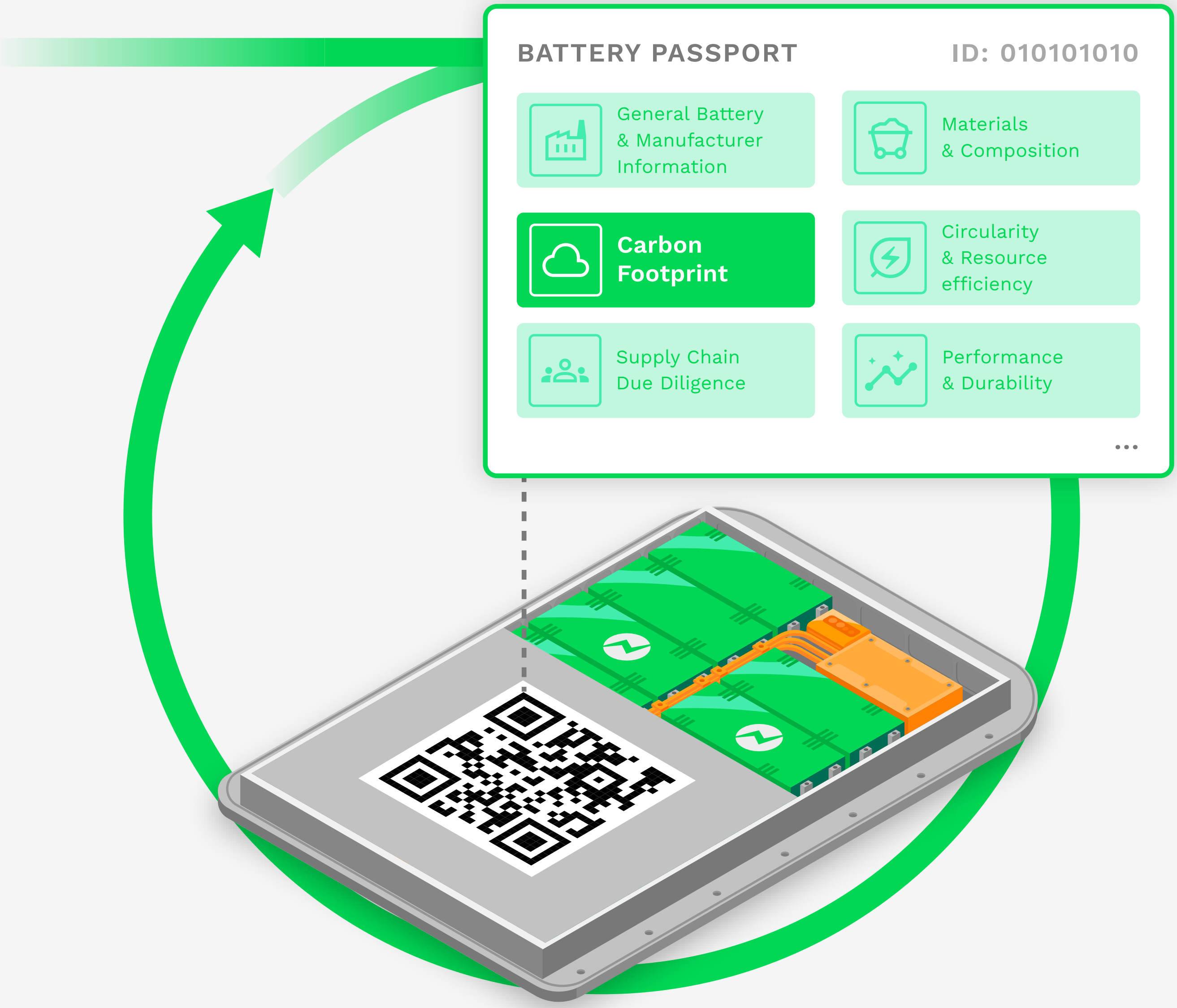
Battery Pass



Battery Carbon Footprint

Rules for calculating the Carbon Footprint of the 'Distribution' and 'End-of-life and recycling' life cycle stages

In collaboration with the **Global Battery Alliance**

Version 1.1 / December 2023

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

The Battery Pass consortium

CONSORTIUM LEAD

CONSORTIUM PARTNERS

*under subcontract

ASSOCIATED PARTNERS

Co-funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the Battery Pass consortium project aims to advance the implementation of the battery passport based on requirements of the EU Battery Regulation and beyond. Led by system change company Systemiq GmbH, the consortium comprises eleven partners and a broad network of associated and supporting organisations to draft content and technical standards for a digital battery passport, demonstrate them in a pilot application and assess its potential value.

DISCLAIMER

This document (the "Document") is for informational purposes only and is being made available to you by the Battery Pass consortium.

This Document is published by the Battery Pass consortium and contains information that has been or may have been provided by a number of sources. The findings, interpretations and conclusions expressed herein are a result of a collaborative process facilitated and endorsed by the Battery Pass consortium. The Battery Pass consortium partners (the partners as set out on page 2 of this Document) endorse the overall project approach and findings and the Battery Pass consortium has made efforts to accurately capture stakeholder positions set out by organisations (including working group members and further experts as set out on page 6 of this Document), although the results may not necessarily represent the views of all individuals or the organisations they represent. The Battery Pass consortium has not separately verified the information provided from outside sources and cannot take responsibility if any of these statements misrepresent a stakeholder position or if positions evolve over time.

To the extent permitted by law, nothing contained herein shall constitute any representation or warranty and no responsibility or liability is accepted by the Battery Pass consortium as to the accuracy or completeness of any information supplied herein. Recipients of this Document are advised to perform independent verification of information and conduct their own analysis in relation to any of the material set out.

The statements contained herein are made as at the date of the Document. The Battery Pass consortium or any member, employee, counsel, offer, director, representative, agent or affiliate of the Battery Pass consortium does not have any obligation to update or otherwise revise any statements reflecting circumstances arising after the date of this Document.

