INTERNATIONAL STANDARD

ISO 20915

First edition
2018-11

Life cycle inventory calculation methodology for steel products

Méthodologie de calcul de l'inventaire du cycle de vie des produits en acier

Reference number
ISO 20915:2018(E)

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 17, *Steel*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The life cycle inventory (LCI) of steel products is an important component in the support of life cycle assessments for a wide range of products and applications that contain steel or where steel is used to support the manufacture, production or delivery of products.

This document describes the methodology for the calculation of the steel life cycle inventories that can be applied to a wide range of steel products, and represents the main process routes for global steel production. This includes the extraction of raw materials from the earth through to the production of steel products at the factory gate, as well as provision for scrap recycling of steel products and the treatment of steel scrap. The methodology conforms to the principles and framework set out in ISO 14040:2006 and ISO 14044:2006 and demonstrates how these principles can be applied to steel product manufacture and steel recycling.

As illustrated in Figure 1, the life cycle of steel products consists of the following stages:

— sourcing of natural resources (which includes mining, transportation and intermediate processing of raw materials) and ferrous scrap (recovered from both the manufacturing process and the end of life of final products);

— production of steel products at the steelworks;

— manufacturing of final products by downstream users, for example, by customers of the steel industry, such as automotive, construction and engineering industries;

— use of final products, where the environmental performance of the final product depends on the steel products being used; for example, the fuel (or energy) consumption of an automobile depends partly upon the weight of its steel components;

— recovery of material from the end of life of final products;

— recycling of ferrous scrap from both the manufacturing process and the end of life of final products to substitute the use of raw materials from the earth.

The schematic diagram of the full life cycle of steel is shown in Figure 1. This document covers life cycle stages including sourcing of raw materials from the earth and ferrous scrap, production of steel products at the steelworks, and recycling of ferrous scrap. It does not cover the manufacturing of final products and the use of final products.

All global steel production is sourced from different ratios of ferrous scrap and primary ores. Therefore, an understanding of the value of steel recycling becomes a necessary part of the steel product LCI.

It is generally understood that the recycling of materials makes a positive contribution towards reducing resource consumption and energy requirements, and helps to avoid the potential impacts of raw materials extraction and processing. However, all recycling routes (including the processing and transport of recycled materials) carry environmental burdens and these can be quantified as part of a life cycle assessment.

A critical factor in the understanding of the benefits of materials recycling is the quality of the materials and products that can be produced from the recycled material. Where the recycled products can be made to the same inherent properties as those sourced from primary materials, this is described as closed loop recycling.

With the existing process and scrap quality controls, steel sourced from (scrap based) steel recycling can be made to the same specification as steels sourced from the (iron ore based) primary routes. The properties of the different steel grades are achieved through different alloying concepts as well as process steps, such as heat treatment. Steel metallurgy allows the control of alloying and tramp elements to achieve closed loop recycling.

Life cycle assessment can be used to quantify the potential benefits of recycling to conform to the guidance set out in ISO 14040:2006 and ISO 14044:2006.

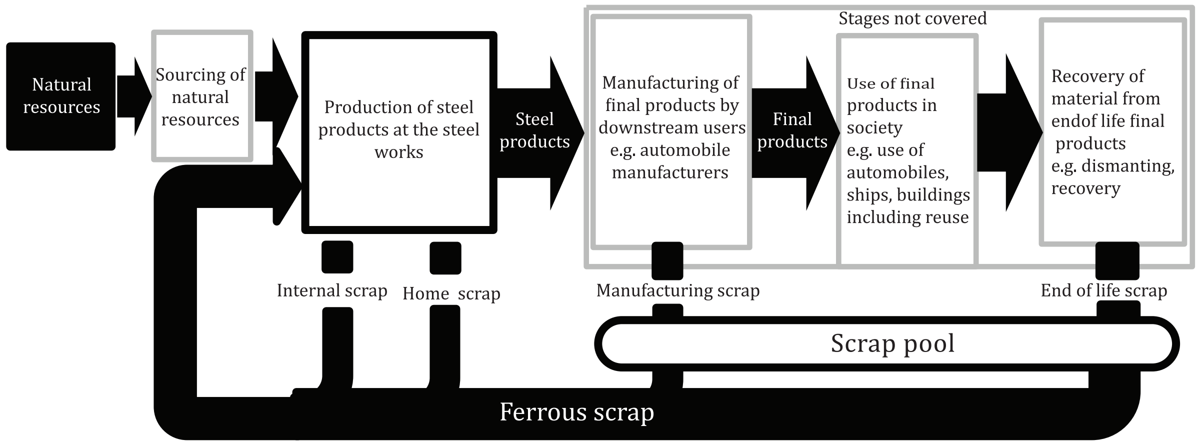


Figure 1 — Schematic diagram of the life cycle of steel

Life cycle inventory calculation methodology for steel products

1 Scope

This document specifies guidelines and requirements for conducting life cycle inventory (LCI) studies of steel products reflecting steel's capacity for closed-loop recycling, including:

a) specification of the functional unit used for LCI calculation of steel products;

b) definition of the system boundaries used for LCI calculation of steel products;

c) evaluation of scrap in LCI calculation of steel products;

d) evaluation of co-products in LCI calculation of steel products;

e) reporting of LCI calculation results of steel products.

The application of LCI results, including life cycle impact assessment (LCIA), is outside the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
steel product
product produced from steel and shipped out from steelworks

EXAMPLE Hot rolled steel, pickled hot rolled steel, cold rolled steel, finished cold rolled steel, electrogalvanized steel, hot-dip galvanized steel, tin-free steel, tinplated steel, organic coated steel, section, plate, rebar, engineering steel, wire rod, seamless pipe, UO pipe, welded pipe.

3.2
final product
product that requires no additional transformation prior to its use

EXAMPLE Automobiles, building structures, building envelopes, packaging.

[SOURCE: ISO/TS 18110:2015, 2.2, modified — The example has been added.]

3.3
scrap
iron and steel material in metallic form that is recovered in multiple life cycle stages, including steel production processes, the manufacturing processes of *final products* (3.2) and the end of life of final products, and is recycled as a raw material for steel production

3.4
internal scrap
scrap (3.3) from a crude steel making unit process that is then recycled within the same unit process [e.g. basic oxygen furnace (BOF) or electric arc furnace (EAF)]

3.5
home scrap
scrap (3.3) from a downstream steel production process within the steelworks (e.g. rolling, coating) that is returned to steel making processes (e.g. BOF or EAF)

3.6
manufacturing scrap
scrap (3.3) from the manufacturing processes of *final products* (3.2), such as automobiles and buildings

3.7
end of life scrap
scrap (3.3) from after the end of life of *final products* (3.2)

3.8
external scrap
scrap (3.3) provided from outside of the steelworks, including *manufacturing scrap* (3.6) and *end of life scrap* (3.7)

3.9
recycling rate
ratio of the mass of *external scrap* (3.8) recycled to the mass of steel products to be shipped out from the steelworks gate

3.10
end of life recycling rate
ratio of the mass of *end of life scrap* (3.7) recycled to the mass of steel in *final products* (3.2)

3.11
manufacturing yield
ratio of the mass of steel contained in *final products* (3.2) to the total mass of *steel products* (3.1) used for manufacturing the final product

3.12
ferrous raw material
raw material from the earth that becomes one of the main constituents of *steel products* (3.1), and which may have undergone intermediate processing to prepare it for ironmaking

EXAMPLE Lump ore, iron ore fine, sinter, pellet, hot briquetted iron (HBI), direct reduced iron (DRI).

