Guidance on methodologies for modelling reuse and remanufacture in LCA Studies

worldsteel ASSOCIATION

31 January 2024 | Task Force on Reuse and Remanufacturing

Table of contents

1. Introduction

The World Steel Association (worldsteel) has developed a Life Cycle Inventory (LCI) database of steel products, which is intended for use in life cycle assessment (LCA) studies involving steel products [1]. Typically, this means studies where all aspects of the product life cycle are considered from raw material extraction through to production, manufacture, use, reuse & remanufacturing and, finally, recycling as shown in Figure 1.

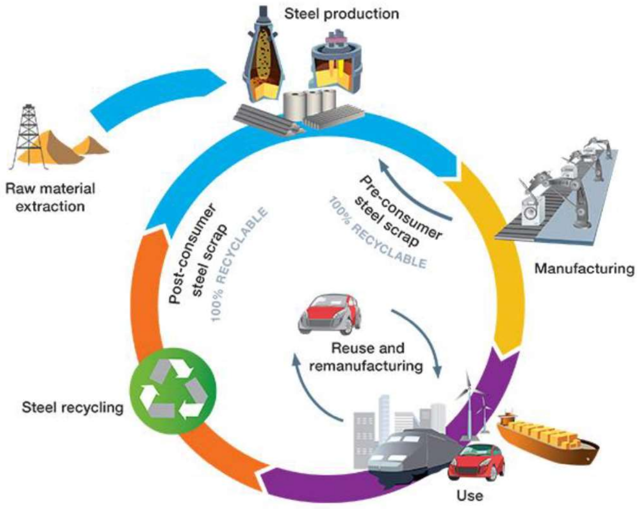


Figure 1: Reuse and Remanufacturing in the context of the life cycle of steel

This document provides guidance for modelling aspects of reuse and remanufacture within the context of the life cycle of a product that uses steel. Whilst some specific approaches are recommended, based on the type of study being undertaken, this document is only advisory and other alternative methods are valid depending on the goals and scope of the LCA study.

2. Defining end-of-life options

When describing the fate of a steel product once it has been used, it is first necessary to define some terms associated with different end-of-life scenarios. These provide specific context for understanding the applicability of different methodologies. The end-of-life scenarios considered are defined as follows:

Reuse

Reuse is using an object or 'simple' material again, either for its original purpose or for a similar purpose, without significantly altering the physical form of the object or material. Because of its durability, steel can be reused or repurposed in many ways, with or without remanufacturing. This already occurs with automotive components, buildings, train rails and many other applications. Reuse of steel is not limited to its original application; repurposing dates back to ancient times ('turning swords into ploughshares'). Reuse occurs in sectors where it is technically possible without compromising safety, mechanical properties and/or warranties. Rates of reuse will increase as eco-design, design for reuse and recycling, and resource efficiency become more commonplace.

Remanufacture

Many steel products, such as automotive engines and wind turbines, can be remanufactured for reuse to take advantage of the durability of steel components. Remanufacturing restores durable used products to like-new condition [2]. A remanufactured product can be a complex assembly of parts & materials, some of which will be new parts and some reused parts. Remanufacture differs from repair, which is a process limited to making the product operational - generally by the rectification of a single fault – as opposed to thorough disassembly and restoration of as-new tolerances and performance, with the possible inclusion of new parts. [3]

Remanufacture can be considered a sophisticated form of reuse. In practice it differs simply in extent and rigour, the difference manifesting as higher or lower material and energy inputs, and life expectancy. and therefore methodologically, remanufacture can be treated in a similar manner to reuse: For this reason, the remaining part of this guidance will refer to the term 'reuse' rather than 'reuse and remanufacture'. This is purely for simplification, but the methods apply equally to remanufacture by simply substituting the word 'reuse' with 'remanufacture'.

Recycle

Recycling has been carried out in the steel industry since steel was first made. Steel is 100% recyclable and can be recycled over and over again to create new steel products in a closed material loop. Recycling involves melting steel scrap such that it can be converted into a completely new steel product. Recycled steel maintains the inherent properties of the original steel. The magnetic property of steel ensures easy and affordable recovery for recycling from almost any waste stream while the high value of steel scrap guarantees the economic viability of recycling. Today, steel is the most recycled material in the world: over 650 Mt of steel are recycled annually, including pre- and post-consumer scrap [4].

3. Rationale for a methodology for accounting for reuse

As part of the worldsteel LCI study, worldsteel has provided guidance on how to account for recycling steel from a product at the end of its life. The methodology developed for treating recycling follows ISO14044: 2006 [5], which sets out allocation procedures for reuse and recycling.

The worldsteel guidance focuses on a methodology for accounting for recycling; there are a number of key principles that underpin this methodology:

- The inputs and outputs from the product system should be treated equally, applying consistent allocation procedures to each.
- Steel is recycled in a closed material loop such that the inherent properties of the primary and secondary products are equivalent. In other words, the production of secondary material displaces primary production.
- Steel can be recycled repeatedly whilst maintaining its inherent properties.

- The demand for steel scrap exceeds the availability of scrap.

One approach would be to apply the same principles to reuse as for recycling. However, there are some features of reuse, which differ from recycling:

- Reuse does not involve melting the product in a steel manufacturing facility at end-of-life. Recycling involves melting steel scrap such that it can be converted into a completely new steel product. As a consequence, steel can be recycled repeatedly. This is substantially different from reuse because the product may only be suitable for reuse once or twice depending on the product application, the loss of functionality or the amount of refurbishment required.

- Reuse is not currently limited by the supply of end-of-life products, which is the limiting factor for increasing the amount of steel that can be recycled. The recycling rates for steel products are already high, and as has already been indicated, steel is the most recycled material in the world. In contrast, rates of reuse are typically lower. The limitations on the amount of steel that is currently reused or remanufactured are associated with the demand for reused material, where designs specifying the use of reused products or design for ease of reuse is not normally part of the design brief. Reuse can also be limited by the physical dimensions of the steel component or its properties, unlike recycling, which impacts on demand. As a consequence, further design incentives may be required to increase the rate of reuse which, in general, has relatively high barriers to market entry compared to the manufacture of new products.

In addition to the differences in processing and the current limitations on the demand for reused products, a further consideration is the connection between recycling and reuse. For example, products which are no longer suitable for reuse or remanufacture will ultimately be recycled and this will result in a valuable output of steel scrap. Equally, reused and or remanufactured steel products will contain some input of steel scrap originating from when the component or product was first manufactured. Figure 2 shows how reuse is connected with recycling.