This Document shall not be treated as tax, regulatory, accounting, legal, investment or any other advice in relation to the recipient of this information and this information should not and cannot be relied upon as such.

If you are in any doubt about the potential purpose to which this communication relates you should consult an authorised person who specialises in advising on business to which it relates.

Table of Contents

Acknowledgements

All sorted alphabetically by organisations and individuals

The Battery Pass Rules were developed by the consortium partner working group members under the leadership of Systemiq GmbH:

- Dr. Johannes Simboeck, acatech – National Academy of Science and Engineering e.V.
- Josef Schön, Audi AG
- Dr. Torsten Freund, BASF SE / Global Battery Alliance
- Hao Liu, BASF SE
- Dr. Bodo Müller, BASF SE
- Maria-Fernanda Sciulli, BASF SE
- Diana Bartaune, BMW AG
- Dr. Othman Mrani, BMW AG
- Dirk Richter, BMW AG
- Dr. André Schmitz, BMW AG
- Niko D'Agostino, Circulor GmbH
- Ophelia Otto, Circulor GmbH
- Johannes Drielsma, Global Battery Alliance / Drielsma Resources Europe
- Anna Sophia Braunfels, Systemiq GmbH
- Achim Teuber, Systemiq GmbH
- Benedicte Robertz, Umicore SA
- Gert Van Hoof, Umicore SA

We would like to express our gratitude to the following individuals for their expertise and contribution in performing a practical test of applying the Battery Pass 'End-of-life and Recycling' rules and data collection process:

- Dr. Bodo Müller, BASF SE
- Lin Guang Liang (Gilbert), Contemporary Amperex Technology Co., Limited
- Wang Xiao Guan (Yuki), Contemporary Amperex Technology Co., Limited
- Robyn Stoney, Glencore
- Aman Chitkara, Li-Cycle Corp.
- Tobi Adesanmi, Li-Cycle Corp.
- James Belham, TES Sustainable Battery Solutions B.V.
- Nils Steinbrecher, TES Sustainable Technology Solutions GmbH
- Gert Van Hoof, Umicore SA

We extend our gratitude to the Global Battery Alliance GHG Working Group for the continuous expert support and content discussions.

Design and editorial:

- Design: Giacomo de Panfilis, FIWARE
- Proofread: Cassandra Rigg
- Formatting: Leon Renner

List of abbreviations

Abbreviation	Definition
CAM	Cathode Active Material
CF	Carbon Footprint
CFF	Circular Footprint Formula
DC	Distribution Centre
EC	European Commission
EF	Environmental Footprint (relating to PEF)
EOL	End-of-life
GBA	Global Battery Alliance
GHG	Greenhouse Gas
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
Li-ion	Lithium-ion
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
pCAM	Precursor Cathode Active Material

List of figures

List of tables

Glossary

Activity data: A quantitative measure of an activity associated with processes to calculate the GHG emissions (e.g., quantity of kilowatt-hours of electricity used or kilograms of purchased material).

Attributional LCA: One of two main LCA approaches (see also consequential LCA). This approach attempts to determine the environmental burdens of a product in relation to global environmental burdens (RE:SOURCE, 2020). Attributional modelling is gathering all environmentally relevant flows from and to the life cycle (Finnveden et al., 2009). Therefore, it makes use of historical, fast-based, measurable data and models the system as it is, was, or is forecasted to be (Eucar, 2020).

Consequential LCA: One of two main LCA approaches (see also attributional LCA). In this approach, the goal is to identify the effect of a product on the global environmental burdens (RE:SOURCE, 2020). Consequential modelling investigates how environmentally relevant flows will change in response to possible decisions (Finnveden et al., 2009). Therefore, a hypothetic supply chain is prognosticated along market mechanisms (Eucar, 2020).

Co-product: Co-products are defined in this document as equivalent to by-products: an output with an economic value above zero, for which demand at the specific production site is available and evidence can be given that the co-product is used as intended (GBA, 2023).

Circular Footprint Formula (CFF): Presents one approach to deal with End-of-life and recycling in LCA, which was proposed and is required by the European Product Environmental Footprint method (European Commission, 2019). In comparison to other allocation methods that favour either ingoing or outgoing secondary materials, the CFF aims at considering both by accounting for the recycled content at the input side as well as recyclability at the EOL. Therefore, it introduces additional parameters such as the change in material quality between life cycle stages as well as allocation factors for recycling and energy recovery processes that are aiming to integrate the balance of supply and demand.

Closed-loop vs. open-loop recycling: "Closed-loop recycling means the reuse of recycled materials in the same application from which the input materials originate. In open-loop recycling, in contrast, the recycled materials are also used in other applications." (Circular Economy Initiative Deutschland, 2021)

Cut-off approach: Presents one approach to deal with the allocation of End-of-life and recycling in LCA. It is also known as 100:0 or recycled content approach (RE:SOURCE, 2020). Thereby, the burdens arising from the recycling at End-of-life are "cut-off" and shifted to the life cycle that uses the recycled materials (GBA, 2023).

Emissions factor: factor that converts activity data into GHG emissions (e.g., kilograms CO2 emitted per kilogram of material).

Life Cycle Assessment (LCA): "Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14044:2006)
.

Life Cycle Inventory (LCI): “Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14044:2006).

Loading rate: The loading rate is the ratio of actual load to the full load/capacity (e.g. mass or volume) that a vehicle carries per trip.

Primary data: “Data pertaining to a specific product or activity within a company’s value chain. Such data may take the form of activity data, emissions or emission factors. Primary data is site-specific, company-specific (if there are multiple sites for the same product) or supply chain-specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material or product balances, stoichiometry or other methods for obtaining data from specific processes in the value chain of the company.” (WBCSD, 2021).

Primary material: Synonymous to virgin material: “Material which has never been processed into any form of end-use product” (ISO 18604:2013).

Manufacturing waste (pre-consumer waste): Material diverted from the waste stream during a manufacturing process, e.g., cuttings, stamping residues, scrappage, etc. leaving the production facility for further treatment. Reutilised materials such as rework, regrind or scrap generated and capable of being reclaimed within the same process that generated it are excluded from this definition (ISO, 2016).

