitrary half-way point (on a spectrum) of modelled approaches that compromises the two extreme approaches.

The 50:50 method falls half way in between the cut-off approach and end-of-life approach. For this reason, it is seen as a compromise method, which credits both recycled content and end-of-life recycling. This method, although a compromise, can be a solution for systems where it is not clear if it is beneficial to provide incentives for recycled content or recycling at end of life.

The Declaration by the Metals Industry on Recycling Principles[13] clearly defines the distinction between the recycled content approach and the end-of-life approach and why the latter is supported by the metals industry.

10.4 Steel recycling practices

To help understand the rationale behind the closed loop recycling methodology, it is useful to first explore steel recycling practice. In the manufacture of steel the term 'primary production' generally refers to the manufacture of iron (hot metal) from iron ore in a blast furnace (BF), which is subsequently processed in the basic oxygen furnace (BOF) to make steel. 'Secondary production' refers to the 'recycling' route, and is typically the electric arc furnace (EAF) process, which converts scrap into new steel by re-melting old steel.

However, primary steel production is not unique to the BOF route and similarly secondary steel production is not unique to the EAF. For example, it is common practice to use 10-30% scrap as iron input in the BOF route. Primary steel production occurs in the EAF route also, when pre-reduced iron is used as a feedstock to the EAF process.

Both the EAF and BOF processes produce primary and secondary steel (see Figure 10.3).

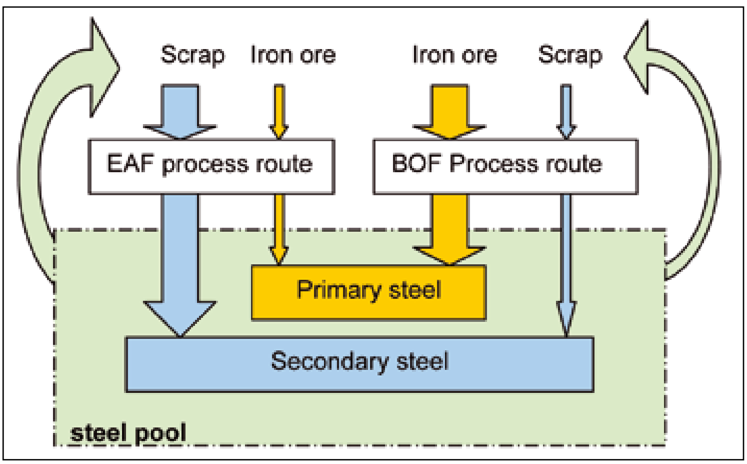


Figure 10.3: Connection between primary and secondary steel production

Steel is 100% recyclable and scrap can be converted to the same (or higher or lower) grade steel depending on the metallurgy and processing of the recycling route. Some recycled products such as rebar require minimal processing whilst the higher value engineering steels require more metallurgical and process controls to meet tighter specifications. The final economic value of the product is not determined by recycled content and there are many examples of high value products that contain large amounts of recycled steel.

Some steel products are principally sourced via the primary route mainly because the steel specifications require low residual elements and this can be achieved most cost-effectively using more primary material. In most cases scrap with a low amount of residual elements commands a higher market price owing to the ease of processing through the recycling routes.

The growing world demand for steel means that there is a continuing capacity to absorb steel scrap. History has shown that there is not enough scrap arising to manufacture all the steel required to satisfy the market. This is not a consequence of deficiencies in collecting scrap as the recovery rates of steel products are high.

10.5 Closed material loop recycling

The choice of recycling methodology can depend on not only the goal and scope of the study but also the recycling system for the material used in the product life cycle. In the worldsteel methodology, the rationale for applying the closed material loop method as default is:

1. Steel scrap has significant economic value which means that where scrap is recovered it will be used for recycling. This means that there is no requirement to create a demand for recycled material as this market is already well established.

2. Steel is recycled in a closed material loop such that the inherent properties of the primary and secondary product are equivalent. In other words, the production of secondary material displaces primary production.