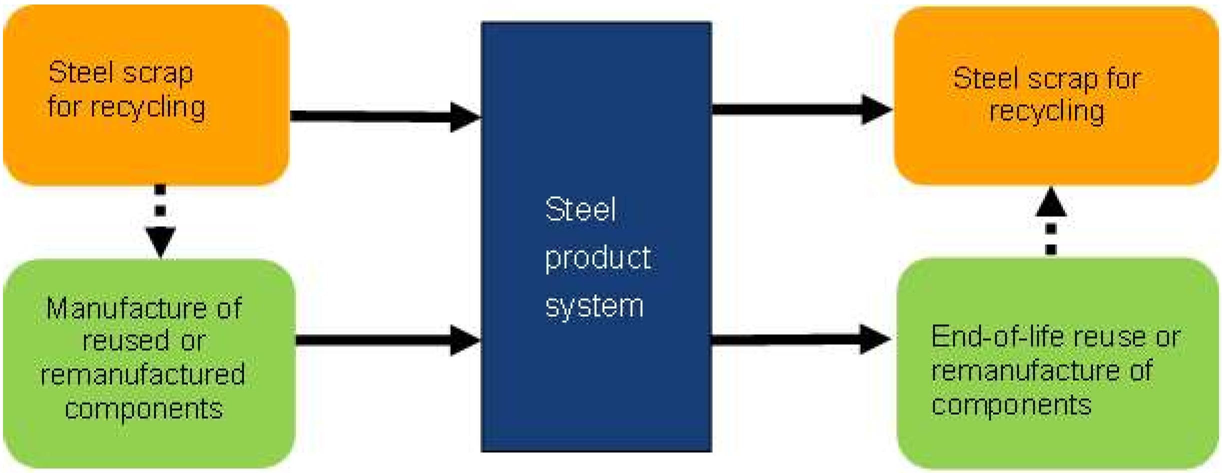


Figure 2: The inputs and outputs of recycled and reused steel, which can be associated with the life cycle of a steel product system. The dashed lines show the inputs and outputs of steel scrap that arise from reused products.

Accounting for flows of both recycled and reused materials, which have different characteristics, has been integrated into the methods described in this document.

4. Approaches for accounting for reuse

Generally, methods for accounting for reuse and/or remanufacture are not considered in as much detail as the topic of recycling in standards and existing methods. Within the standards, methods for accounting for recycling are also considered to have relevance in the context of reuse:

The standards where reuse is considered are:

- ISO 21930: 2017 Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services [6]
- EN 15804: 2012 + A2:2019 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products [7]
- European Commission, PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, December 2017 [8].

Approaches that have been considered in developing this guidance fall into four main areas:

- Cut-off approach (100-0)

The cut-off approach considers the impacts associated with the product system and does not consider loads or benefits associated with either a previous life or the next life of the product. From a policy perspective, it rewards the specification of products which have previously been used rather than the design of products, which have the potential to be reused or remanufactured at end-of-life. For example, it would incentivise reused content rather than incentivise the use of structures, which are readily disassembled for reuse, or more durable components, which can be remanufactured.

- End-of-life approach (0-100)

The end-of-life approach takes a holistic approach and considers loads or benefits associated with reuse which occur either in a previous life or the next life of the product. It differs from the cut-off approach as it rewards the design of products which are reused or remanufactured at end-of-life rather than rewarding design for reused content. It incentivises the use of structures which are easily disassembled for reuse or more durable components which can be remanufactured. The end of life approach is currently widely used to model the life cycle environmental benefits of steel recycling and has been adopted as an international standard (ISO 20915: 2018 Life cycle inventory calculation methodology for steel products) [9]. However, it may have less relevance in the context of reuse as in some scenarios the reuse rate may be less certain than the recycling rate.

- Market based approach

The market-based approach considers the ability of the market to supply a reused or remanufactured product as compared to the demand for reused or remanufactured product. If the demand is relatively low as compared to supply, then this approach incentivises the uptake of reused products by applying a market allocation factor (A) which is high. Conversely, if demand is high as compared to supply, design for reuse at end-of-life is incentivised. Such an approach has been proposed in the European Commission's product environmental footprint guidance document [8].

- Multiple reuse approach (n lives)

Multiple reuses considers the number of times a product is reused or remanufactured and the impacts associated with manufacture and recycling are shared between the number of times the product is used. This approach incentivises increasing the life span of a steel product by either reusing or remanufacturing existing products or designing products which can be reused or remanufactured multiple times.

5. Applicability of a methodology as determined by the goal and scope of the study

In an LCA study which is being carried out in accordance with ISO14044: 2006, one of the first steps is to define the goal and scope of the study. This includes the definition of a functional unit and a consideration of intended purpose of the study. The goal and scope of the study determines a number of factors associated with the study including the extent of data collection, modelling and the range of environmental impacts to be considered. It also influences the choice of methods for dealing with issues associated with allocation.

- The guidance provided in this document includes a number of different approaches for accounting for reuse. The applicability of each of these methods is described in terms of the goal and scope of the study. Some examples of studies where it might be necessary to evaluate reuse include:
- The assessment of a product for the purpose of environmental labelling (EPDs).
- A comparative assessment of different design options to assess which has the lowest environmental impact (a remanufactured component vs. a less durable single use design).
- The assessment of a project where the end-user wishes to specify reused components or include features, which facilitate reuse at end-of-life (e.g. steel components for a building or new infrastructure).
- The assessment of a complex assembly of parts, such as a motor, where some parts may be reused and new parts added in order to better understand the life cycle environmental benefits of reuse and identify environmental hot spots.

6. Methods for accounting for reuse

The guidance provided here focuses on three methods for accounting for reuse. The first method is an end-of-life approach which incentivises the design for reuse. The second approach is based on a market allocation factor, which reflects the emerging market for reused products. The third approach is based on the concept of multiple reuse, which reflects the number of times a steel product could be reused or remanufactured.

The cut-off method is discussed under the market allocation-based factor as it is similar to the case where there is no market for the reused product at end of life. Use of the functional transfer method was also considered, and showed some promise, but since this approach has not been widely adopted and tested for recycling, it has not been described in detail in this guidance document.

In all the of the methods described the quality of the reused product is assumed to be similar to the original product and that refurbishment restores the product to a nearly new condition. If the properties of the reused product are significantly reduced, then it is recommended that an additional quality factor is considered to attribute impacts between the original product and the reused product. Methods for assessing quality and applying a quality correction factor could include, for example, a consideration of the life expectancy of the reused product vs. the new product, or a reduction in the relative performance/efficiency of the reused product vs. the new product. The number times the product could technically be reused may also be an indicator of quality although in this case a separate method for handling multiple reuse has been provided in this guidance.

Within each method, as well as describing how to account for reuse there is some additional guidance on how to model steel scrap flows that either originate from the manufacture of the first product or are produced when the product can no longer be remanufactured or reused at end-of-life. This guidance aligns with the worldsteel methodology for accounting for recycling [1].

In the case of complex products, where these are assembled from multiple components, the methods contained in this guidance document can be applied using one the following approaches:

1. Assessing multiple components, as a group, where they are manufactured from the same materials and have identical reuse parameters (e.g. rates of reuse and/or recycling)
2. Assessing each component individually and summing the total results to obtain the overall impact of the complex product. This is for the case where each component has different reuse parameters or has different manufacturing impacts.