Recycled content: Share/amount of secondary material(s) in the overall material(s).

Representative process: Processes “that are preponderant (of superior weight, influence or prevalence) in the market” (GBA, 2023).

Run-around scrap: Scrap generated and capable of being reclaimed within the same process or process chain within the same facility that generated it.

Scrap: Material diverted from the waste stream, that has not yet been processed into secondary material. Scrap is further treated in material recovery processes (recycling) while waste is landfilled or incinerated.

Secondary material: Synonymous with recycled material: “materials which have been reprocessed by a manufacturing process from recovered (remanufactured) materials and made into a finished product or component for incorporation into a product” (Circular Economy Initiative Deutschland, 2021).

Secondary data: “Data that is not from specific activities within a company’s value chain but from databases, based on averages, scientific reports or other sources” (WBCSD, 2021). In this document, secondary data are any data that are not primary data, i.e. all kind of data not directly measured or gathered from company owned information systems. Secondary data include e.g. life cycle inventory data from a third party, emission factors from inventory guidebooks, data from scientific papers and other kind of literature. (Note that data sourced from information systems or engineering models that collect or obtain data directly from specific processes in the value chain of the company (e.g., the International Material Data System [IMDS] of the automotive industry), shall be considered primary data.)

Substitution approach: Approach to deal with allocation of End-of-life and recycling in LCA. It is also known as 0:100, recyclability substitution, avoided burden or end-of-life approach (GBA, 2023). The method uses system expansion to evaluate the impact of recycling on the net virgin acquisition of a material (GHG Protocol, 2011).

Transport payload: The maximum mass allowed per transport.

Utilisation ratio: Synonymous with loading rate: the ratio of actual load to the full load/ capacity (e.g. mass or volume) that a vehicle carries per trip.

Waste: "Materials, outputs or emissions without economic value that the holder discards, intends to discard or is required to discard" (GBA, 2023). See also distinction to scrap.

Well-characterised process: Processes that do not "require allocation amongst co-products, or for which allocation amongst co-products is clear and consistent on a global basis (e.g. chlor-alkali process for co-production of chlorine and sodium hydroxide)" (GBA, 2023).

1 Introduction

1.1 Background

As per the Battery Pass project contract and within its "content standards" scope, the Battery Pass work package "Carbon Footprint (WP2a)" aims at determining and validating relevant standards for the consistent collection of the GHG footprint of batteries across the life cycle, from mine to product, distribution and including effects from the use of secondary materials. In close alignment with the Global Battery Alliance (GBA), the Battery Pass Rules complement the GBA GHG Rulebook version 1.4 which focuses on upstream emissions (cradle-to-gate). The rules were integrated in the GBA GHG Rulebook version 1.5. The GBA GHG Rulebook is a methodological application of carbon accounting rules to provide guidance to battery value chain participants to calculate and report the battery carbon footprint based on primarily company-specific data. The Battery Pass mapped the GBA GHG Rulebook against existing standards confirming its general compliance with the Product Environmental Footprint (PEF) and Product Environmental Footprint Category Rules (PEFCR) – the most relevant standard in the context of the Battery Regulation's carbon footprint requirements. As a result, only minor deviations from these standards with no significant impact on the overall reporting were identified, except for electricity and EOL modelling. The Battery Pass consortium and the GBA GHG working group will continue to work on an alignment and harmonised approach in regard to these outstanding topics. For instance, it remains open which approach to electricity modelling will be implemented in the delegated act. The GBA proposed a dual reporting approach, which has benefits compared to the proposal made by the JRC, particularly in light of global value chains where residual grid mix data are not always publicly available.

Version 1.1 of the Battery Pass rules includes changes to sections 5.1.5 and 5.3 to give more guidance on multi-output allocation procedures and sections 5.1.6 and 6.1.3 on manufacturing waste modelling.

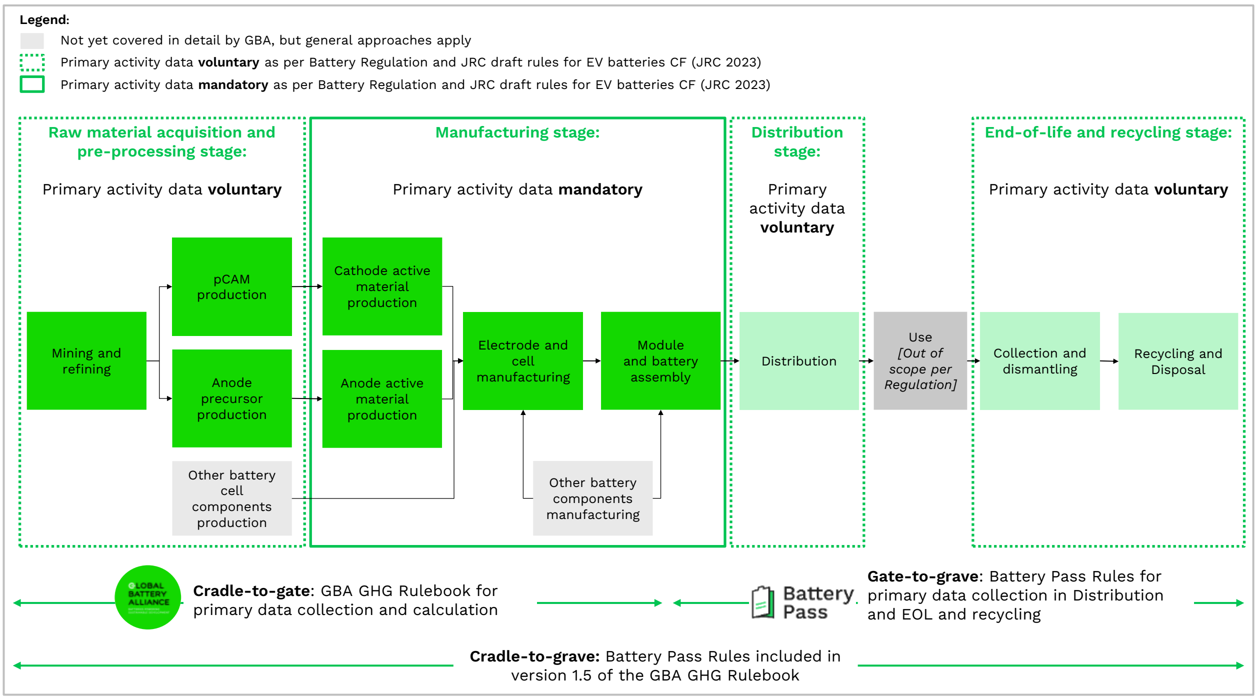
Based on this assessment, the Battery Pass proposed to complement the GBA GHG Rulebook currently focusing on upstream emissions (cradle-to-gate). Sections 4, 5, and 6 of this document are included as chapter additions to the cluster-specific rules in version 1.5 of the GBA GHG Rulebook (see Figure 1).