3.13
process coal
coal used in iron and steel making processes

EXAMPLE Coking coal, injection coal, sintering coal, BOF coal, EAF coal, DRI coal.

3.14
non-ferrous raw material
non-ferrous ingredient material for *steel products* (3.1) other than *ferrous raw material* (3.12) or *process coal* (3.13)

EXAMPLE Zinc, tin. aluminium.

3.15
ferro alloy
alloy of iron with non-iron alloy metals, such as manganese, silicon or chromium used in the steelmaking process

3.16
other input material
material input and consumables for steel production other than *ferrous raw material* (3.12), *process coal* (3.13), *non-ferrous raw material* (3.14), *ferro alloy* (3.15) and *scrap* (3.3), which does not ultimately form part of the *steel product* (3.1)

EXAMPLE Refractory, electrode, chemical materials, limestone, dolomite.

3.17
fuel
energy source for generating heat, steam and power other than *process gas* (3.20)

EXAMPLE Boiler coal, fuel oils, natural gas, LPG.

3.18
industrial gas
gas for steel production other than *fuels* (3.17) or reducing agent

EXAMPLE Oxygen, nitrogen, argon, hydrogen, carbon dioxide, compressed air.

Note 1 to entry: Hydrogen can be used as a fuel, or is included here as an industrial gas when used as an uncombusted industrial gas, e.g. for the provision of reducing atmospheres in production processes.

3.19
co-product
any of two or more products coming from the same unit process or product system

[SOURCE: ISO 14044:2006, 3.10]

3.20
process gas
gas that is produced as part of the processes on the steel production site

EXAMPLE Coke oven gas, blast furnace gas, BOF gas.

3.21
waste
materials disposed of in landfills, both internal and external to steel works, or incinerated

4 Basic conditions for LCI of steel products

4.1 General requirements

The requirements and guidelines set in this document shall be followed in addition to those set by ISO 14040:2006 and ISO 14044:2006.

4.2 Function and functional unit

The function of steel products is to form a part of final products, such as automobiles, cans and bridges.

For a LCI of steel products, the functional unit should be set as a mass-based unit of steel products to be shipped out from the steelworks gate. Where applications are based on other functional capacities, suitable explanation and conversion guidance shall be provided.

4.3 System boundary

As shown in Figure 2, the system boundary used for the LCI study of steel products shall include all of the production steps from input materials (raw materials in the earth, scrap, etc.) to finished products ready to be shipped from the steelworks, including the recycling of steel products (i.e. cradle to gate). This includes production processes at the steelworks and all the upstream processes, including energy conversion, raw material mining, material preparation and transportation of materials to the steelworks site. The effect of scrap recycling, or the burdens of using scrap and the credits for the recovery of steel products, should be considered according to the procedure described in 5.3. The calculation of steel product LCIs should include allocation on scrap to reflect the nature of closed loop recycling. Cradle to gate LCIs without scrap allocation may be reported when this is aligned to the goals and scope of the study. Additionally, care should be taken that if no burdens are assigned to scrap inputs, then no credits should be applied to steel recycling. Also, the recovery and use of steel industry co-products outside of the steelworks shall be taken into account according to the allocation procedure described in 5.5. The system boundary does not include the manufacturing of final products using steel products or their use in the society.

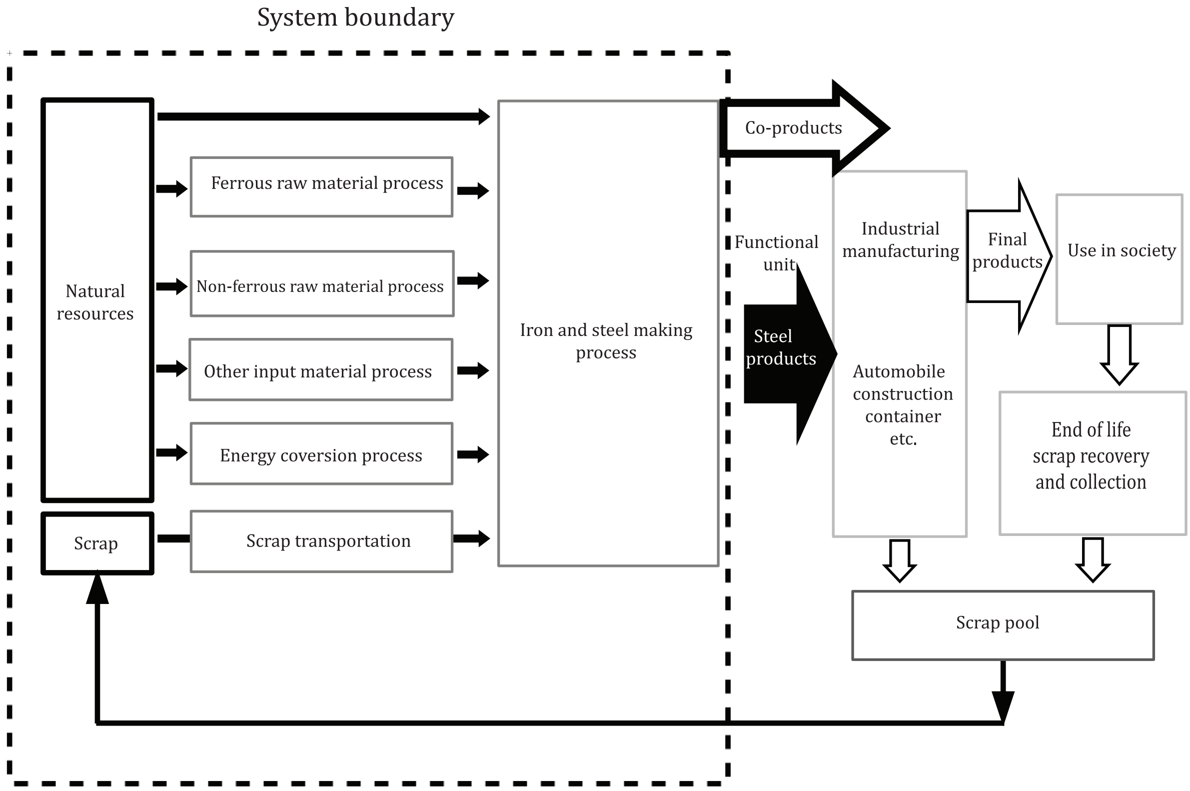


Figure 2 — System boundary

The following items should be excluded from the system boundary. If any of them are included in the system boundary, this shall be clearly stated and explained.

— Transportation of steel products beyond the gate.

— Transportation of co-products beyond the gate.

— Manufacturing of final products.

— Use of final products.

— Research and development.

— Business travel of employees.

— Production, decommissioning, repair and maintenance of capital goods.

— Cleaning and legal services.

— Marketing.

— Operation of administration offices.

4.4 Data quality

4.4.1 General

The data quality requirements set out in of ISO 14044:2006, 4.2.3.6, should be followed, including time-related coverage (4.4.2), geographical coverage (4.4.3) and technology coverage (4.4.4).