These two approaches are shown schematically in Figure 3

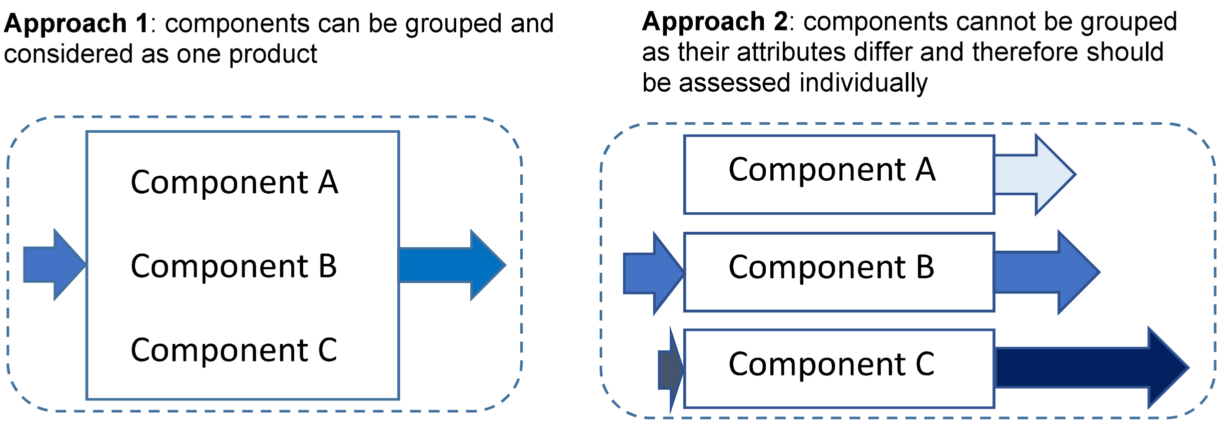


Figure 3: Approaches for modelling the reuse of a complex product consisting of an assembly of components.

Before explaining the detail of these methods some common terminology is defined.

6.1. Terminology

The parameters used in the methods build upon those that are already contained in Appendix 2 of the worldsteel LCI methodology report and includes some additional parameters relating to reuse. The full list of parameters that are defined for use in the different methods are as follows:

Term	Definition
X	Refers to any LCI input or output parameter e.g. natural gas, CO_2, water, limestone etc.
Parameters relating to steel production and recycling	
X_m	LCI for the manufacture of the original product, which contains primary and secondary steel.
X_{re}	LCI for 100% secondary steel production from scrap in the EAF, assuming 100% scrap input
X_{pr}	LCI for theoretical 100% primary steel production, from the BOF route, assuming 0% scrap input
X_{sc}	LCI of scrap either as an input or an output
Y	The process yield (or efficiency) of the EAF process, It is the ratio of steel output to scrap input (more than 1kg scrap is required to produce 1kg steel)
R_1	The amount of scrap used in the steelmaking process to make a specific product. This is also referred to as the steel scrap input (defined as S in the worldsteel recycling methodology).
R_2	The fraction of steel recovered as scrap after the lifetime of a steel product. This is also referred to as the end of life recovery rate or recycling rate (RR).
Parameters relating to steel reuse	
X_{refurb}	LCI for 100% refurbishment for reuse or remanufacture of a steel product.
$X_{inc\ recycling}$	Cradle to gate LCI, including the end of life impacts of recycling, for a product which is suitable for reuse or remanufacture. This is also referred to as the $LCI_{Including\ EoI}$ in the worldsteel guidance on recycling.
Z	The yield (or efficiency) of the refurbishment process relating to reuse or remanufacture. This is to account for products that are damaged or identified as unusable during the remanufacturing or refurbishment process.
n	Number of uses of the product before recycling. For example, if the product can be used twice with a refurbishment step after the first life then n=2.
R_{u1}	The amount of a previously used product that is taken as an input to the reused or remanufactured product.
R_{u2}	The fraction of steel recovered during the lifetime of a steel product, including end-of-life, that is either reused or remanufactured rather than recycled.
R^*_1	The amount of scrap, used in the steelmaking process, which is used in the manufacture of the product which is reused or remanufactured.
R^*_2	The fraction of steel recovered as scrap after the product is no longer suitable for reuse or remanufacture. This includes any scrap that is generated during the refurbishment or remanufacturing process.
A_u	Allocation factor of burdens and credits between supplier and user of reused materials.

Table 1: A description of the parameters which are used to evaluate recycling and reuse.

Figure 4 shows how the flows of materials defined in Table 1 map onto the product life cycle.

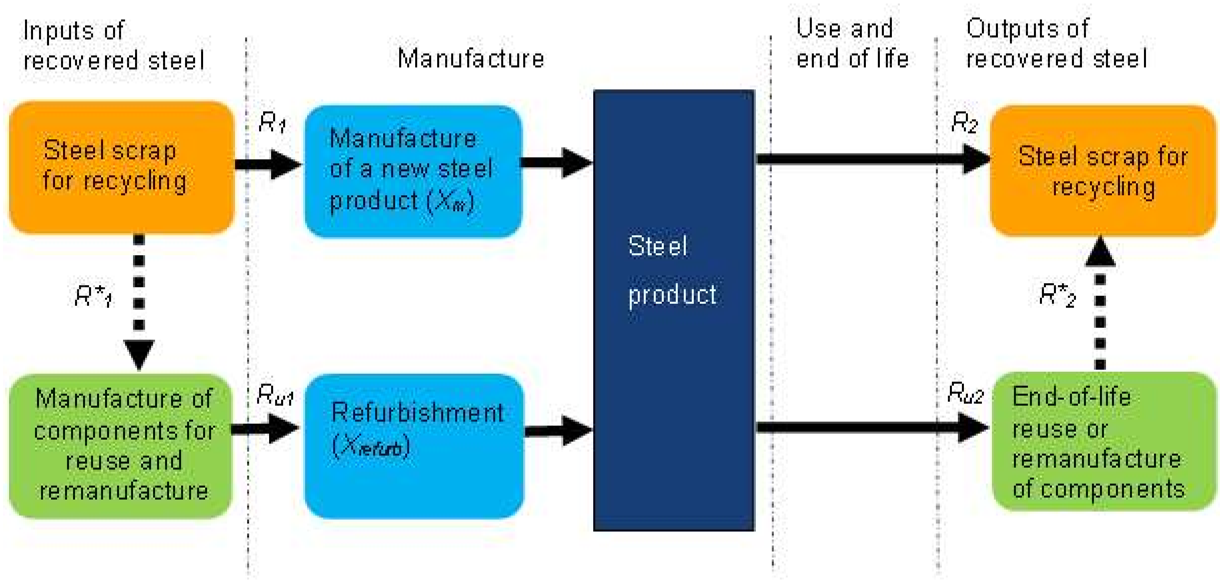


Figure 4: The physical flows of reused and recycled materials across the product life cycle.

6.2. End-of-Life method for accounting for reuse

The end-of-life approach is also known as the 0:100 method and how this can be used to evaluate reuse in LCA studies involving steel products is described in the following sections:

6.2.1. The LCI for the manufacture and end of life recycling of a product which is suitable for reuse Xinc recycling

Before considering reuse the first aspect of the methodology is to account for recycling. Accounting for recycling is necessary because once the product is no longer suitable for reuse or remanufacture it will be recycled. The LCI for a product including recycling $X_{inc\ recycling}$ is calculated using the steel scrap LCI (X_{sc}), the proportion of the product that can be recycled at end of life (R^*_2), once it is no longer feasible to reuse or remanufacture the product at the end of life, and the amount of scrap used in the initial steelmaking process (R^*_1):

$$X_{inc\ reycling} = X_m - (R_2^* - R_1^*)X_{sc} \qquad (1)$$

This follows the worldsteel method for recycling where steel scrap is assigned an LCI (X_{sc}) and a recycling credit is calculated based on the net amount of scrap:

$$X_{sc} = (X_{pr} - X_{re})Y \qquad (2)$$

Any losses that occur through the recycling process are expressed in terms of a scrap processing yield (Y).