In this document, rules for life cycle stages that are required by the EU Battery Regulation but were not yet covered by the GBA GHG Rulebook have been developed and recommended. The GBA GHG Rulebook focused on stages 1 and 2 of the below list as well as own electricity production. Therefore, Battery Pass covers **stages 3 and 4**.

As per *Annex II paragraph 4*, the Battery Regulation requires a carbon footprint calculation for four life cycle stages:

- **Stage 1:** Raw material acquisition and pre-processing
- **Stage 2:** Main product production *[company-specific data mandatory as per Battery Regulation]*
- **Stage 3:** Distribution
- **Stage 4:** End-of-life and recycling

Figure 1: Company-specific data requirements as per the Battery Regulation and the JRC draft rules



1.2 Aim, scope and methodology

The goal of this document is to draft rules for accounting the carbon footprint of the life cycle stages "Distribution" and "End-of-life and recycling" as required by the Battery Regulation. These are proposed to the Global Battery Alliance as a complementation of the Greenhouse Gas Rulebook version 1.4 and were included in the version 1.5. Based on the GBA scope and the GHG Rulebook chapters "End-of-Life allocation" (3.4.2.) and "Recycled content of materials" (3.5.) and extending to relevant carbon accounting standards, specific rules were developed for accounting this life cycle stage including data collection and requirements.

The guiding principles to derive specific battery carbon footprint rules follow GBA principles.

- The rules must be USADAC – understandable, standardised, accurate, differentiating, auditable and comparable
- The rules must align with global standards, (e.g., ISO standards) *[Addendum Battery Pass: with PEF/PEFCR being prioritised as per the EU Battery Regulation]*
- The rules must align with the approaches taken in the GBA GHG Rulebook or else seek to change/amend existing approaches

The general approach taken by Battery Pass to writing the rules are as follows:

1) Assessment of requirements as per Battery Regulation (section 2)
2) Assessment of requirements as per existing standards, with PEF/PEFCR being prioritised (Annex A.1)
3) Evaluation of the chosen approaches, for recycling allocation in terms of a qualitative and quantitative assessment (section 3)

4) Developing rules as proposal for inclusion in the next version of the GBA GHG Rulebook (section 4 and section 5):
    a. **General rules:** System boundary, functional unit, allocation, specification of data requirements and description of processes to include in calculations
    b. **Cluster-specific rules:** Application of processes and calculation logics per process including data collection
5) Translating the methodological choice of the Cut-off approach for the EOL and recycling allocation into a guidance and set of rules complying with the EU requirements of the Circular Footprint Formula (section 6).

The general rules for calculating end-of-life (EOL) and recycling emissions as presented in this document are applicable to all battery types, while the cluster-specific rules initially focus on electric vehicle (EV) batteries with a particular focus on lithium-ion batteries. They present a basis on which further battery chemistries, according materials and production processes (e.g., recycling processes) can be included and additional rules developed.

While the general rules provide EOL allocation methods to be used by economic operators having or wanting to declare the carbon footprint, the cluster-specific rules are for recycling providers to calculate the carbon footprint based on the defined data collection.

Section 2 provides relevant regulatory background. Section 3 discusses the Battery Pass carbon footprint working group approach to account for the Distribution and EOL and recycling life cycle stages. Section 4 then proposes the Battery Pass carbon footprint rules for the Distribution life cycle stage. Section 5 specifies the Battery Pass carbon footprint rules for the EOL and recycling life cycle stage. Section 6 provides the extension of the EOL and recycling rules specified under the Cut-off approach to comply with the specific EU requirements of the Circular Footprint Formula (CFF). Section 7 gives an outlook.

2 Regulatory requirements as basis for rules: Article 7 and Annex II of the Battery Regulation

The requirements for the battery carbon footprint follow from the EU Battery Regulation. *Article 7* holds that “For rechargeable industrial batteries with a capacity above 2 kWh, light means of transport batteries and electric vehicle batteries a carbon footprint declaration shall be drawn up, for each battery model per manufacturing plant, in accordance with the *[to be developed]* delegated act (…) and containing” (…) inter alia the carbon footprint of the battery, calculated as kg of carbon dioxide equivalent per one kWh of the total energy provided by the battery over its expected service life (European Commission, 2023). Thereby, the carbon footprint of the battery must be differentiated per life cycle stage as described in *point 4 of Annex II*.

The calculation of the battery carbon footprint shall build on the essential elements in *Annex II* and must be compliant with the latest version of the European Commission Product Environmental Footprint (PEF) (European Commission, 2021) method and relevant Product Environmental Footprint Category Rules (PEFCRs) (Recharge, 2018) and reflect the international agreements and technical/scientific progress in the area of life cycle assessment (bringing in flexibility for following different approaches). A delegated act specifying the methodology to calculate and report the battery carbon footprint for EVs will be published until 6 months after entry into force of the Regulation. As a basis for the delegated act, the EU Joint Research Centre (JRC) published a draft version of rules for the calculation of the carbon footprint of electric vehicle batteries – as it is still in consultation, the final version was not available at time of publishing this document (Joint Research Centre, 2023). The methodologies for other battery categories will be implemented later, with delegated acts to be implemented.