4.4.2 Time-related coverage

The timeframe of data collection should be one full representative year to adjust for seasonal variations. If the data set is not possible for a full year, this shall be explained and justified. Moreover, since the LCI results are prone to change over time for reasons, such as changes in operational rate due to economic conditions and technological improvements, the time period in which the data are collected shall be stated clearly. Primary data sets used in LCI studies should not be more than five years old. Any secondary data used should be less than 10 years old, unless its ongoing validity is justified. When using data outside of the reference year, the choice shall be explained and justified.

4.4.3 Geographical coverage

An LCI study of steel products may be reported with various geographical representations, for example, one steelworks, one steel company, national, regional or global coverage. When the study covers multiple steelworks (or companies, regions, etc.), the geographical coverage and representation should be clearly stated. The LCI should be presented as a weighted average by the production quantity of the covered scope, not a simple arithmetic average. For example, Product A produced by sites 1, 2 and 3 with mass M1, M2 and M3 would be averaged as: (LCI1 × M1 + LCI2 × M2 + LCI3 × M3)/(M1 + M2 + M3). Manufacturers contributing to the LCI shall be documented, and use of the data set shall be noted as applicable within the bounds of the contributing manufacturers.

4.4.4 Technology coverage

This document covers production technologies of unalloyed steels and alloy steels, as defined in ISO 4948-1:1982. This document does not cover the production of stainless steel.

4.4.5 Sources of the data

Steel production data shall be directly sourced from steel producers based on primary data, such as measurement, engineering calculations and purchasing records.

Upstream data produced by suppliers should be used. If the information is not available, secondary data produced by LCA-related organizations, academic institutions, public institutions, such as regional and national governments, and steel-related organizations may be used. All secondary data should be checked for geographical relevance to the LCI.

4.4.6 Cut-off criteria

As stated in ISO 14044:2006, 4.2.3.3.3, the cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described. In particular, for LCI of steel products, cut-off criteria may be established for all energetic inputs and outputs to the process stages, including fuels, electricity, steam and other converted energy as well as for all inputs and outputs to the process stages of ferrous raw materials, process coal and non-ferrous raw materials.

To avoid the need to pursue trivial input and outputs to the system, cut-off criteria should be applied as follows:

— all energetic inputs to the process stages should be reported including fuels, electricity, steam and compressed air;

— each excluded material flow should not exceed 1 % of mass, energy or environmental relevance for each unit process;

— the sum of the excluded material flows in the system should not exceed 5 % of mass, energy or environmental relevance.

5 Methodological procedure for LCI calculation of steel products with provision for scrap recycling

5.1 General

The calculation of steel product LCIs should include allocation on scrap to reflect the nature of closed loop recycling. Cradle to gate LCIs without scrap allocation may be reported when this is aligned to the goals and scope of the study.

To evaluate the benefits of steel recycling it will be necessary to allocate a LCI value to scrap and to apply this value to both the inputs (burdens) and outputs (credits) of the system. The reporting of this will depend upon the goals of the study, but if no burdens are assigned to scrap inputs, then no credits shall be applied to the external scrap (i.e. end of life and manufacturing scrap). It is important to be consistent with the allocation of credits and burdens throughout the scope of the life cycle study. Note also that the value assigned to scrap reflects the initial investment of the primary production of steel, which if recycled, will be carried forward for future generations. The resulting formulae show that the LCI burdens of steel in an application are reduced by higher end of life recycling rates (R) and by improving the yield of the recycling process (y). This indicates that the sustainability of product designs involving steel products should make provision for high values of R and y.

The LCI for steel products which takes account of scrap recycling is calculated in three stages (see Figure 3), as follows.

— A: In a first step, the LCI of the steel product to the factory gate is calculated without allocation for scrap. At this stage, scrap will appear as a mass input but will not be allocated with an LCI (inventory flows to/from earth related to scrap).

— B: Secondly, an LCI value for scrap (as described in 5.3) is calculated. It is then applied in the substages B1 and B2 as described below. Both of these steps have to be conducted.

  — B1: The LCI value is applied as a burden for the mass of scrap consumed in the process.

  — B2: The same LCI value for scrap is credited for the mass of scrap that is going to be recovered.

— Thirdly, by aggregating the three components (A + B1 + B2) the LCI value for the steel product with consideration for scrap recycling can be determined.

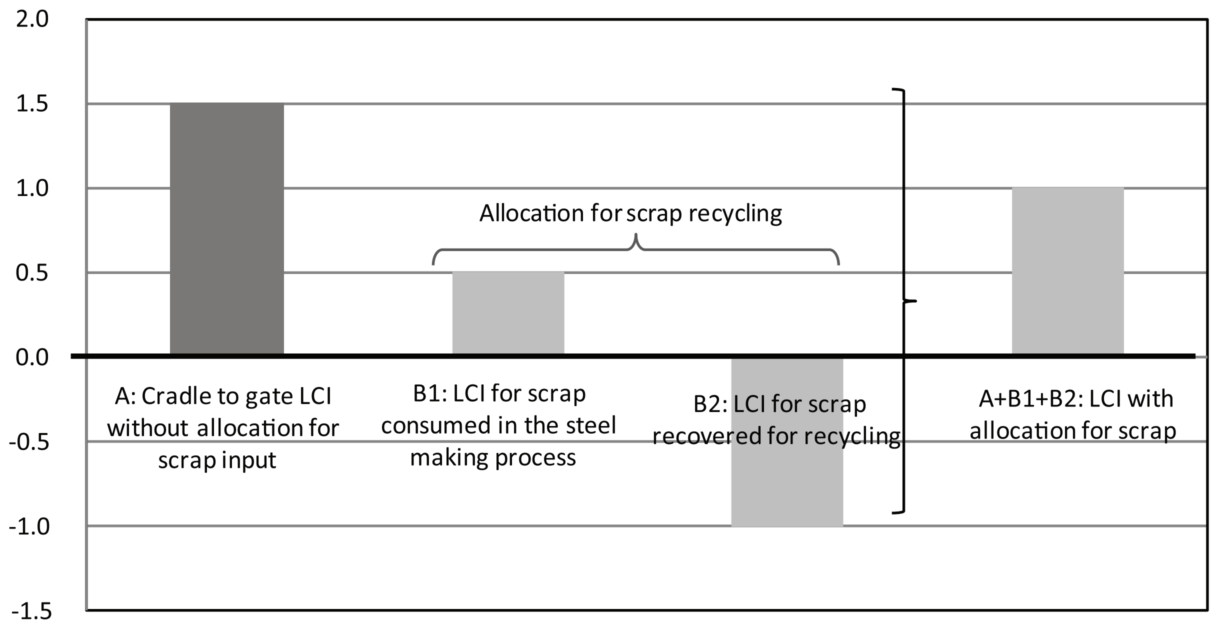


Figure 3 — Illustration of LCI of steel products

5.2 Calculation of cradle to gate LCI without allocation for scrap input

The cradle to gate LCI without a burden for scrap input is calculated process by process by aggregating the upstream LCI of each input (other than scrap) as well as what happens on-site. An example of calculation flow is depicted in Figure 4.