6.2.2. The LCI for a product which can be refurbished for reuse

In order to account for reuse, in a similar manner to recycling, the end of life method assigns a value to the use of products, which can be refurbished and credits for the reuse or remanufacture of products at end-of-life. The value of reuse is related to the LCI for the product, after accounting for recycling ($X_{inc\ recycling}$), minus the burden associated with refurbishment (X_{refrub}) , multiplied by the yield of the refurbishment process (Z).

$$LCI\ for\ a\ product\ that\ can\ be\ refurbished\ = (X_{inc\ recycling} - \ X_{refurb})Z \qquad (3)$$

$X_{inc\ recycling}$ = LCI for the manufacture of the initial product, which contains primary and secondary steel. The LCI is cradle to gate including the end-of-life aspects relating to recycling (as described in section 6.2.2)

X_{refurb} = LCI for 100% refurbishment for reuse or remanufacture of a steel product.

Z = The yield (or efficiency) of the refurbishment process relating to reuse or remanufacture. This is to account for products that are damaged or identified as unusable during the refurbishment process or parts that need to be replaced.

6.2.3. Applying the reused and refurbished product LCI burden and credit

To apply the methodology, to account for reuse and refurbishment using the end-of-life method, it is necessary to consider the inputs and outputs of steel scrap and components which are reused or remanufactured. Figure 5 shows the possible inputs and outputs across the complete life cycle of a steel product.

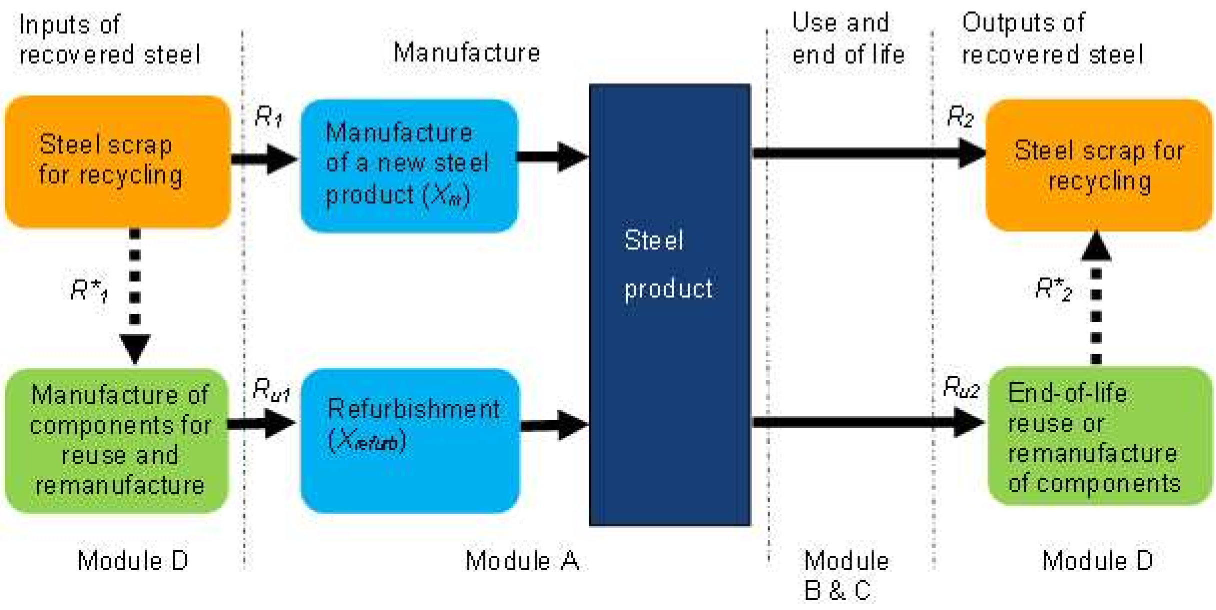


Figure 5: The life cycle of a steel product which is either reused or remanufactured. The dashed lines show the inputs and outputs of steel scrap that arise from the manufacture or end-of-life of reused products.

Figure 5 also shows a product that contains both new components and refurbished components, which after use are either recycled or refurbished for reuse or remanufacture. Examples of such a product could be a building or a vehicle where certain steel components can be refurbished.

To apply the methodology, to account for reuse and refurbishment, both the scrap LCI and the LCI for the product which can be refurbished are included in the calculation of the LCI for the product system.

The scrap LCI (X_{sc}) is used to calculate the burdens and credits associated with the inputs (R_1) and outputs (R_2) of steel scrap for recycling. In addition, for the inputs (R_{u1}) and outputs (R_{u2}) of reused product the:

$$Net\ LCI\ credit\ or\ burden\ related\ to\ recycling\ =\ (R_2 - R_1 +\ (R_{u2} - R_{u1})(R_2^* - R_1^*))X_{sc} \qquad (4)$$

The LCI for the product that is refurbished for reuse is used to calculate the burdens and credits associated with the reused inputs (R_{u1}) and outputs (R_{u2}) of steel components for reuse:

$$Net\ LCI\ credit\ or\ burden\ related\ to\ reuse\ and\ remanfuacture$$

$$= (R_{u2} - R_{u1})(X_{inc\ reycling} - X_{refurb})Z \qquad (5)$$

Thus, the LCI for the product system, from cradle to gate, including end-of-life benefits and burdens, can be calculated as:

$$LCI\ including\ end\ of\ life\ for\ a\ reused\ or\ remanufactured\ product$$

$$= \overbrace{\{(1 - R_{u1}Z)X_m + (R_{u1}Z)X_{refurb}\}}^{Manufacture}$$

$$- \{\underbrace{(R_2 - R_1 + (R_{u2} - R_{u1})(R_2^* - R_1^*))X_{sc}}_{net\ benefit\ of\ end\ of\ life\ recycling} + \underbrace{(R_{u2} - R_{u1})(X_{inc\ reycling} - X_{refurb})Z}_{net\ benefit\ of\ reuse}\} \qquad (6)$$

It is recommended that the end-of-life impacts are reported separately from manufacture, to maximise transparency and to allow the assessment of when different impacts or benefits occur in the life cycle of products.

In the construction sector, standards for environmental product declarations (EPD) categorise the life cycle stages into modules and Figure 5 shows how each stage of the life cycle can be split into the relevant modules (A to D) for the purposes of reporting the results from an LCA study [6,7].

In LCA studies which involve recycling and reuse, credits may also be reported in an aggregated form together with the cradle-to-gate LCI.