3. The magnitude of steel recycling is driven by end-of-life recycling rates and an end-of-life approach captures the impact of different recycling rates in different regions and for different end-product categories.

4. The demand for steel scrap exceeds the availability of the scrap. This is magnified partly due to the long lifetime of steel products. Designing products for easier end-of-life disassembly and recycling will enable more steel scrap to be recycled.

Using the closed material loop methodology, recovered steel scrap for recycling is usually allocated a credit (or benefit). When scrap is used in the manufacture of a new product there is an allocation (or debit) associated with the scrap input. In this way, the benefit of net scrap arising or the debit of net scrap input can be accounted. Based on guidance from ISO 14044:2006 this scrap is allocated a value associated with avoided impacts such as an alternative source of equivalent (virgin) ferrous metal.

In the case of steel, the best approximation for the virgin product replaced by using scrap is the first recognisable steel product, which is cast steel or steel slab. In this case, it can be argued that secondary steel from scrap (in the EAF route) avoids primary steel from the BOF route. With this approach the allocation for scrap needs to be adjusted to take account of the scrap/steel yield associated with secondary steelmaking.

The worldsteel methodology follows the end-of-life approach because it accounts for the full life cycle of a product, from cradle to grave, the 'grave' being the furnace into which the steel scrap is recycled.

10.6 worldsteel methodology

The worldsteel methodology for the use of steel scrap in the steelmaking process and the production of steel scrap at the end of a product's life is described in detail below.

10.6.1 Terminology required

A number of parameters need to be defined relating to steel and recycling which will be used in the following explanations. The main terms are as follows:

1. Recovery rate (*RR*): this is the fraction of steel recovered as scrap during the lifetime of a steel product and includes any scrap that is generated after manufacturing the steel product under analysis.

2. Metallic yield (*Y*): is the process yield (or efficiency) of the EAF. It is the ratio of steel output to scrap input (i.e. >1 kg scrap is required to produce 1 kg steel).

3. LCI for primary steel production (X_{pr}): the theoretical LCI for 100% primary metal production, from the BOF route, assuming 0% scrap input.

4. LCI for secondary steel production (X_{re}): the LCI for 100% secondary metal production from scrap in the EAF (assuming scrap = 100%).

5. The letter X in each of these terms refers to any LCI parameter, e.g. natural gas, CO_2, water, limestone, etc.

6. S is the amount of scrap used in the steelmaking process to make a specific product.

10.6.2 The LCI of steel scrap

The worldsteel methodology assumes the burdens of scrap input and the credits for recycling the steel at the end of the life of a product are equal and that all scrap is treated equally. In reality there are numerous grades of steel products and steel scrap but it is not feasible to calculate an LCI for each grade.

Collecting scrap at the end of the product's life and recycling it through the steelmaking process enables the saving of primary, virgin steel production.

This is known as the integrated or BOF steelmaking route, but in reality, some steel scrap is always required in the process. Thus there is no process using 100% new material (with 0% scrap input) and this theoretical value therefore needs to be calculated (see section 10.6.3).

Furthermore, it is not the scrap itself that replaces this primary steel, as the scrap needs to be processed or recycled to make new steel. The EAF process is an example of 100% scrap recycling, though some EAFs also use hot metal or DRI as an input to the process.

And finally, the EAF process is not 100% efficient, i.e. it needs more than 1 kg of scrap to make 1 kg steel.

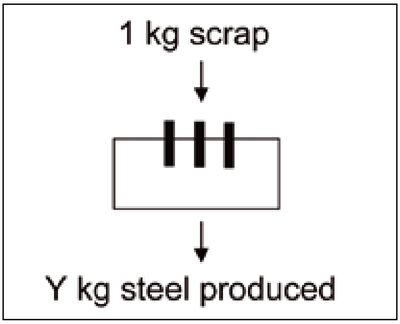


Figure 10.4: The yield of the EAF process

The LCI associated with the scrap is thus equal to the credit associated with the avoided primary production of steel (assuming 0% scrap input), minus the burden associated with the recycling of steel scrap to make new steel, multiplied by the yield of this process to consider losses in the process:

$$ScrapLCI = (X_{pr} - X_{re})Y$$

X_{pr} = the theoretical LCI for 100% primary metal production, from the BOF route, assuming 0% scrap input.