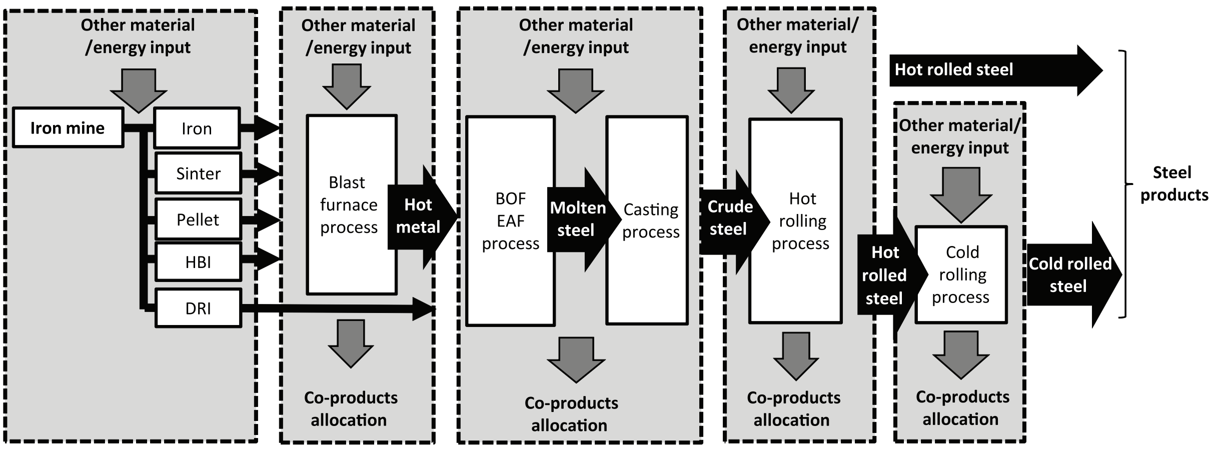


Figure 4 — Schematic example of calculation procedure for cradle to gate LCI without allocation for scrap input

5.3 Allocation for scrap recycling

5.3.1 General

Steel can be recycled into new steel products without loss of inherent properties. Because of this nature, a closed-loop allocation procedure for the recycling of steel is described in this document; this follows ISO 14044:2006, 4.3.4.3, which describes the allocation procedures for closed loop material recycling. Allocation methods shall be clearly documented along with justification.

Detailed guidance for calculation is provided in 5.3.2, 5.3.3 and 5.3.4.

Scrap inputs shall only carry a burden providing that scrap allocations have been applied to system inputs (burdens) and system outputs (credits) equivalently. This will ensure consistency with ISO 14044:2006.

5.3.2 LCI calculation methodology for scrap

The LCI of scrap is determined by considering the benefits of producing new steel from scrap compared with producing the same steel from purely iron ore based process route. Providing that the LCI associated with the process of recycling scrap (X_{re}) is less than the LCI of producing steel from iron ores (X_{pr}), then this will be beneficial to society. In the evaluation of X_{re} and X_{pr}, scrap is assumed to be free of burdens. The resulting value of the LCI of scrap can then be input into the product LCI study, where the scrap inputs, scrap outputs, recycling rates and recycling yields are known. This LCI of 1 kg of scrap, X_{sc}, can be calculated from Formula (1):

$$X_{sc} = \left(X_{pr} - X_{re}\right) \times y \tag{1}$$

where

X_{pr} is the LCI of producing 1 kg of crude steel without steel scrap;

X_{re} is the LCI of producing 1 kg of crude steel only from steel scrap;

y is the yield of crude steel in the X_{re} route (the mass of crude steel per 1 kg of scrap input).

The values for X_{re} and y may be obtained as primary data or as secondary data from reliable sources.

In practice, it is rare for steel to be produced without scrap inputs. Therefore, X_{pr} is a theoretical value based upon calculations derived from real data sets. The approach to these calculations is given in Annex A. One of the methods is an extrapolation of LCI data values for sets of data from iron ore based process routes with varying degrees of scrap inputs (typically from 3 % up to 20 %), which can then be extrapolated to estimate zero scrap (0 %) input value for the iron ore based process route (X_{pr}). This method can be useful when analysing specific LCI values but becomes less practical to apply across all LCI values. The alternative is described in Annex A.

5.3.3 Calculation of the burden for scrap input to produce the specific steel product under study

The burden for scrap input to produce one functional unit of a specific steel product under study, $B1$, can be calculated shown by Formula (2):

$$B1 = X_{sc} \times M_{sc} \tag{2}$$

where

X_{sc} is the LCI of scrap [see Formula (1)];

M_{sc} is the mass of scrap used for producing one functional unit (e.g. 1 kg) of steel products.

5.3.4 Calculation of the credits for scrap recovery

The credit for scrap recovery, $B2$, is calculated as shown by Formula (3):

$$B2 = X_{sc} \times R \tag{3}$$

where

X_{sc} is the LCI of scrap [see Formula (1)];

R is the recycling rate.

The recycling rate, R, is calculated as shown by Formula (4):

$$R = (a + b) / P \tag{4}$$

where

a is the mass of manufacturing scrap recycled;

b is the mass of end of life scrap recycled;

P is the mass of steel products shipped out of the gate.

Moreover, the end of life recycling rate, β, is calculated as shown by Formula (5):

$$\beta = b / F \tag{5}$$

where

b is the mass of end of life scrap recycled;

F is the mass of steel products contained in the final product.

Depending on the goals and scope of the study, either of these recycling rates may be used.

Details for calculating the recycling rate are given in Annex E.

5.4 Collecting data

5.4.1 General

In the system boundary described in 4.3, all inputs and outputs of materials, energy and co-products across each unit process shall be captured.

5.4.2 Co-products

Among the outputs listed in Table 1, those which are used beneficially are co-products of steel production. Co-products other than main products (coke, hot metal, slab, bloom, billet, steel products) shall be allocated in accordance with 5.5. If there are co-products other than those listed in Table 1, they can also be allocated.

Table 1 — Examples of main outputs from iron and steel making processes

Processes	Main outputs/co-products
Coke making	Coke Light oil Benzene Tar Toluene Xylene Sulfur Ammonia Coke oven gas Recovered steam
Iron making	Hot metal Blast furnace gas Slag Dust Recovered electricity
Steel making (basic oxygen furnace, BOF) + casting	Steel (slab, bloom, billet) BOF gas Slag Dust Recovered steam Scrap (internal scrap)
Steel making (electric arc furnace, EAF) + casting	Steel (slab, bloom, billet) Slag Dust Electrode Scrap (internal scrap)
Other processes	Steel products Iron powder Zinc oxide Dross Sludge Dust Recovered steam Recovered electricity Scrap (home scrap) Scale

5.4.3 Ferrous raw materials

Many of these iron resources are processed before used in steel production. Cradle to gate LCIs associated with processing of raw materials, such as direct reduced iron (DRI) making, pelletizing, hot briquetted iron (HBI) making and sintering, shall be included, both for the cases where the processing is done in-house and external to the steelworks.

If no primary data or upstream data are available, the LCI may be based on secondary and literature data.

5.4.4 Process coal

For the iron and steel making processes, different kinds of coals are used (coking coal, injection coal, sintering coal, DRI coal, BOF coal, EAF coal and other coals for iron and steel making processes) and appropriate LCIs shall be collected separately for those types of coal. For each of these types, an average value (e.g. national or regional, whichever is deemed to be most appropriate) shall be used to reflect the wide variety of their characteristics.

The LCI for coal shall consider the whole supply chain from coal mining to coal processing as well as the transport to the coal terminal of the source country. All relevant process steps and technologies shall be covered; the data shall be representative of deep coal mining and open cast mining. The LCI may be based on secondary and literature data as applicable for the coal used.