6.3. Market-based method for accounting for reuse

The market-based method is similar to the end-of-life method except that the end-of-life burden and credit for reuse is shared between reused content (inputs) and reused outputs by a market allocation factor (A_u). This factor allocates burdens and credits based on the market demand for reused or remanufactured products as compared to the ability of the market to supply these products.

$$LCI\ including\ end\ of\ life\ for\ a\ reused\ or\ remanufactured\ product$$

$$= \overbrace{\{(1 - R_{u1}Z)X_m + (R_{u1}Z)X_{refurb}\}}^{Manufacture}$$

$$- \{\underbrace{(R_2 - R_1 + (R_{u2} - R_{u1})(R_2^* - R_1^*))X_{sc}}_{net\ benefit\ of\ end\ of\ life\ recycling} + \underbrace{(\mathbf{1} - \boldsymbol{A_u})(R_{u2} - R_{u1})(X_{inc\ reycling} - X_{refurb})Z}_{net\ benefit\ of\ reuse}\} \qquad (7)$$

The value of A_u is measured on a scale of 0 (full end-of-life benefit associated with reuse, and no benefit to reused inputs) to 1 (no end-of-life benefit associated with reuse, but full benefit to reused inputs). If A_u is equal to one then there are no credits or burdens associated with reuse at end-of-life and it can be considered to be a cut-off type method for evaluating reuse. In contrast, if A_u is equal to zero then the calculation is equivalent to the end-of-life method, which is described in the previous section and provides a credit for reuse at end-of-life.

One approach for determining A_u would be to consider the relative financial value of the non-reused, end of life product as compared to the new product. If the value is low then this can be an indication that the market is not demanding reused products. However, this could be an oversimplification if the difference in value is driven by other factors beyond market demand such as collection and costs of reuse.

The market for reuse is often not well established and therefore it can be challenging to identify how the market would react to new developments relating to reuse. In these instances, it is recommended that a value of A_u = 0.5 should be used to reflect that there is a need to create a market for reuse and refurbishment by stimulating both the demand for reused goods as well as supply.

6.4. Multiple reuse method

A multiple reuse method considers the number of times (*n*) a product is (re)used before recycling. The burdens for each life cycle are shared equally across *n* life cycles. For example, if a product is only reused once before recycling then burdens from manufacture and end of-life recycling are shared equally between the two product lives. This could also be considered the same as extending the life of the product through reuse. Figure 6 shows the example of a product that is reused a number of times before finally being recycled.

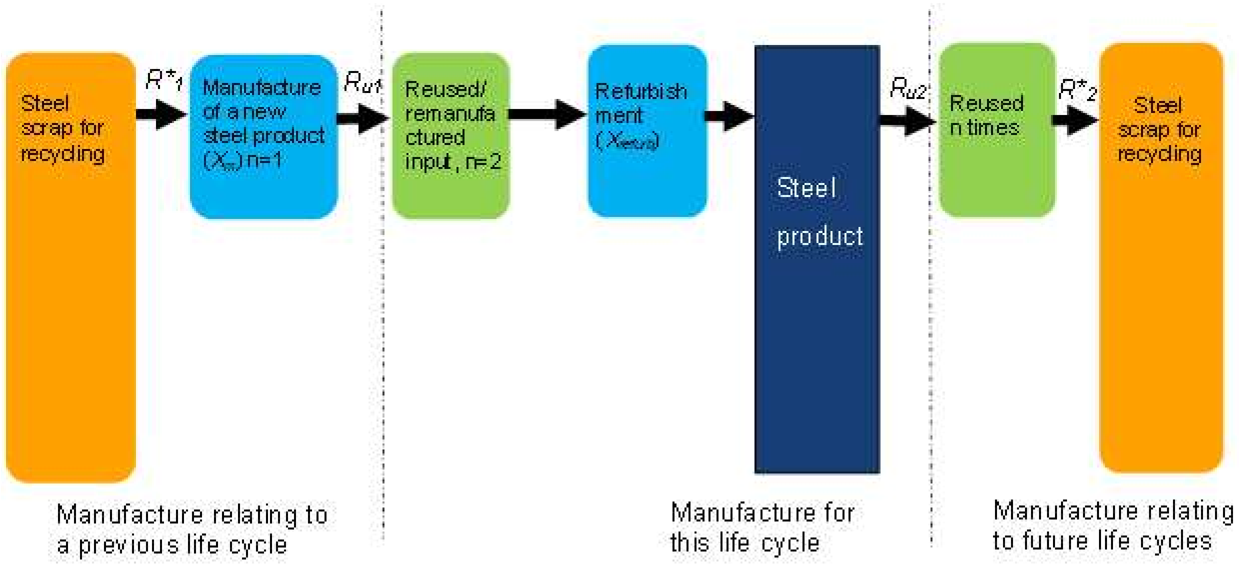


Figure 6: The life cycle of a steel product which is either reused or remanufactured a specific number of times before being recycled.

The details of the multiple reuse method are described in the following sections:

6.4.1. Evaluating the shared impacts over multiple life cycles

Using the multiple reuse method, the total number of times the product is reused or refurbished determines the total refurbishment impact. This is combined with the original manufacturing impacts, associated with the first life, and the total divided by the number of times the product is used (*n*):

$$LCI\ for\ a\ product\ that\ is\ reused\ or\ remanufactured\ = \frac{\left(X_{inc\ reycling} +\ \ (n-1)X_{refurb}\right)}{n} \qquad (8)$$

$X_{inc\ reycling}$ = LCI for the manufacture and end of life recycling of the initial product, which contains primary and secondary steel.

X_{refurb} = LCI for 100% refurbishment for reuse of a steel product.

n = number of uses of the product before recycling.

As the number of times the product is reused increases, the impacts decrease until they approach the level of the impact of refurbishment (X_{refurb}). For simplicity, yield losses occurring during reuse have not been considered and the impacts of recycling have been accounted for in the LCI for the manufacture of the original product. If yield losses occur then this would need to be considered additionally.

6.4.2. The LCI for the manufacture of the initial product accounting for recycling.

The LCI for the manufacture of the initial product ($X_{inc\ reycling}$) also includes end-of-life because the reused or remanufactured product will be recycled once it is no longer suitable for reuse or remanufacture. The value of X_{inc} recycling is calculated using the steel scrap LCI (X_{sc}), the proportion of the product that can be recycled at end of life (R^*_2) once it is no longer feasible to reuse the product at the end of life, and the amount of scrap used in the initial steelmaking process (R^*_1):

$$X_{inc\ recycling} = X_m - (R_2^* - R_1^*)X_{sc} \qquad (9)$$

This follows the worldsteel method for recycling where steel scrap is assigned an LCI (X_{sc}) and a recycling credit is calculated based on the net amount of scrap:

$$X_{sc} = \left(X_{pr} - X_{re}\right)Y \qquad (10)$$

For all the methods described in this guidance, the worldsteel recycling methodology is applied to account for inputs and outputs of steel scrap (Section 6.2.2). This is for the reasons outlined in Section 3.

6.4.3. Applying the multiple reuse method

The multiple reuse methodology can be applied by considering the inputs and outputs of reused and recycled material. Figure 7 shows a product that contains both new components and refurbished components, which after use are either recycled or reused. In the case of reuse this occurs a limited number of times before recycling. This could be a steel component in a building or vehicle, which can be reused once or twice before being recycled.