The calculation of the life cycle carbon footprint shall be based on the bill of material, the energy, and auxiliary materials used in a specific plant to produce a specific battery model. In particular, the electronic components (e.g., battery management systems, safety units) and the cathode materials have to be accurately identified, as they may become the main contributor to the battery carbon footprint. All activity data related to the battery’s anode, cathode, electrolyte, separator, and cell-casing shall refer to a specific battery model produced in a specific production plant. This means, for these processes, no default activity data shall be used which entails that company-specific activity data are required. The battery-specific activity data shall be used in combination with the relevant Product Environmental Footprint compliant secondary datasets (European Commission, 2023).

The carbon footprint must be calculated and reported per life cycle stage. Table 1 shows the life cycle stages required for the battery carbon footprint declaration in accordance with *Article 7 (1)*. As per *Annex II (4)*, the Distribution stage only covers the transport to the point of sale. For the EOL and recycling stage, the underlying processes of collection, dismantling and recycling are included. Besides these, the Regulation does not specify the requirements further, except that manufacturing of equipment for battery recycling shall be excluded. This is due to the fact that impacts have been calculated as negligible in the PEFCR for high specific energy rechargeable batteries for mobile applications (European Commission, 2023).

As a result of this, the specific modelling requirements for these life cycle stages will be determined in secondary legislation (category-specific delegated acts). As the calculation needs to be in compliance with PEF and PEFCR, the requirements follow from these standards (see Annex A.1 for a summary).

Table 1: Life cycle stages as per Battery Regulation essential elements (Annex II)

Stage #	Life cycle stage	Short description of the process included
Stage 1	**Raw material acquisition and pre-processing**	Includes mining and other relevant sourcing, pre-processing and transport of active materials, up to the manufacturing of battery cells and batteries components (active materials, separator, electrolyte, casings, active and passive battery components), and electric/electronics components.
Stage 2	**Main product production**	Assembly of battery cells and assembly of batteries with the battery cells and the electric/electronic components
Stage 3	**Distribution**	Transport to the point of sale
Stage 4	**End-of-life and recycling**	Collection, dismantling and recycling

3 Battery Pass approach

The rules are derived from prevalent standards and based on the EU regulatory requirements. They were developed based on continuous working group meetings. The rules are applicable for all battery manufacturers having to declare the battery carbon footprint in the EU and companies involved in the respective operation of the life cycle stage (e.g. recycling providers). The rules were proposed in a condensed version to the GBA GHG working group for inclusion, and have been adopted in the GBA GHG rulebook version 1.5 (GBA, 2023).

3.1 Approach for the Distribution stage

Based on the results of the Battery Pass carbon footprint working group, the Battery Pass consortium developed a set of rules as outlined in section 4 of this document. The Battery Pass proposes to follow the calculation logic for transportation-related emissions based on company-specific data as provided by the GBA GHG Rulebook (section 4.2.4). Where company-specific data are not available, default scenarios provided by the Product Environmental Footprint (PEF) methodology shall be used. These transport scenarios reflect the EU transport scenarios; as reporting the Distribution life cycle stage is a European regulatory requirement, this is deemed appropriate.

3.2 Approach for the EOL and recycling stage

Based on the evaluation of Battery Pass carbon footprint working group and a benchmark of the three approaches on accounting for EOL and recycling emissions, the Battery Pass consortium proposes the rules as outlined in section 5 of this document. The working group developed this document to provide recyclers with a coherent set of rules for accounting the EOL and recycling emissions and battery manufacturers placing the battery on the market with guidance on allocating the EOL and recycling for the respective life cycle stage reporting.