Regarding methane emissions, the net value shall be provided (occurring mine methane emissions minus the use of captured mine methane).

As for process coal, all the upstream LCI of process coal shall be considered.

5.4.5 Non-ferrous raw materials

As for non-ferrous raw materials, all the upstream LCI of non-ferrous raw materials shall be considered.

5.4.6 Ferro alloy

As for ferro alloys, the upstream LCI of all ferro alloys shall be considered.

5.4.7 Other input materials

As for other input materials, all the upstream LCI of these materials shall be considered. Minor material inputs may be omitted in accordance with the cut-off criteria as defined by the person who is conducting the LCI calculation.

5.4.8 Fuels

Upstream LCI of fuel production should cover mining, processing and transportation.

5.4.9 Process gases

Process gases are produced from blast furnaces, coke ovens and BOF. Process gases can be used as energy sources within and outside steelworks. Therefore, data on the amount produced and used should be collected.

Process gases are used as energy sources for steel production processes within the steelworks and partially as energy sources for electricity generation facilities on or off the steelworks. For this reason, the generation of process gases shall be equal to the sum of the use of process gases on-site and the amount exported and flared.

Process gas can be either used to produce thermal energy or electricity. 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 process gases would be coal, fuel oil or natural gas for the production of thermal energy.

In case of electricity the national/regional grid should be used as replaced energy. The replaced fuel or electricity is determined by the site as part of the data collection process and the national grid mix for the country of location.

When process gases are partially exported outside the steelworks or boundary of the steel product LCI, the choice of equivalent fuel should be justified and reported. For example, where process gases are exported outside of the steelworks to an electricity generation facility nearby, the credit should be equivalent to the fuels that are avoided in the electricity generation of the local electricity grid (system expansion).

5.4.10 Electricity

Electricity may be supplied from the grid or generated on-site. Data should be collected for each source used (see Annex F).

5.4.11 Steam

Steam may be supplied from outside of the steelworks or generated on-site. Data should be collected for each source used (see Annex F).

5.4.12 Sea water

Data on sea water used for once-through cooling of condensers, heat exchangers, furnaces, etc. shall be collected.

Data on electricity consumption associated with intake and drainage of sea water shall be collected.

Emission of chemical agents associated with sea water shall be collected.

All other uses of sea water shall be collected.

5.4.13 Fresh water

Fresh water is supplied as circulating cooling water and as a source of process water, such as de-ionized water. The amount of water shall be collected.

Data on electricity consumption and chemical inputs associated with intake and drainage facilities, de-ionizer, water treatment facility and fresh water circulating facility shall be collected.

Data on emissions to water associated with drainage shall be collected.

5.4.14 Industrial gases

When industrial gases are supplied from outside of the steelworks, the upstream LCI of production and transportation of those gases shall be collected.

When industrial gases are produced on-site, inventories are calculated from consumed utilities, such as electricity and materials.

5.4.15 Emissions to air, water and soil

A list of all emissions to air, water and soil to be included in the study shall be defined and collected for each process stage. Emissions, such as CO_2, that cannot be measured directly should be calculated from available information, such as energy consumption and/or appropriate emission factors.

5.4.16 Flares

Data on flares of blast furnace gas, coke oven gas and BOF gas should be measured and all known emissions included.

When the quantity of flares cannot be measured directly, the amount of flared gas may be calculated either as the difference between the generation and the use of process gas, or as the difference between the balance of carbon content of hot metal, input carbon used as heat source and carbon content of recovered BOF gases. The emissions associated with flaring shall also be included.

5.4.17 Transportation

LCI of external transport shall be calculated for rail (electricity and diesel powered), road, sea and river, based on the types of transport and distances for the shipment of the main raw materials (in terms of tonnage) to the steelworks.

Internal transport should be included if possible. The fuel consumption associated with on-site transport should be included, if available.

5.5 Allocation procedure for co-products

5.5.1 General requirement

During the production of steel products, co-products, such as process gases and slags, are also created. Within an individual area of steel production (e.g. blast furnace) process division cannot always be applied as a means of avoiding allocation of co-products. Therefore, following ISO 14044:2006, 4.3.4, which states that, wherever possible, allocation should be avoided, system expansion should be used to account for co-products from steel production. When system expansion cannot be applied, allocation procedures may be used. Details are noted in ISO 14044:2006, 4.3.4.2, Step 2 and 3.

5.5.2 System expansion

To apply system expansion, selection of alternative systems shall be carried out based on actual usage of co-products.

When choosing the alternative system for system expansion, it shall be chosen regarding the regional situation. The choice of system should be the most likely production method that would be offset. See Annex C for some examples.

6 Reporting

LCI results shall be reported for all of the components shown in Table 2, with the exception of those cases where the goal and scope do not include an allocation for scrap burdens and credits. In such cases, cradle to gate values without scrap allocation can be reported alone (Column A), provided that columns “B1”, “B2” and the “LCI including scrap allocation” are reported as “not declared”. Examples of the LCI result reporting format are provided in Annex B. The components of reporting explained in Annex B show that cradle to gate reporting (A) includes scrap as a material input but without allocation of burdens or credits. The components which take into account scrap burdens (B1) and scrap credits (B2) are derived using the allocation methodology described in 5.3, but as expressed in 5.3.1 an alternative methodology can be selected. The aggregated report is a summation of these three components (A, B1 and B2). It is important to ensure that the aggregate reporting is relevant to the goals and scope of any study to which the data are being applied.

Table 2 — Components for steel LCI reporting

A: Cradle to gate LCI without allocation for scrap input	Allocation for scrap recycling		A+B1+B2: LCI with allocation for scrap
	B1: LCI for scrap consumed in the steel making process	B2: LCI for scrap recovered for recycling	

NOTE Example comparison with reporting in construction-related standards is provided in Annex D.

Along with the LCI results, the following information, in particular, shall be reported:

a) products, their function and functional unit;

b) data sources:

1) data source for electricity from the grid;

2) scrap recycling rate and the data source (can be omitted if scrap is not allocated);

3) data source for X_{re}, X_{pr} and y used for the calculation of the LCI of scrap (can be omitted if scrap is not allocated);

c) time-related coverage and geographical coverage, including age of data.

Also, data sources for other inputs (steam, transportation, coal, alloys, virgin ferrous inputs, etc.) should be reported, when considered important by the person who is conducting the LCI calculation.

7 Critical review

When carrying out a critical review, ISO 14044:2006, Clause 6, shall be followed.

Annex A
(informative)

An example for calculating X_{pr}

Collecting scrap and recycling it through the steelmaking process reduces the environmental burdens related to steel production from iron ore, often referred to as primary steel production.

In practice, it is rare for steel to be produced without scrap inputs. Therefore, X_{pr} is a theoretical value based upon the calculations shown below. When there are sufficient data sets and only a few LCI values to be analysed, a numerical approach can be used as an approximation. The latter uses an extrapolation from sets of LCI data for iron ore based process routes (typically BF-BOF) with varying degrees of scrap inputs (typically from 3 % up to 20 %) to estimate zero scrap input value for the iron ore based process route (X_{pr}).