X_{re} = the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.

The letter X in each of these terms refers to any LCI parameter, e.g. natural gas, CO_2, water, limestone etc. To calculate the CO_2 for scrap would therefore be done as follows:

$$CO_2Scrap = (CO_{2pr} - CO_{2re})Y$$

Y is the process yield of the EAF (i.e. >1kg scrap is required to produce 1 kg steel).

The values for X_{re} and Y are known by the industry as these values come from the worldsteel LCI data collection exercise, from the steel producers themselves. However, the theoretical value of X_{pr} needs to be calculated.

10.6.3 Theoretical value of 100% primary BOF steel, X_{pr}

This can be calculated based on the LCI of steel slab made by the primary, or BOF route, which is calculated by worldsteel based on actual data provided by the steel producers. As the steel slab contains a certain amount of scrap, this needs to be 'removed' from the LCI so that only virgin steel is accounted for.

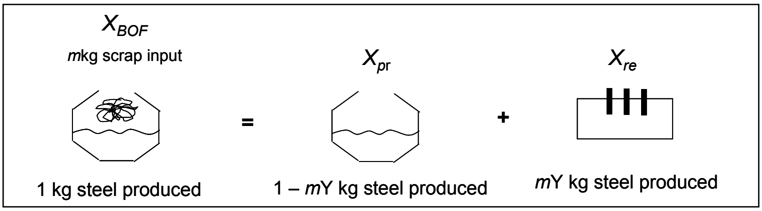


Figure 10.5: Theoretical value of X_{pr}

The scrap input to the BOF process (m kg scrap per 1 kg steel produced) that needs to be 'removed' would be melted in the EAF process producing mY kg steel, Y being the yield of the steelmaking process. Therefore the theoretical 100% primary route, X_{pr}, needs to produce 1-mY kg steel.

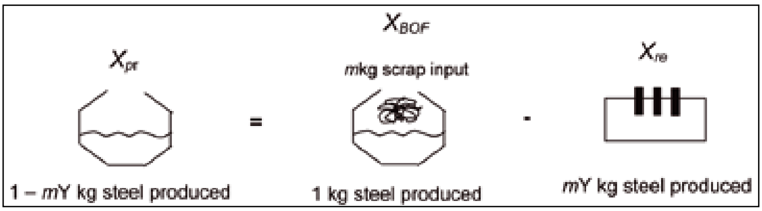


Figure 10.6: Theoretical value of X_{pr}

In effect:

$$X_{BOF} = (1 - mY)(X_{pr}) + mYX_{re}$$

m = scrap input to the BOF route ($Scrap_{BOF}$) and $Y = \frac{1}{Scrap_{re}}$

Therefore, $mY = \frac{Scrap_{BOF}}{Scrap_{re}}$

This would then give the following:

$$X_{BOF} = \left(1 - \frac{Scrap_{BOF}}{Scrap_{re}}\right)(X_{pr}) + \left(\frac{Scrap_{BOF}}{Scrap_{re}}\right)X_{re}$$

Rearranging this equation enables the theoretical value for 100% primary steel to be calculated:

$$X_{pr} = \frac{X_{BOF} - \left(\frac{Scrap_{BOF}}{Scrap_{re}} X_{re} \right)}{1 - \frac{Scrap_{BOF}}{Scrap_{re}}}$$

This value for X_{pr} can now be included in the scrap LCI equation and will therefore be applied to each of the inputs and outputs of the LCI.

$$X_{pr} = \frac{1.7558 - \left(\frac{0.119}{1.092} 0.386 \right)}{1 - \frac{0.119}{1.092}}$$

$X_{pr} = 1.9 \text{ kg } CO_2$

It should be noted that if an extrapolation was carried out in order to determine the theoretical value for X_{pr} with zero scrap input, based on the values of X_{BOF} and X_{re}, the same values would be reached for X_{pr} of 1.9kg CO_2.