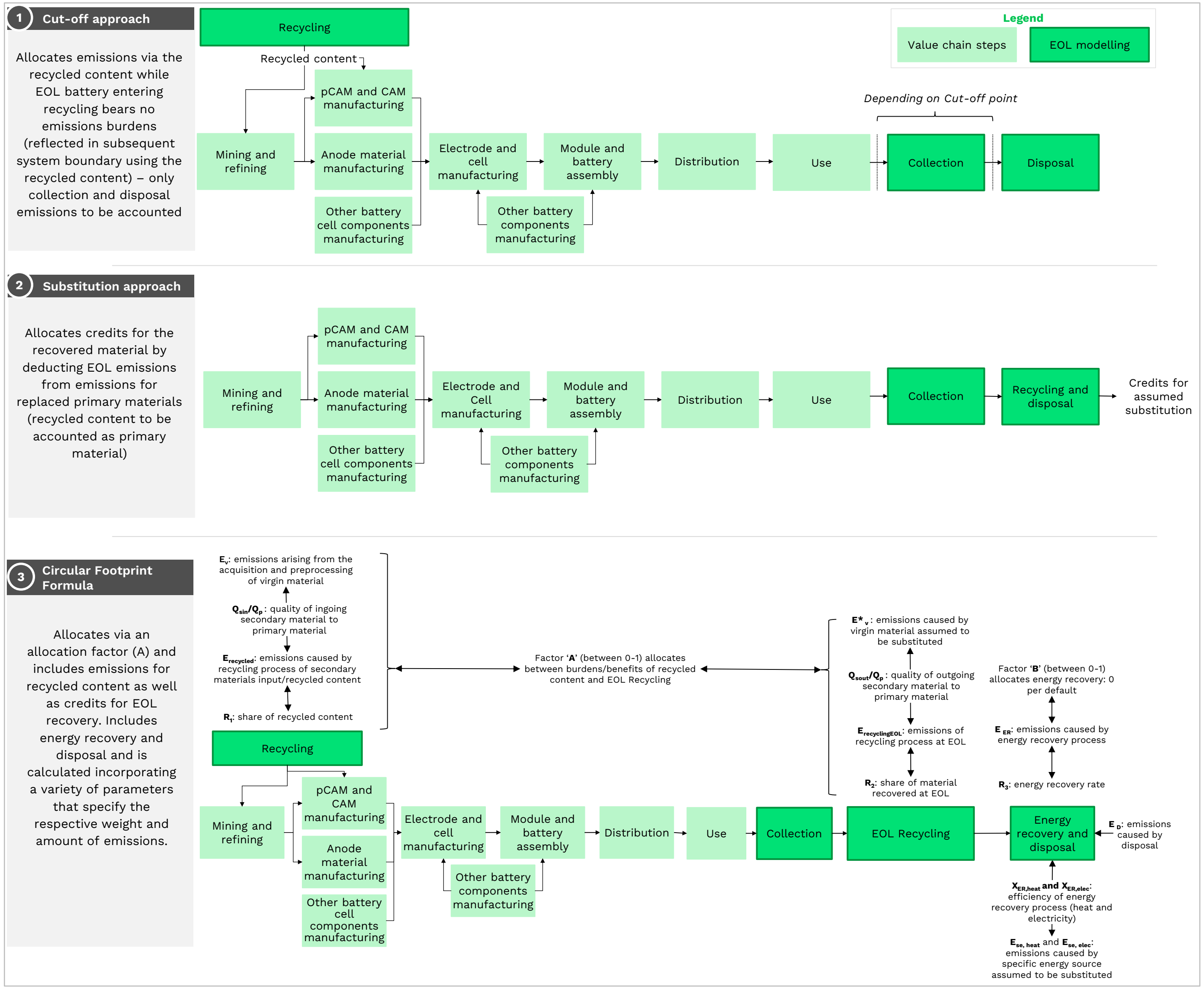
In current academic studies on battery recycling, the avoided burden assumed for substituting primary materials through recycling is credited (Substitution approach) to highlight the benefits of recycling. The approach applied in scientific studies, e.g., (Rinne et al., 2021); (Mohr et al., 2020); (Rajaeifar et al., 2021), is feasible to evaluate whether overall recycling is leading to environmental benefits, regardless of which actor in the value chain can claim the credits from recycling (recycler or the actor that uses the recycled material in a new product). For the purpose of calculating the product carbon footprint of a battery, that credit ownership becomes an important element for the actual calculation. If recycling outputs are credited, the product system using the recycled content would have to account for the recycled materials with primary emissions factors. Therefore, this approach would not be suitable for including recycled content emissions in the battery carbon footprint. In the particular context of the battery regulation where the carbon footprint has to be declared when placing the battery on the market and for the battery life cycle including upstream production, the methodological choice taken in academic studies is not suitable. Additionally, these considerations require that the functional unit is specified differently compared to academic studies such that it corresponds to the upstream system boundary.

The discussions and analysis of the three approaches have resulted in the fact that the Cut-off approach is the most feasible and transparent approach to take into account primary data from recycling processes and implement attributional LCA principles. While there are trade-offs between each of the approaches, the Substitution approach as well as the Circular Footprint Formula both would result in using sensitive assumptions on EOL processes that lie in the future. This means that the Substitution approach and parts of the CFF estimate the EOL contribution of the footprint based on data which may not accurately reflect the real contributions (e.g., due to changes in technologies). The Substitution approach and CFF both give credits for secondary material supplied at EOL which are unverifiable at placement on the market. These credits reduce the overall battery carbon footprint and thus reduce the accuracy of the overall result (based on assumption on the battery model's EOL fate). In particular, the current specification of key parameters of the CFF give strong weight to EOL credits, which poses a risk due to the sensitive EOL assumptions.

Instead, the Cut-off approach can include primary data at the time of the battery production and the placement on the market (i.e. CF declaration). Additionally, it corresponds to the goals of the Battery Regulation to increase the share of recycled content in batteries and thus the demand for battery-grade recycled materials, indirectly incentivising production waste and EOL waste batteries collection and recycling. Nevertheless, the CFF will have to be considered as it will likely be demanded by the EU Battery Regulation via reference to the PEF/PEFCR. Defining the primary data collection through the Cut-off approach, however, yields the first part of the CFF and can be subsequently complemented. Therefore, the rules for recycling activity data collection and carbon footprint calculation are specified under the Cut-off approach (section 5) while guidance and rules to comply with the PEF CFF requirements are provided in a chapter addition (section 6).

Figure 2 shows the allocation mechanisms in the Cut-off approach, Substitution approach and CFF. A detailed analysis comparing the three approaches can be found in the document provided by the Battery Pass project: "*Comparison of end-of-life allocation approaches: An analysis complementing the Battery Pass Rules for calculating the Carbon Footprint of the 'End-of-life and recycling' life cycle stage*".

Figure 2: Allocation mechanisms in the Cut-off approach, Substitution approach and CFF



4 Distribution rules

The Distribution rules cover the transport-related emissions that occur in the life cycle stage "Distribution". It follows the calculation logic for transportation-related emissions based on company-specific data as defined in the GBA GHG Rulebook section 4.2.4 (GBA, 2023). Where this is not feasible, default scenarios provided by the Product Environmental Footprint (PEF) standard may be used.

The Distribution stage comprises the transport of the battery from the manufacturing site to the final use site (or to a reference entry point into the market). The final client is generally defined as the user of the battery (use phase). This means that the following scenarios need to be included in the Distribution stage:

- transport from battery supplier to manufacturer placing the battery on the market (='Original Equipment Manufacturer (OEM)') factory (if battery assembly is not performed by the economic operator placing the battery on the market)
- from manufacturer placing the battery on the market (='OEM') factory to user (use phase)

Additionally, the end-of-life collection (to be accounted for in EOL and recycling stage) follows the same principles and approaches as the Distribution stage.