Alternatively, and more practically, when analysing full LCI values, the calculation below can be used to determine X_{pr}. This is based on the premise that steel scrap is often required in the process, there is no process using 100 % new material (with 0 % scrap input) and this theoretical value therefore needs to be calculated. 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. In this case, the EAF process can be an example of 100 % scrap recycling, though some EAFs also use hot metal or DRI as an input to the process. And finally, more than 1 kg of scrap is required to make 1 kg of steel products, as shown in Figure A.1.

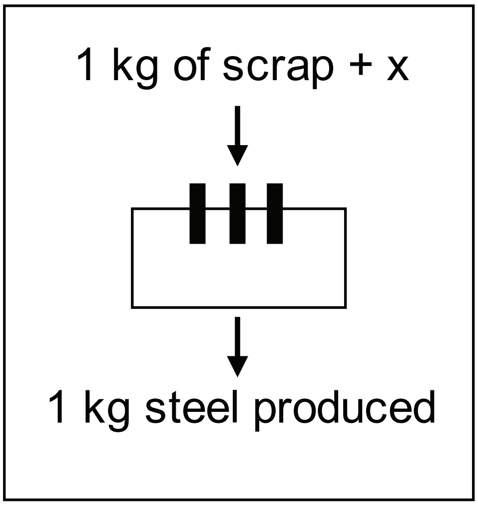


Figure A.1 — The yield of the EAF process

The theoretical value of X_{pr} can be calculated based on the LCI of crude steel made by the primary or BOF route (X_{BOF}). As the crude steel contains a certain amount of scrap, this needs to be “removed” from the LCI so that only primary steel is accounted for, as shown in Figure A.2.

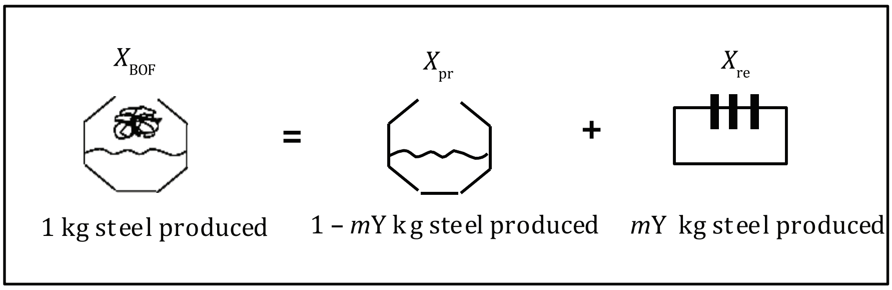


Figure A.2 — Theoretical value of X_{pr}

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 X_{pr}, needs to produce 1-mY kg steel, as shown in Figure A.3.

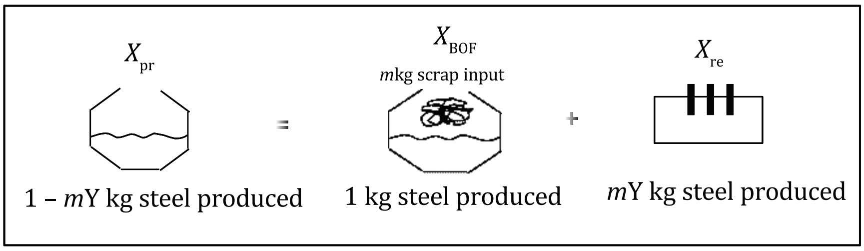


Figure A.3 — Theoretical value of X_{pr}

In effect:

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

where

m is the scrap input to the BOF route ($Scrap_{BOF}$);

$$Y = \frac{1}{Scrap_{re}}$$

Therefore,

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

This would then give

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

Rearranging this formula enables the theoretical value for X_{pr} to be calculated:

$$X_{pr} = \frac{X_{BOF} - \dfrac{Scrap_{BOF}}{Scrap_{re}} X_{re}}{1 - \dfrac{Scrap_{BOF}}{Scrap_{re}}}$$

Annex B
(informative)

Example of LCI result reporting

Examples are given in Tables B.1, B.2, B.3 and B.4.

Table B.1 — LCI result reporting document example 1

<table>
<tr><th colspan="5">Inputs (mass, kg)</th></tr>
<tr><th rowspan="3"></th><th colspan="3">Components of LCI for steel products with allocation for scrap recycling</th><th rowspan="3">A+B1+B2: LCI with allocation for scrap</th></tr>
<tr><th rowspan="2">A: Cradle to gate LCI without allocation for scrap input</th><th colspan="2">B: Allocation for scrap recycling</th></tr>
<tr><th>B1: LCI for scrap consumed in the steel making process</th><th>B2: LCI for scrap recovered for recycling</th></tr>
<tr><td>Carbon dioxide</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Crude oil (resource)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dolomite</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ferrous scrap</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hard coal (resource)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Iron ore</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lignite (resource)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Limestone (calcium carbonate)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Natural gas (resource)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tin ore</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Uranium (resource)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Water</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Zinc ore</td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="5">Emissions to air (mass, g)</th></tr>
<tr><th rowspan="3"></th><th colspan="3">Components of LCI for steel products with allocation for scrap recycling</th><th rowspan="3">A+B1+B2: LCI with allocation for scrap</th></tr>
<tr><th rowspan="2">A: Cradle to gate LCI without allocation for scrap input</th><th colspan="2">B: Allocation for scrap recycling</th></tr>
<tr><th>B1: LCI for scrap consumed in the steel making process</th><th>B2: LCI for scrap recovered for recycling</th></tr>
<tr><td>Carbon dioxide</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Methane</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nitrous oxide (laughing gas)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sulfur dioxide</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nitrogen dioxide</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nitrogen oxides</td><td></td><td></td><td></td><td></td></tr>
</table>

Table B.1 *(continued)*

NMVOC (unspecified) non-methane volatile organic compounds				
Particles to air				
Carbon monoxide				
Hydrogen chloride				
Hydrogen sulphide				
Cadmium (+II)				
Lead (+II)				
Mercury (+II)				
Chromium (total)				
Dioxins (unspec.)				
Emissions to fresh water (mass, g)				
	Components of LCI for steel products with allocation for scrap recycling			**A+B1+B2: LCI with allocation for scrap**
	A: Cradle to gate LCI without allocation for scrap input	**B: Allocation for scrap recycling**		
		B1: LCI for scrap consumed in the steel making process	**B2: LCI for scrap recovered for recycling**	
Cadmium (+II)				
Lead (+II)				
Nickel (+II)				
Chromium (total)				
Iron				
Zinc (+II)				
Ammonia (NH4+, NH3, as N)				
Phosphate				
Phosphorus				
Nitrogenous matter (unspecified, as N)				
Biological oxygen demand (BOD)				
Chemical oxygen demand (COD)				
Solids (dissolved)				