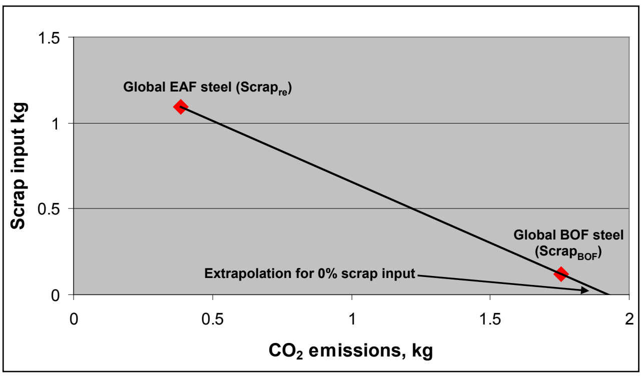


Figure 10.7: Extrapolation to show CO_2 emissions for 0% scrap input

And for CO_2, the equation would be as follows (i.e. X = CO_2):

$$ScrapLCI = (X_{pr} - X_{re})Y$$

$$ScrapLCI = [1.92 - 0.386]\frac{1}{1.092}$$

Scrap LCI = 1.405kg CO_2

10.6.4 Summary of scrap LCI calculations

The methodology for determining the LCI for steel scrap, as described in sections 10.6.2 and 10.6.3, can be summarised in Figure 10.8. The figure uses CO_2 as an example.