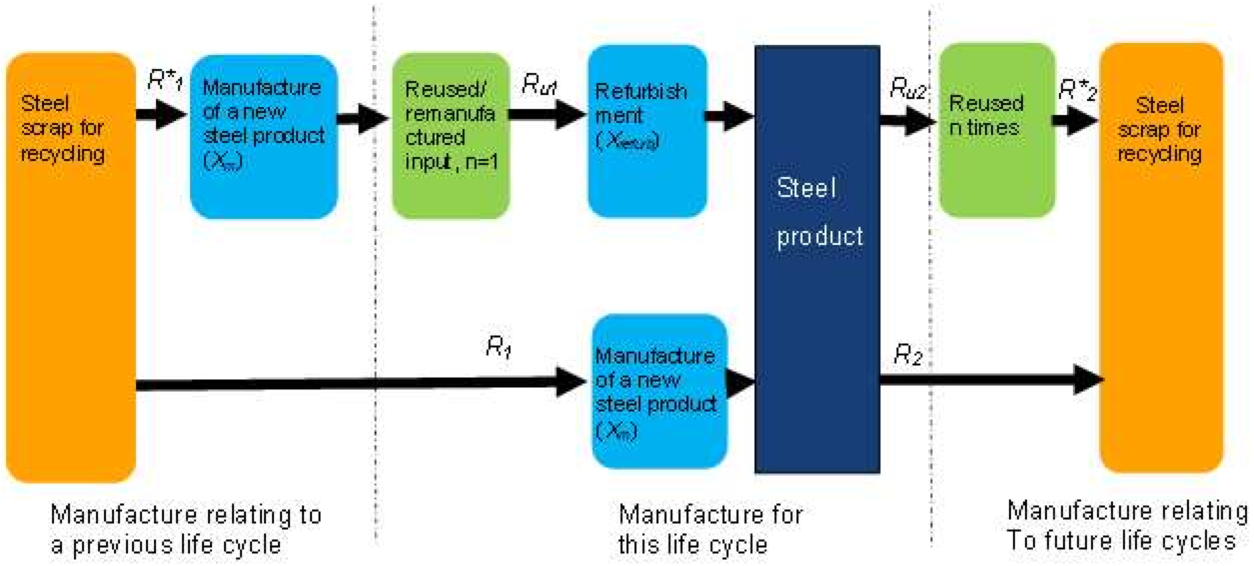


Figure 7: The life cycle of a steel product which contains components that are either reused or remanufactured a specific number of times (n) before being recycled. This product also contains some components which are made from new steel and some which are recycled at end-of-life rather than being refurbished.

The LCI associated with the manufacture of the product, excluding end of life can be calculated as:

$$LCI\ for\ manufacturing = \{(1 - R_{u1}Z)X_m + (R_{u1}Z)X_{refurb}\} \quad (11)$$

The LCI for the product, including the shared benefits for a product which is reused, can be calculated as:

$$LCI\ for\ a\ product\ which\ is\ reused\ or\ remanufactured\ n\ times$$

$$= \frac{\left(X_m - (R_2^* - R_1^*)X_{sc} + (n-1)X_{refurb}\right)}{n} \quad (12)$$

Where a product contains both reused components as well as new components these should be evaluated separately unless the refurbishment impacts at end-of-life for the new components and the inputs/outputs of steel scrap over the product life cycle are identical to the existing components (in other words $R^*_2 = R_2$ and $R^*_1 = R_1$).

In the case where the lifespan of the resused product reduces the number of reuse cycles should be adjusted to account for this reduction in functionality over the life cycle.   For example if the product had three lives but the reduction in lifespan was 50% for every time the product was reused then the value of *n* would be 1.75 as *n*=1+(0.5x1)+(0.5x0.5x1)=1.75

7. Selecting the most appropriate methodology for an LCA study

As has already been discussed in Section 3, there are two significant differences between recycling and reuse (or remanufacture). Firstly, unlike recycling, products are not reused indefinitely and can generally only be reused a limited number of times before being recycled. Secondly, the market for reused and refurbished steel products is less well established than is the case for steel scrap recycling, and consequently demand is limited. These notable differences have resulted in the need to consider alternative approaches to the existing worldsteel guidance for accounting for recycling, which focuses on an end-of-life approach. The guidance developed for accounting for reuse has focused on two additional approaches which take account of both the need to model a limited number of product lives (a multiple reuse method) and the market for reused products (a market-based method)

A further consideration in selecting the most appropriate methodology is the goal and scope of the LCA study. For example, in the area of product labelling and environmental product declarations, the goal is to provide environmental indicators that relate to an existing product system. Typically, unless the system is specifically designed for reuse, the environmental benefits relating to situations such as reuse will be quantified using product category average information. However, when performing an LCA study for a new product development, where the main goal is to quantify the benefits of design for reuse, as compared to an existing product, there is a case for extending the scope of the analysis to consider potential scenarios related to reuse. Examples could include evaluating the trade-offs between increasing the durability of a steel product as compared to extending the potential for reuse. Presenting different scenarios can also help to add value and clarity for situations where the final fate of the product, at end-of-life, is not well known and beyond the control of those involved in the study.

In order to select the most appropriate method for the study it is recommended that the following hierarchy is followed.

(i) Where one of the goals of the LCA study being undertaken is to evaluate opportunities relating to reuse, and the number of times the product can be reused or remanufactured has been quantified, it is recommended that a multiple reuse method is applied (as described in section 6.4). If the number of reuse cycles is unknown the multiple reuse method can also be applied. However, in this case, for modelling purposes the number of times the product is reused should be limited to once (i.e. n = 2) as a conservative assumption.

(ii) If the number of potential reuse or refurbishment cycles is unknown then it is recommended that a market-based method (as described in section 6.3) is applied. In this instance, a value of A_u=0.5 should be applied to reflect that the market for reuse is relatively immature or unknown. This method is also applicable for studies where reuse is a secondary consideration. For consistency, it should also be noted in the study report that the market-based method will provide a comparable result to the multiple reuse method where the value of n = 2.

Where the goal of the LCA study is to provide an environmental product declaration or label for a commercialised product, and there are clearly defined product category rules (PCR) for the product, then the methods defined in the PCR (or standard), for evaluating reuse should be adopted. In the absence of any pre-existing PCR, it is recommended that future PCRs follow the hierarchy of methods provided in above.

8. Future work on other methodologies

Over time new methodologies may be proposed and these should be investigated to look at the suitability of incorporating them into the LCA work undertaken by the steel industry.

One method that needs further development and testing is the functional transfer approach.

The functional transfer approach assesses the embodied impacts associated with each stage of product manufacture and considers the features (or functionality) of the product that are either retained and can be passed onto the next life cycle or lost as a result of end-of-life collection and processing. It aligns with the principles of an end-of-life approach and considers both inputs and outputs of recycled or reused material. Similar approaches have been discussed in the context of modelling recycling [10] but are not widely incorporated into developing standards and LCA software tools.

References

1) worldsteel, worldsteel LCI Methodology Report, 2017

2) Lund, R. 1984. Remanufacturing: The experience of the United States and implications for developing countries. World Bank technical paper, ISSN 0253- 7494, no. 31. Integrated resource recovery series 2. Washington, DC: World Bank and United Nations Development Program, The International Bank for Reconstruction and Development.

3) Lund, R. 1993. Remanufacturing. In The American edge: Leveraging manufacturing's hidden assets, edited by J. Klein and J. Miller. New York: McGraw-Hill.