Table B.2 — LCI result reporting document example 2

Inputs (mass, kg)				
	Components of LCI for steel products with allocation for scrap recycling			
	A: Cradle to gate LCI without allocation for scrap input	**B: Allocation for scrap recycling**		
		B1: LCI for scrap consumed in the steel making process	**B2: LCI for scrap recovered for recycling**	
Carbon dioxide		ND	ND	ND
Crude oil (resource)		ND	ND	ND
Dolomite		ND	ND	ND
Ferrous scrap		ND	ND	ND
Hard coal (resource)		ND	ND	ND
Iron ore		ND	ND	ND
Lignite (resource)		ND	ND	ND
Limestone (calcium carbonate)		ND	ND	ND
Natural gas (resource)		ND	ND	ND
Tin ore		ND	ND	ND
Uranium (resource)		ND	ND	ND
Water		ND	ND	ND
Zinc ore		ND	ND	ND
Emissions to air (mass, g)				
	Components of LCI for steel products with allocation for scrap recycling			
	A: Cradle to gate LCI without allocation for scrap input	**B: Allocation for scrap recycling**		
		B1: LCI for scrap consumed in the steel making process	**B2: LCI for scrap recovered for recycling**	
Carbon dioxide		ND	ND	ND
Methane		ND	ND	ND
Nitrous oxide (laughing gas)		ND	ND	ND
Sulfur dioxide		ND	ND	ND
Nitrogen dioxide		ND	ND	ND
Nitrogen oxides		ND	ND	ND
NMVOC (unspecified) non-methane volatile organic compounds		ND	ND	ND
Particles to air		ND	ND	ND
Carbon monoxide		ND	ND	ND
Hydrogen chloride		ND	ND	ND
Hydrogen sulphide		ND	ND	ND
Cadmium (+II)		ND	ND	ND
Lead (+II)		ND	ND	ND
Mercury (+II)		ND	ND	ND
Chromium (total)		ND	ND	ND

Table B.2 *(continued)*

Dioxins (unspec.)		ND	ND	ND
Emissions to fresh water (mass, g)				
	Components of LCI for steel products with allocation for scrap recycling			**A+B1+B2: LCI with allocation for scrap**
	A: Cradle to gate LCI without allocation for scrap input	**B: Allocation for scrap recycling**		
		B1: LCI for scrap consumed in the steel making process	**B2: LCI for scrap recoverered for recycling**	
Cadmium (+II)		ND	ND	ND
Lead (+II)		ND	ND	ND
Nickel (+II)		ND	ND	ND
Chromium (total)		ND	ND	ND
Iron		ND	ND	ND
Zinc (+II)		ND	ND	ND
Ammonia (NH4+, NH3, as N)		ND	ND	ND
Phosphate		ND	ND	ND
Phosphorus		ND	ND	ND
Nitrogenous matter (unspecified, as N)		ND	ND	ND
Biological oxygen demand (BOD)		ND	ND	ND
Chemical oxygen demand (COD)		ND	ND	ND
Solids (dissolved)		ND	ND	ND
Key ND = not declared.				

Table B.3 — LCI result reporting document example 3

Inputs (mass, kg)		**No allocation for scrap burdens and credits applied. B1, B2 and LCI including scrap allocation not declared**
	A: Cradle to gate LCI without allocation for scrap input	
Carbon dioxide		
Crude oil (resource)		
Dolomite		
Ferrous scrap		
Hard coal (resource)		
Iron ore		
Lignite (resource)		
Limestone (calcium carbonate)		
Natural gas (resource)		
Tin ore		
Uranium (resource)		
Water		
Zinc ore		

Table B.3 *(continued)*

Emissions to air (mass, g)		
	A: Cradle to gate LCI without allocation for scrap input	
Carbon dioxide		
Methane		
Nitrous oxide (laughing gas)		
Sulfur dioxide		
Nitrogen dioxide		
Nitrogen oxides		
NMVOC (unspecified) non-methane volatile organic compounds		
Particles to air		
Carbon monoxide		
Hydrogen chloride		
Hydrogen sulphide		
Cadmium (+II)		
Lead (+II)		
Mercury (+II)		
Chromium (total)		
Dioxins (unspec.)		
Emissions to fresh water (mass, g)		
	A: Cradle to gate LCI without allocation for scrap input	
Cadmium (+II)		
Lead (+II)		
Nickel (+II)		
Chromium (total)		
Iron		
Zinc (+II)		
Ammonia (NH4+, NH3, as N)		
Phosphate		
Phosphorus		
Nitrogenous matter (unspecified, as N)		
Biological oxygen demand (BOD)		
Chemical oxygen demand (COD)		
Solids (dissolved)		

Table B.4 — Example of reporting document for information along with the LCI results

Product				
Product details (function and functional unit)				
The reference year				
Geographical information (region, country, company)				
Practitioner				
Details of data for scrap allocation				
	Used data	Data source		
Scrap recycling rate				
X_{re}				
X_{pr}				
y (yield)				
Details of data for calculation				
Electricity grid				
Alternative energy for process gas				

Annex C
(informative)

Example uses of co-products outside of the system boundary

Table C.1 provides some examples of uses of co-products of the steel production system outside of the system boundary. Data should be sourced from appropriate sources.

Table C.1 — Example uses of co-products outside of the system boundary

Steel co-product	Co-product function	Avoided production
Blast furnace slag, basic oxygen furnace slag, electric arc furnace slag	Cement or clinker production	0,9 tonne per tonne of cement. Portland cement (CEM I)
	Aggregate or roadstone	Gravel production
	Fertiliser	Lime production
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
	Electricity production	1MJ gas = 0,365 MJ electricity
Electric arc furnace dust	Zinc production	1 kg dust = 0,5 kg Zinc
Electricity from energy recovery	Electricity production	Electricity production
Steam from energy recovery	Heat generation	Steam production from natural gas 85 % efficiency
Hot water from energy recovery	Heat generation	Steam production from natural gas 85 % efficiency
Ammonia	Any ammonia application	Ammonia production
Ammonium sulfate	Any ammonium sulfate application	Ammonium sulfate production
Benzene	Any benzene application	Benzene production based on different technologies
BTX	Any BTX application	Benzene production based on different technologies
Scales	Metallurgical input to steelmaking	Iron ore extraction
Sulphuric acid	Any sulphuric acid application	Sulphuric acid production
Tar	Any tar application	Bitumen production
Used oil	Heat generation	Coal, heavy fuel oil, light fuel oil or natural gas
Zinc	Any zinc application	Zinc production
Zinc dust	Any zinc application	Zinc production
Electrode	Electrode making	Electrode mix

Annex D
(informative)

Comparison among standards

While this document does not follow the modularity principle used in ISO 21930:2017 and EN 15804:2012, Table D.1 demonstrates how the LCI data obtained using this document may be applied to provide data for construction EPD studies following ISO 21930:2017 and EN 15804:2012.

Table D.1 — Comparison table

<table>
<tr><th>Standard</th><th>Cradle to gate steel production</th><th colspan="2">Allocation for scrap recycling</th><th>Aggregated reporting</th></tr>
<tr><td rowspan="2">This document</td><td colspan="3">Components of LCI for steel products with allocation for scrap recycling</td><td rowspan="2">LCI for steel products with provision for scrap recycling
(Sum of three columns to the left)</td></tr>
<tr><td>Cradle to gate LCI without allocation for scrap input</td><td>LCI for scrap consumed in the steel making process</td><td>LCI for scrap recovered for recycling</td></tr>
<tr><td>ISO 21930: 2017</td><td>A1~3
PRODUCTION
Stage
A1 Extraction and upstream
A2 Transport to factory
A3 Manufacturing</td><td colspan="2">D
Potential net benefits from future reuse, recycling and/or energy recovery beyond the system boundary</td><td>—</td></tr>
<tr><td>EN 15804: 2012</td><td>A1~3
PRODUCTION Stage
A1 Raw material supply
A2 Transport
A3 Manufacturing</td><td colspan="2">D
Benefits and loads beyond the system boundary
Reuse–recovery recycling potential</td><td>—</td></tr>
</table>