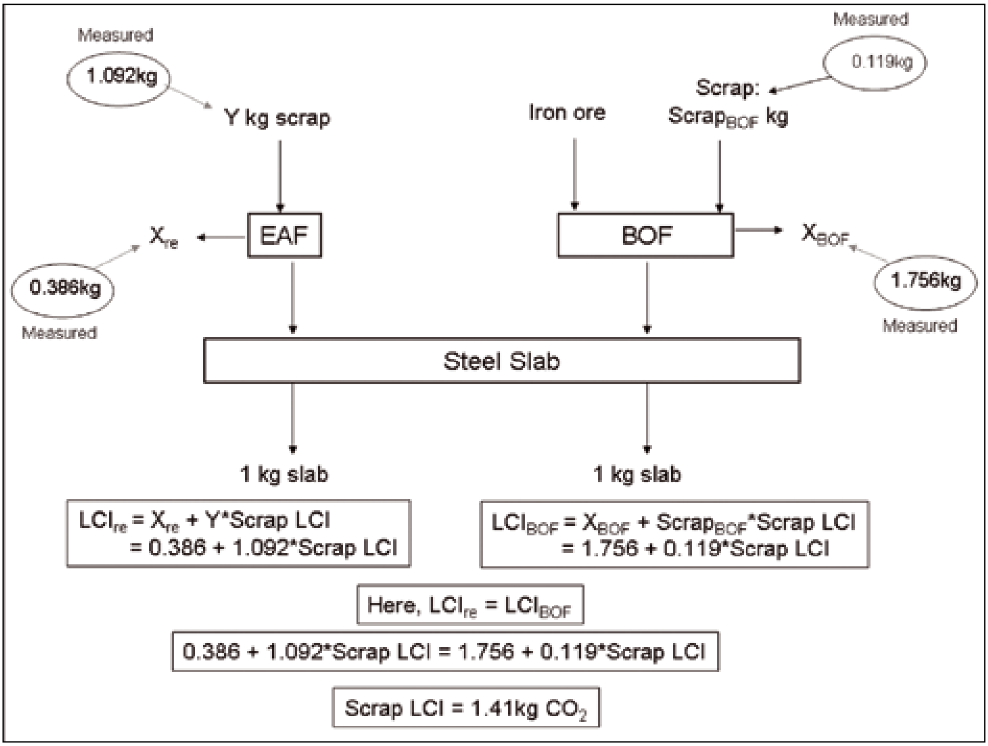


Figure 10.8: Overview of scrap LCI calculations

10.6.5 Applying the scrap LCI burden and credit

The scrap LCI, defined as $ScrapLCI = (X_{pr} - X_{re})Y$ is applied to the steel product cradle-to-gate LCIs in order to include the end-of-life phase. A credit is given for the amount of steel scrap that will be recycled at the end-of-life of the product, and this is referred to as RR. However, in doing this, a burden needs to be applied to any scrap that is used in the steelmaking process, referred to as S.

Thus, the LCI of a product, from cradle-to-gate including end of life, can be calculated as:

$$LCI_{includingEoL} = X - (RR - S)(X_{pr} - X_{re})Y$$

Where X is the LCI of the product being studied and is cradle-to-gate, i.e. including all upstream as well as steel production.

To calculate the LCI of a steel product, including end-of-life recycling, an example for carbon dioxide emissions is shown below, for global hot-rolled coil, using an end-of-life recycling rate of 85%.

The value of scrap, $(X_{pr} - X_{re})Y$, has been calculated above and the CO_2 emissions and scrap content of hot-rolled coil is provided from the global average data published in February 2010.

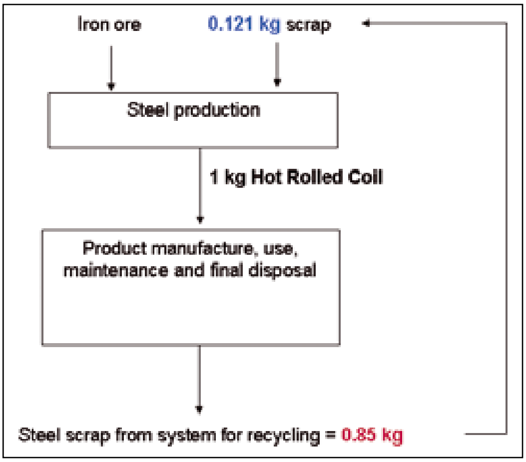


Figure 10.9: Example cradle-to-grave system

$$LCI_{includingEoL} = 1.889 - (0.85 - 0.121)*1.405$$
$$LCI_{includingEoL} = 0.86kgCO_2$$

Carbon dioxide is used in this example as it is one of the most commonly used LCI flows. The same calculation method applies to all inputs and outputs of the LCI.

Appendix 11: Deviations from the 2000 methodology report

This methodology covers an update of the global steel industry LCI data. The methodology is based on the previous studies and methodology report which has been critically reviewed by a peer review panel. During this update, changes were made to the previous methodology, and for ease of comparison, these differences are summarised here. Further information can be found in the relevant sections of the report.

- The modelling software used for this update is GaBi 4. All upstream data which have not been collected by worldsteel from industry associations are based on GaBi 4 upstream data. The previous study used the TEAM modelling software and the associated DEAM database.

- Data collection was conducted using the GaBi Web Questionnaire, which was created through an interface with the worldsteel model in GaBi 4. The previous study used an Excel-based questionnaire.

- In creating the steel product LCI data, a weighted average is now used, based on the production volume of the specific product from each site. The previous study used an arithmetic average based on political decisions within the steel industry.

- For coal upstream data, the modified German coal LCI data are no longer used. The average global coking coal mix that is now used is developed from data from different countries, according to the 2006 IEA coking coal production mix, with a specific adaption by lower heating value from average hard coal to coking coal (using a lower heating value of global average coking coal of 29.02 MJ/kg).