The manufacturer placing the battery on the market for its intended use (economic operator as per the Battery Regulation) is set equal to OEM in this document. The Distribution rules cover the transport from OEM factory to final user. If the battery assembly does not take place at the OEM factory but at the supplier, the step from battery supplier to OEM needs to be included as well (otherwise accounted for under the respective upstream process step). The following sections set general rules for the respective outlined scenarios and specifies primary data collection guidance as well as, in case specific data are not available, default scenarios and values.

The final user needs to be clarified by the applicant of the rulebook. As the battery carbon footprint declaration is tied to the placement of the market, the user shall be the final client (use phase). As the PECFR for batteries has shown that the Distribution life cycle stage has a negligible impact on the battery carbon footprint, by default, there is no waste of products during the Distribution life cycle stage and storage emissions may be omitted (Recharge, 2018).

4.1 General rules

4.1.1 System boundaries and processes

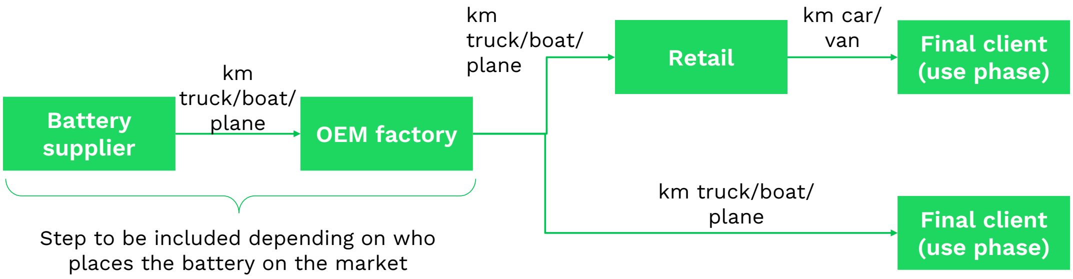
As the battery assembly and system integration generally takes place at the OEM placing the battery on the market, transport from battery supplier to OEM factory is to be accounted for in the respective upstream production process. If this is not the case, the transport must be accordingly modelled.

In the general case, this means that the following scenario needs to be included in the Distribution stage:

- **Only required if battery assembly does not take place at OEM level: transport from battery supplier to OEM factory**[1]
- **from OEM factory to user (use phase)**

The distribution might take place directly or via retailers (see Figure 3). For each of these, the respective transport distance, vehicle type, transport type and utilisation ratio need to be specified. If this is not possible, default scenarios may be applied (refer to section 0).

Figure 3: Transport scenarios for the Distribution life cycle stage



4.1.2 Functional unit and reference flow

The distribution transport process requires partitioning related emissions to the specific battery model per battery manufacturing plant. The functional unit and reference flow for the distribution processes shall be:

- **For final product production/OEM factory to final user:** the transport of one final (integrated) battery pack/module placed on the market

The reference flow can be in piece or kg and the weight per piece shall be given to convert piece to kg or vice versa. The carbon footprint of the battery pack shall contain the necessary information, e.g., the nominal or usable capacity of the battery pack in kWh, to translate the carbon footprint as calculated as kg of carbon dioxide equivalent per one kWh of the total energy provided by the battery over its expected service life.

4.1.3 Data collection requirements

The GHG emissions related to the Distribution life cycle stage usually have a negligible contribution to the total environmental impacts over the battery life cycle (Recharge, 2018). Nevertheless, the battery carbon footprint shall consider the transport from battery assembly to the client (including consumer transport). Supply-chain-specific information (primary data) shall be prioritised and used for the calculation of GHG emissions related to the Distribution

[1] Where final battery assembly takes place at the OEM placing the battery on the market, the transport emissions from supplier to OEM factory need to be accounted for under the respective production process step (i.e. battery assembly).

stage using three approaches following the GBA GHG Rulebook (GBA, 2023). For further details please refer to section 4.2 of this document.

The applicant of the Rulebook shall use specific transport data and related EF compliant datasets to calculate the carbon footprint. Where a specific detailed assessment based on primary data cannot be documented, the default scenarios and standard transport distances provided by the PEF methodology shall be used (EC, 2021). The user may apply tools that are in line with accepted industry standards, such as the GLEC framework (e.g. EcoTransIT World[2]).

The period for data collection is annual per default. This can be either calendar year or fiscal year. Which time period was used, shall be indicated in the data collection sheet.

4.1.4 Allocation of distribution transport burdens

To allocate the impacts from transport to the battery product system, emission factors per transported mass should be coupled with transport distances and vehicle types. Hence, values shall be nominated in tkm (tonne-km) expressing the environmental impact for 1 tonne (t) of product that is transported for 1 kilometre (km), for instance in a truck, average freight train or shipping container with a certain load (EC, 2021). The transport emissions are allocated based on the transported battery mass, resulting in emissions being partitioned to the mass share of the battery. For example, a truck of 28-32 t has a maximum mass allowed (i.e. payload) of 22 t. In case the product is 0.5 t, the share of emissions is 0.5/22 of the truck's full emissions. When a full freight's mass is lower than the truck's load capacity (e.g., 10 t), the transport of the product may be considered volume limited. In this case, the environmental impact shall be calculated using the real mass loaded (EC, 2021).

The transport payload should be modelled in a parameterised way through the utilisation ratio. The utilisation ratio is calculated as the mass of the real load divided by the mass of the (maximum) payload and shall be adjusted when the dataset is used. For instance, in case the truck is fully loaded for delivery but half empty upon its return, the utilisation ratio is: 22 t real load / 22 t payload * 50% km + 11 t real load / 22 t payload * 50% km = 75%.

The user of these rules shall specify the utilisation ratio to be used for each transport modelled, as well as clearly indicate whether the utilisation ratio includes empty return trips. **If the load is mass limited, a default utilisation ratio of 64% shall be used** in line with the current PEF guidance (EC, 2021). This utilisation ratio includes empty return trips and thus shall not be modelled separately.