4) Bureau of International Recycling (BIR), World Steel Recycling in Figures 2009-2013, 2014.

5) ISO 14044: 2006 Environmental management – Life Cycle Assessment – Requirements and guidelines

6) ISO 21930: 2017 Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services

7) EN 15804: 2012 + A1: 2019 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.

8) European Commission, PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, December 2017.

9) ISO 20915: 2018 Life cycle inventory calculation methodology for steel products

10) Koffler, C & Finkbeiner, M. 2017. Are we still keeping it "real"? Proposing a revised paradigm for recycling credits in attributional life cycle assessment.

Appendix 1. Guidance on how to model reuse and remanufacture: A case study of a component containing 1kg of hot dip galvanized steel.

The purpose of this appendix is to illustrate how the different reuse methodologies can be applied to model reuse of a steel product and how the results compare across different methods. The product used for this case study is a hot dip galvanized (HDG) steel component, which has a mass of 1kg. This could be a steel component in a vehicle, which is a part of a remanufactured assembly or a building product that is reused.

The key features of this example are as follows:

- The data used for modelling is based on worldsteel global average data for steel manufacture.
- It is assumed that the end of life of the product, which is no longer suitable for reuse, that 95% of the product will be recovered for recycling.
- In order to reuse or remanufacture the product there is a refurbishment impact of 0.1kg CO2e per kg.
- Impacts of disposal and recovery at end-of-life have been excluded (Referred to as Module C in construction EPD standards).

To illustrate how each of the methodologies can be applied to model different options for reuse and remanufacture a number of different scenarios were developed. The modelling parameters that remain constant for all scenarios are shown in Table 1 along with the complete list of scenarios and relevant additional parameters in Table 2.

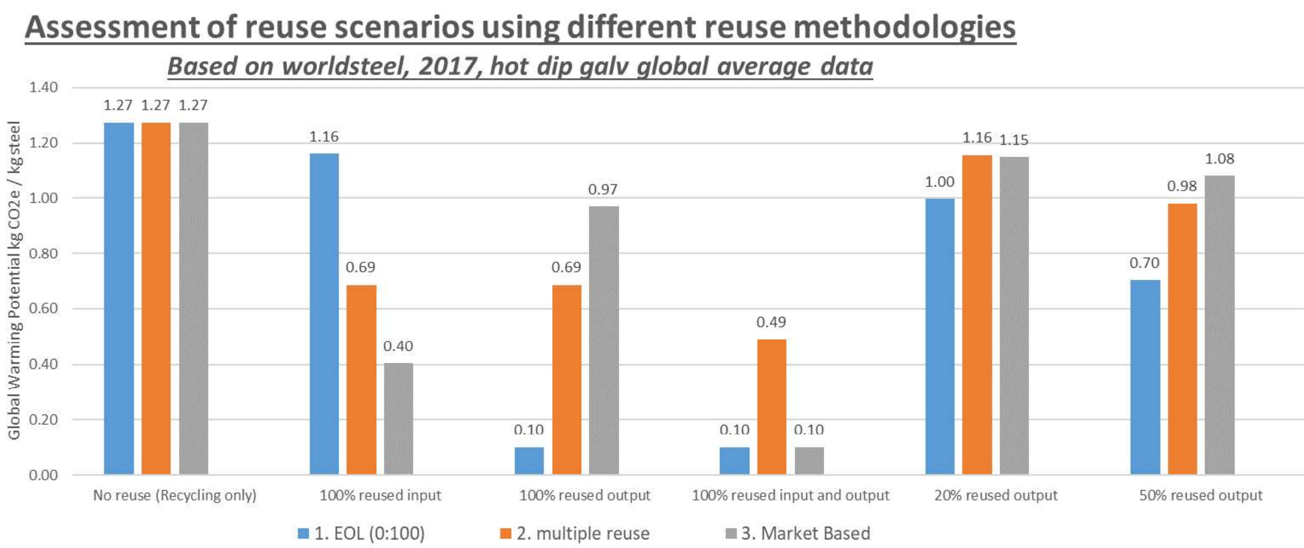
Parameter	Quantity	units	Comment
X_m	2.70	kg CO_2e/kg	Based on cradle to gate data for HDG
X_{sc}	1.62	kg CO_2e/kg	The value of scrap inputs and outputs
R^*_1	0.07	kg	Scrap input as from the life cycle inventory for HDG
R^*_2	0.95	kg	Scrap Recycled at end of life of the reused product
Z	1		Refurbishment is assumed to have no yield loss
X_{refurb}	0.1	kg CO_2e/kg	LCI for refurbishing the product.

Table 1 Fixed parameters relating to steel production, recycling and reuse

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	95% recycled at end-of-life with no reuse	100% reused content and 0% Reuse & 95% recycling at End-of- life	0% reused content and 100% reuse & 0% recycling at End of-life	100% reused content and 100% Reuse & 0% recycling at End-of- life	0% reused content and 20% reuse & 80% recycling at End of-life	0% reused content and 50% reuse & 50% recycling at End of-life
n	1	2	2	3	2	2
R_1	0.07	0	0.07	0	0.07	0.07
R_2	0.95	0.95	0	0	0.8	0.5
R_{u1}	0	1	0	1	0	0
R_{u2}	0	0	1	1	0.2	0.5

Table 2 Scenario based parameters relating to steel production, recycling and reuse

The results for each of the 3 methods are shown below.



Appendix 2 Critical Review Statement

Background

The Guidance document Guidance on methodologies for modelling reuse and remanufacture in LCA studies has been created by worldsteel. The Guidance has been critically reviewed after testing in industry by a team comprising:

- Elena Payne, Oakdene Hollins BSc (Project Manager
- David Parker, Oakdene Hollins MEng, CEnv, MBA (Principal)
- Hüdai Kara, Metsims Sustainability Consulting, BSc, PhD (Managing Director)

All members of the review panel were independent of any party with a commercial interest.

The aim of the review has been to ensure that (where applicable):

- the methods used to carry out the LCA study are consistent with the 14044:2006 standard;
- the methods used are scientifically and technically valid given the goal of the study;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretation of the results and the conclusions of the study reflect the goal and the findings of the study; and
- the study report is transparent and consistent.

The critical-review process involved the following:

- a review of the goal and scope definition at the outset of the project;
- a two stage process of
  - critiquing the approach scope and treatment of limiting cases of remanufacturing, re-use and repair over multiple lives and product complexities;
  - testing compliance of the Guidance against the principles of ISO 14044:2006.
- interleaving the two stages, checking two levels of modification to the Guidance offered by worldsteel, at which point all points had been addressed.

Conclusion of the critical review

The review team confirms that this LCA study followed the guidance of and is consistent with the international standards for the approach to Life Cycle Assessment (14044:2006).

Communication of the study results

The Guidance note is intended to communicate and assist in practice and methods for the evaluation of GWP impacts of re-use and recycling methods within practitioners. Its methods are transparent and suitable for this. Because feedback from case study companies is ongoing at the time of this report, some further explanatory notes on application may be needed in future.