- The electricity input to each site is based on the national electricity grid mix for the location of each site and uses GaBi upstream data for this. Previously, the electricity input was adapted for each country using the 'Energy Statistics of OECD Countries, 1997-1998, 2000 Edition' and the 'Energy Agency Statistics - US Department of Energy, North American Electric Reliability Council (NAERC)'.

- In contrast to the previous LCI data results, the recyclability of steel at the end of a final products' life is considered in the steel product LCI. A burden is applied to the scrap input to the steelmaking process and a credit is applied to the steel that will be recycled when the final product reaches the end of its life. This enables the practitioner to utilise the steel product LCI data as cradle-to-grave, excluding final product manufacture or use phase. Data excluding these recycling aspects are available on request. The allocation procedure for calculating this burden and credit is detailed in section 4.6.3. 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.

- In addition to now using country-specific electricity grid mix data, country specific data is also provided for inputs of anthracite, coal and natural gas. The other energy related inputs (e.g. heavy fuel oil and propane) are now region-specific data. This was not previously the case, where one average value was used.

Appendix 12: List of all available questionnaires

- Coke oven
- Sinter plant
- Blast furnace
- Alternative ironmaking
- Basic oxygen furnace
- Electric arc furnace
- Direct sheet plant
- Plate mill
- Hot strip mill
- Pickling
- Cold-rolling
- Annealing and tempering
- Section rolling
- Rebar
- Engineering steel
- Wire rod
- Seamless pipe making
- UO pipe making
- Welded pipemaking and tubemaking
- Electrogalvanizing
- Hot-dip galvanizing
- Electrolytic chrome coating (ECCS or tin-free steel)
- Tinplating
- Organic coating
- Softening/deionising water
- Application of co-products
- 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)
- GHG accounting (coke oven, blast furnace, basic oxygen furnace, off gas)
- Fresh water supply
- Sea water supply
- Isolated blast air compressor
- Isolated compressed air compressor
- Isolated turbo alternator
- Stockpile emissions

Appendix 13: Matrix of steel product uses

Application	1 = preferable 2 = possible	Plate	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
Framework	Profiles			1	1	2		2	1				1			
	Framing								1							
Automotive	Body in white				2		1	1	1	2						
	Structural parts				1		1	1	1	2						
	Engine														1	
	Drive equipment														1	
	Transmissions														1	
	Wheels				1											
	Tyres															1
Construction	Structural parts		1	1					2	1			1			
	Wall elements							1	1	1						
	Basement												1	1		
	Concrete reinforcement													1		
	Cladding			2				1	1	1						
	Roofing								1	1						
	Farm building walls								2	1						
	Gutter system (ducts)								1	1						
	Chimney ducts			2												
	Construction components			2	2			1	1	1						
	Farm building components								2	1						
	Doors and garages								2	1						

	Fences								2							
	Stairs			1					2							
	Tiles								2	1						
	Ceiling 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	Furniture						2	1		1						
	White goods						1	1	1	1						
	Heating, ventilation and air conditioning						1	1	1	1						
Packaging	Steel food and general line cans									1	1	1				
	Pails											1				
	Beverage cans									1	1	1				
	Drums						1	1								
Machinery	Rail												1			
	Machines						1								1	
	Pipes		1													
Others	Tubes			1	2		1									
	Pools								2	2						
	Water tanks								1							
	Greenhouses								2	2						
	Signs								2							
	Tools														1	
	Dies														1	
	Wires													1		1

Appendix 14: Critical review: World Steel Association life cycle inventory Study for steel products

14.1 Commissioned by

World Steel Association (worldsteel), Brussels, Belgium

14.2 Review panel

Dr. David Dowdell, Cheltenham, England
Prof. Dr. Matthias Finkbeiner (chair), Berlin, Germany
Prof. Dr. Atsushi Inaba, Tokyo, Japan
Prof. Dr. Steven B. Young, Waterloo, Canada

14.3 Reference

- ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework
- ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines

14.4 Scope of the critical review

The review panel had the task to assess whether

- the methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the technological coverage of the steel industry in the prevalent LCA study is representative of current practice,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed according to paragraph 6.2 of ISO 14044, because the study as such is not intended to be used for comparative assertions intended to be disclosed to the public. This does not preclude, that the data may be used in studies where comparative assertions are made, provided a separate review of that study is carried out. This review statement is only valid for this specific report in its final version received on 22.06.2011.