Annex E
(informative)

Details for calculating the recycling rate

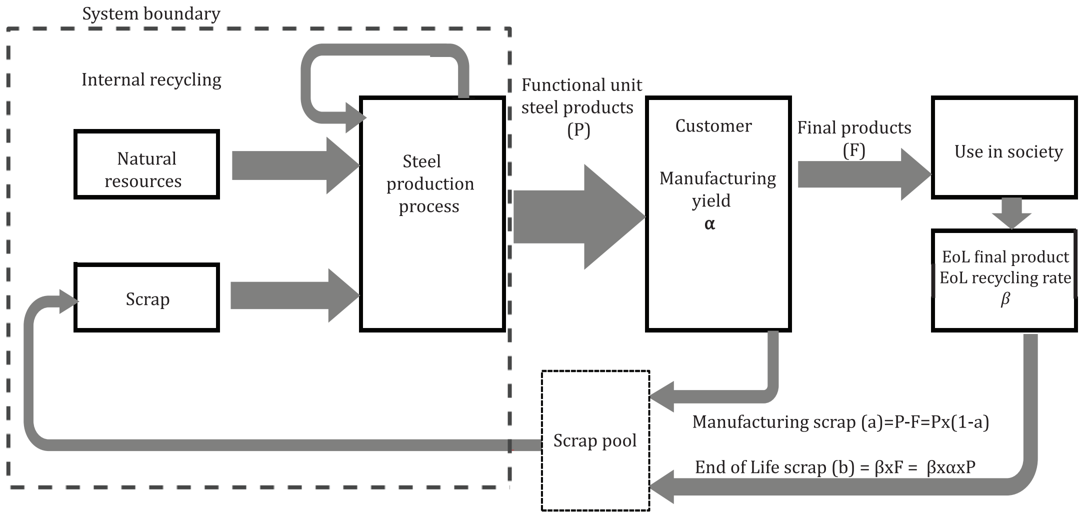
Recycling rate, R, is defined by Formula (E.1):

$$R = (a + b) / P \tag{E.1}$$

where

a	is the mass of manufacturing scrap recycled;
b	is the mass of end of life scrap recycled;
P	is the mass of steel products shipped out of the gate.

Figure E.1 provides a description of the recycling rate:



Key

a	is the mass of manufacturing scrap recycled;
b	is the mass of end of life scrap recycled;
α	is the manufacturing yield;
β	is the end of life recycling rate.

Figure E.1 — Description of recycling rate

Accordingly,

$$\begin{aligned} R &= (a+b)/P \\ &= 1-\alpha+\alpha\beta \\ &= 1-(1-\beta)\times\alpha \end{aligned} \qquad (E.2)$$

Formula (E.2) is based on the following definitions and assumptions.

a) Manufacturing yield is the ratio of the mass of steel contained in the final products to the total mass of steel products used for manufacturing of the final product.

b) End of life recycling rate is the ratio of the mass of steel scrap recovered and recycled at the end of life of a final product to the total mass of steel products contained in the final product.

c) The recycling rate of manufacturing scrap is 100 %.

Because the product life is different for every final product, it is considered difficult for steel companies to measure for themselves the end of life recycling rate. On the other side, there are national, regional and world level statistics. Data on the end of life recycling rate may be obtained from the following sources, for example:

— recycling rate for each final product (e.g. recycling rate of steel cans);

— estimates from public data of final products (car recycling rate).

Manufacturing yield can be calculated from the following information:

— the mass of manufacturing scrap recycled (a);

— the mass of steel products shipped out of the gate (P).

$$\alpha = 1 - a/P$$

However, there may be cases where the mass of manufacturing scrap cannot be estimated from available statistics. In such case, the end of life recycling rate may be used as the recycling rate. It shall be noted that this recycling rate is a lower estimate compared to the true recycling rate.

Annex F
(informative)

LCI calculations for electricity and steam

F.1 Electricity

Electricity is supplied from the external power grid and/or from the in-house power plants using process gases and/or recovered energy.

The upstream burden of electricity purchased from the grid depends on the fuel mix used by the electricity generator and/or provider to the grid. On the other hand, the burden of electricity generated within the steelworks using process gases or fossil fuels depends on the combination of those fuels. Moreover, energy sources for electricity generation from recovered energy from steel production processes are recorded as a burden and it is impossible to separate them on a process level. Therefore, system expansion should be applied to the recovered energy which is exported from each process. In the situation where the electricity is exported outside of the steelworks, the alternative system should be the grid electricity. Where the electricity is used inside the steelworks but outside of the scope of the study, the alternative system should be the in-house power generation.

Therefore, the LCI of electricity consumed in the steel production processes should reflect the power source configuration.

The average LCI of electricity, $E_{average}$, is calculated according to Formula (F.1):

$$E_{average} = \frac{E1 \times E_{grid} + E2 \times E_{onsite} + E3 \times E_{recovered}}{E_{total}} \tag{F.1}$$

where

E_{grid}	is the grid power supply;
E_{onsite}	is the on-site power generation;
$E_{recovered}$	is the reovered energy power generation;
E_{total}	is the total power consumption.

Where E1, E2 and E3 are defined as follows:

— **E1 LCI of electricity from the grid**

National or regional data should be used for grid electricity, in order to represent the actual supply as closely as possible. The choice of electricity grid mix (either national or regional) should be clearly stated.

— **E2 LCI of electricity from in-house (on-site) power plant**

The LCI should be derived from measured data, such as fuel configuration.

— **E3 LCI of electricity from energy recovery**

The LCI of the electricity from energy recovered is considered the same as the LCI for grid (E1) or in-house power generation (E2). This should be based on system expansion with the most scientifically suitable replaced electricity LCI.

F.2 Steam

Steam can be generated using process gas in addition to the supply from the outside of the system boundary. The LCI of the consumed steam should reflect the steam source configuration.

The average steam LCI, $S_{average}$, is calculated according to Formula (F.2):

$$S_{average} = \frac{S1 \times S_{grid} + S2 \times S_{onsite} + S3 \times S_{recovered}}{S_{total}} \tag{F.2}$$

where

S_{grid}	is the steam supply from outside;
S_{onsite}	is the on-site steam generation;
$S_{recovered}$	is the steam generated from energy recovery;
S_{total}	is the total steam consumption.

Where S1, S2 and S3 are defined as follows:

— **S1 LCI of steam supply from outside**

The LCI offered from the supplier should be used. If not available, data can be used from LCA databases.

— **S2 LCI of in-house (on-site) steam generation**

The LCI should be derived from measured fuel configuration.

— **S3 LCI of steam generation from energy recovery**

In the case that steam is supplied from outside the system boundary, the LCI of the steam generation from energy recovery should be considered to be the same value (S1) based on the system expansion. In the case that no steam is supplied from outside the system boundary, the LCI of the steam generation from energy recovery should be considered to be the same as in-house (on-site) steam generation (S2).

Bibliography

[1] ISO 4948-1:1982, *Steels — Classification — Part 1: Classification of steels into unalloyed and alloy steels based on chemical composition*

[2] ISO/TS 18110:2015, *Nanotechnologies — Vocabularies for science, technology and innovation indicators*

[3] ISO 21930:2017, *Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services*

[4] EN 15804:2012, *Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products*

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