Doctor Hüdai Kara	*David Parker*	*Elena Payne*

December 2023

Critical Review Conduct

Context of the Review

worldsteel has developed guidance for conducting LCAs for remanufactured products, building on previous experience related to recycling and reuse LCAs. worldsteel understands the importance of supporting the circular economy through accurately crediting the benefits associated with remanufacturing and, ultimately, demonstrating the value of steel use to support remanufacturing processes.

The guidance document is currently being assessed through a pilot study within the Remanufacturing Working Group, managed by the worldsteel economics team. To support the pilot study, worldsteel also require a review of the method by a third-party organisation.

About the Review

worldsteel has substantial weight within the sector, offering leadership on the important topic of contributions to Net Zero and other environmental impacts. Its authority and credibility need robust systems of assurance to ensure that its recommendations, practices and guidance can be used with confidence. Accordingly, as part of these checks and balances, an external critique of its approaches and implementation of – in the current case – estimation of global warming potential (GWP) in its methods is prudent and expected. Typically, such a review ensures alignment with ISO 14044, but also with current and best practices in life-cycle analysis and assessment, such as PCR and EPD.

worldsteel contracted Oakdene Hollins and Metsims Sustainability Consulting to conduct such a review – both scope and method – the conduct of which is described below.

Process of the Formal Review

The proposed method aligns with the previous worldsteel verification approach. With this background, it was not considered appropriate or necessary for a full-panel review focused on the mechanics of LCA evaluation. Instead, the review consisted of a 2-stage process employing joint perspectives of two specialist interests covering the content of LCA. These were:

- An initial – but iterative with worldsteel – review process of the approach, scope and implications for the application of the proposed procedures. Lead: Oakdene Hollins.
- A linked second stage review which examined the compliance of the approach and mechanistic assumptions against the ISO 14044 standard. Lead: Metsims Sustainability Consulting.

The iterative application of these two perspectives was deemed to be as robust as a panel review process.

Feedback and consolidation of stage 1 review.

After the initial stage, we held a debrief session for all parties to discuss the findings. The examinations largely explored how the procedure could best reflect the actual practice of remanufacturers, repairers and re-user agents (consolidating this with previous guidance), particularly in relation to the extreme cases of single-material products and complex multi-material products. In addition, there was a consideration of the treatment of multiple lives and how this might be handled for products given an as-new life versus those which were repaired and so might only be expected to displace a partial life.

worldsteel undertook one round of major revisions prior to the above meeting and, after a second examination, offered some minor adjustments and clarifications.

ISO 14044 guidance review

ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements. The first stage of examination also involved Metsims Sustainability Consulting, so some consideration of the ISO 14044 compliance had already been made. Therefore, it was anticipated that the formal ISO review would not be problematic. Factors under consideration included advice on suggested updates to the guidance document needed to align with ISO 14044, ensuring a robust and credible guidance document as a basis for further dissemination.

Review Commentary

Stage 1 review of approach

Oakdene Hollins' examination generated a number of comments placed within the preliminary guidance note, but we considered that a fuller stand-alone discussion document would better assist worldsteel in understanding the comments. The stand-alone document tackled the issues described above concerning simple and complex products, and the treatment of life extension and new-life approaches. It also offered some practical guidance relevant to how remanufacturers would likely be able to provide data to undertake a carbon assessment of their 're-use' processes.

A key suggested re-orientation of the method took this practical issue into account, and the need for this was confirmed by the response in the pilot study: For complex products, such as machinery, re-use agents typically take a 'cohort' approach. In essence, considering the input of say, 100 used devices, 5 might be deemed beyond repair and undergo direct recycling. Of the remainder, say, a certain percentage of material would be machined away and replaced, involving the use of process energy to yield, say, 85 working devices. The cohort could then be considered as a black box with inputs of old devices, new materials and energy with useful products output and residuals sent for recycling. The benefits would accrue across the 85 output devices, scaled down from the 100 devices which provided feedstock and which needed to be replaced by the addition of new devices.

Under repair, a similar consideration is necessary in comparing life extension. For simple single-material products such as beams, it is feasible that repair and diagnostic assays can validate a whole new life for the item; for complex assemblies, a simple repair addresses a single failure in one or more parts, but lifetime is characterised by the expected performance of the entire assembly (or at worst, the shortest lived part). Again, this is a cohort approach whereby a repair confers a fractional life benefit, on average say 50% life.

Both the above approaches are consistent with the United Nations Environment Programme International Resource Panel report on Value Retention.

Stage 2 Review of ISO compliance

In summary, the worldsteel Guidance explains and evaluates all available approaches in life cycle assessment for the purposes of capturing the further benefit available through reuse and remanufacture of steel products or parts. The guidance incorporates well-establish recycling approaches and their benefits.

Along with ISO 14044, the Guidance takes into account the following standards when developing the guidance for LCA for reuse and remanufacture:

- ISO 21930: 2017 Sustainability in buildings and civil engineering works-Core rules for environmental product declarations of construction products and services
- EN 15804: 2012 + A2:2019 Sustainability of construction works-Environmental product declarations. Core rules for the product category of construction products
- European Commission, PEFCR Guidance document-Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, December 2017.

The current LCA approaches on the end of life for steel focus on recycling as the main scenario. It is therefore refreshing to see that worldsteel is further thinking about the function of the product and its relation to its embodied impacts. Benefiting from retaining the function of a product rather than salvaging embodied emissions is a higher goal for implementation in standards and tools.

worldsteel considers four approaches to handle the reuse and remanufacture of products/parts. Each approach is explained clearly with consideration of how it might work in real life. The proposed approaches beyond recycling are novel and welcome as adjuncts to the default recycling case. However, since these options are not as well developed as recycling, the proposed market-based method and multiple reuse method seem reasonable for accounting their benefits in the LCA studies.

Presenting different scenarios can also help to add value and clarity for situations where the final fate of the product, at end-of-life, is not well known such as being beyond the control of those involved in the study. The formulae put forward for each of the potential reuse methodologies are solid and in line with the descriptions. Accounting for flows of both recycled and reused materials (which have different characteristics) has been integrated into the methods described in the Guidance.

Explanations are given in detail for the parameters involved in each calculation. The example provided as an annex explains very well the thought process behind the methodology and demonstrate how much the results differ for each one of them. We believe this guidance will clarify any mismodelling of end of life in the LCA studies particularly when developed for labelling purposes such environmental product declarations. To that end, perhaps, this guidance could be a good opportunity to promote and handle reuse and remanufacture in the new product category rules (PCRs) being developed and/or updated.

Where the goal of the LCA study is to provide an environmental product declaration or label for a commercialised product, and there are clearly defined product category rules (PCR) for the product, then the methods defined in the PCR (or standard) for evaluating reuse should be adopted. In the absence of any pre-existing PCR, it is recommended that future PCRs follow the hierarchy of methods provided in the worldsteel Guidance.

World Steel Association

Avenue de Tervueren 270
1150 Brussels
Belgium

T: +32 (0) 2 702 89 00
F: +32 (0) 2 702 88 99
E: steel@worldsteel.org

C413 Office Building
Beijing Lufthansa Center
50 Liangmaqiao Road
Chaoyang District
Beijing 100125
China

T : +86 10 6464 6733
F : +86 10 6468 0728
E : china@worldsteel.org

worldsteel
ASSOCIATION