The analysis of the LCI model and the verification of individual datasets are outside the scope of this review.

14.5 Review process

The review process was coordinated between worldsteel and the chair of the review panel. As a first step in the review process, the panel members were selected based on their technological and LCA competence. In addition, it was intended and achieved that the panel members represent the main steel producing regions (Americas, Asia and Europe). After the review panel was established the first draft final report was submitted to the panel on 29.10.2010. The kick-off-meeting (telephone conference) to provide general comments and to agree on the review process was held on 11.11.2010.

The review panel provided 267 comments of general, technical and editorial nature to the commissioner by the end of 2010. Worldsteel responded by providing an updated report addressing the majority of the comments on 21.02.2011 which was discussed in a second review meeting (telephone conference) on 02.03.2011. The meeting addressed the actions taken on the review comments and allowed common understanding to be reached on unresolved issues. To implement some of the comments more time was needed in order to collect and consolidate information from member companies. These issues were resolved in a third review call on 27.04.2011. The main outcome of this call was the decision to add an annex entitled "Recycling Methodology Description" to the report that provides a detailed and transparent documentation of the chosen recycling approach. Due to the importance of this topic, it was seen as valuable to address it in a comprehensive way. This annex was discussed in a final review call on 17.06.2011. The feedback provided and the agreements on the treatment of the review comments were adopted in the finalisation of the study. The final version of the report was provided on 22.06.2011. All critical issues and the majority of recommendations of the review panel were addressed in a comprehensive and proper manner.

The review panel checked the implementation of the comments and agreed to the final report. The review panel acknowledges the unrestricted access to all requested information as well as the open and constructive dialogue during the critical review process.

14.6 General evaluation

The study is the result of a cooperative effort of the leading steel producers in the world organised by its global industry association worldsteel. The current study is the second update of the first LCIs provided in 1995/6 with a first update in 2000/1. As a result, the methodology has reached a high level of maturity and the study is performed in a professional manner using state-of-the-art methods. The outstanding feature of this study is the large amount of primary data collected to reach representative results for global steel production. Primary data were collected at 49 sites operated by 15 companies, including 24 blast furnace operations and 12 electric arc furnace operations. The companies contributing data to the LCI study account for over 25% of global crude steel production. Geographically, they cover Europe (Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, the Netherlands, Norway, Spain, Sweden, and the UK), Asia (China, India and Japan) and North America.

The LCI data are provided as cradle-to-gate with or without end-of-life recycling. Because the focus of the study is the production of a material that can be used in a variety of products with very different use profiles, the chosen cradle-to-gate approach is appropriate. The guidance in the report with regard to the treatment of the end-of-life phase is comprehensive and well documented. As the decisions involved in modeling recycling contain value choices it is appreciated, that worldsteel provides not only the datasets with its own recycling approach but also datasets without end-of-life credits. This allows the data user to make their own value choices for a particular study.

Several assumptions were addressed and checked by sensitivity analyses of critical data and methodological choices. As a result, the report is deemed to be representative for the global production of steel. The defined and achieved scope for this LCI study was found to be appropriate to achieve the stated goals.

14.7 Conclusion

The study has been carried out in compliance with ISO 14040 and ISO 14044. The review panel found the overall quality of the methodology and its execution to be of a high standard for the purposes of the study. The study is reported in a comprehensive manner including a transparent documentation of its scope and methodological choices.

Matthias Finkbeiner David Dowdell Atsushi Inaba Steven B. Young

10 July 2011

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