4.2 Distribution – data collection guidance

4.2.1 Supply-chain-specific transport modelling

Primary data shall be prioritised and used for the calculation of GHG emissions related to the Distribution stage using three approaches following the GBA GHG Rulebook section 4.2.4 (GBA, 2023):

Own truck fleet: The first approach requires the amount of consumed fuel, e.g., the diesel consumption of a company owned truck fleet. The fuel consumption is multiplied with the carbon footprint for the supply of the fuel and with emission factors from e.g., the 2006 IPCC

[2] https://www.ecotransit.org/en/

Guidelines for mobile combustion (IPCC, 2006). The user of these rules shall partition the emissions as outlined in section 4.1.4.

Transport of goods used by company: The second approach is based on driven mileage of a known and defined means of transport (e.g., articulated truck > 33 t, with 50% or 100% load) that is entirely used to transport specific goods for which the user of the rulebook wants to calculate the GHG emissions related to transport. Emission factors for this approach shall be taken from the PEF database if available and otherwise from different accessible sources.[3] These shall be multiplied with the distance to obtain the GHG emissions for the mass of goods transported by the defined means of transport.

Based on starting point and destination: The third approach applies if only the start and destination are known, but no further information is available. In this case, the user shall estimate the distances based on a simplified logistic chain (e.g., 40 t truck from location of origin to a possible harbour, ship transport to a possible harbour in the vicinity of the destination and a final truck transport). Distances for the different transport sections may be calculated based on web calculators.[4] Finally, a multiplication of distance and mass results in a mass-distance unit, such as tonne-kilometre (tkm) which shall be taken from the PEF database if available and otherwise from different accessible sources.[5]

The following inputs and outputs shall be specified and linked to EF-compliant databases (see Table 2).

Table 2: Input-output table for supply-chain-specific transport

	Unit	Data	Specification
Input			
Battery placed on market	kg		
Vehicle type			e.g. lorry (28-32 t)
Transport type			e.g. truck transport, plane, boat
Transport distance	km		
Payload / utilisation ratio	%		If load mass is limited, use default 64%
GHG emissions factors	kg		Per fuel type
Output			
GHG emissions per transported battery	kg		Allocation based on payload and mass-transport distance

[3] For instance https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021
[4] For instance www.sea-distances.org or Google Maps
[5] For instance Defra's Greenhouse gas reporting conversion factors website https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021

4.2.2 Default scenarios as per PEF recommendation and PEFCR guidance

In case the above mentioned specific data are not available, the following default scenarios from the PEF recommendation and PEFCR guidance may be applied. The applicant shall clearly specify why these default scenarios where used. Within the respective EF-compliant datasets concerning transport-related emissions, the fuel production, the fuel consumption by the transport vehicle, the infrastructure needed and the amount of additional resources and tools needed for logistic operations (e.g., cranes and transporters) are included. To allocate the impacts from transport to the product, secondary datasets using emission factors per transported mass are coupled with transport distances and vehicle types. Hence, EF-compliant datasets for truck transport are nominated in tkm (tonne-km) expressing the environmental impact for 1 tonne (t) of product that is transported for 1 km in a truck with a certain load. The respective weight of the transported battery shall be used to calculate the respective emissions.

Only where battery pack assembly does not take place at the OEM level: From supplier to OEM factory

a. For suppliers located within Europe (utilisation ratio 64%)
   - 130 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio; and
   - 240 km by train (average freight train; UUID 02e87631-6d70-48ce-affd-1975dc36f5be); and
   - 270 km by ship (barge; UUID 4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae).

b. For all suppliers located outside Europe (utilisation ratio 64%)
   - 1,000 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), for the sum of distances from harbour/airport to factory outside and inside Europe. PEFCR specific utilisation ratio; and
   - 18,000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63) or 10,000 km by plane (cargo; UUID 1cc5d465-a12a-43da-aa86-a9c6383c78ac).

If producer's country (origin) is known: the adequate distance for ship and airplane should be determined using online sources.[6] The user of these rules shall state which transport type is typically used. Where it is unknown whether the supplier is located within or outside Europe, the transport shall be modelled as the supplier being located outside Europe.

From OEM factory to final client (use phase):

In case no supply-chain-specific transport scenario is available, the default scenarios outlined below (see also Figure 3) shall be used as a basis in combination with a number of specific values (e.g., utilisation ratio if available):

- Ratio (X%) between products sold through retail and **directly to the final client**;
- **For OEM factory to final client:** Ratio (X%) between local, intracontinental and international supply chains;
- **For OEM factory to retail:** distribution (X%) between intracontinental and international supply chains;

[6] The PEF methodology proposes http://www.searates.com/services/routes-explorer or https://co2.myclimate.org/en/flight_calculators/new

The Ratio X% shall be determined by the user.

a. X% from **OEM factory to final client**:
   - X% local supply chain: 1,200 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio.
   - X% intracontinental supply chain: 3,500 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio.
   - X% international supply chain: 1,000 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio and 18,000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63).

Note that for specific cases, plane or train may be used instead of ship. The user of these rules shall state which transport type is typically used.

b. X% **from OEM factory to retail**:
   - X% local supply chain: 1,200 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio.
   - X% intracontinental supply chain: 3,500 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57) (Eurostat 2014), PEFCR specific utilisation ratio.
   - X% international supply chain: 1,000 km truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio and 18,000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63).

Note that for specific cases, plane or train may be used instead of ship.

c. X% **from retail to final client**:
   - 62%: 5 km, by passenger car (average; UUID 1ead35dd-fc71-4b0c-9410-7e39da95c7dc), PEFCR specific allocation
   - 5%: 5 km round trip, by van (lorry <7.5t, EURO 3 with utilisation ratio of 20%; UUID aea613ae-573b-443a-aba2-6a69900ca2ff)
   - 33%: no impact modelled

5 End-of-life and recycling rules

The End-of-life and recycling rules cover the collection and EOL treatment of post-consumer waste batteries and pre-consumer battery manufacturing waste.[7] This includes recycling through a combination of processes spanning from dismantling, pyrolysis (pre-treatment), mechanical/shredding treatment, pyrometallurgical treatment to hydrometallurgical treatment. It is subdivided into the different recycling process steps that recover the battery metals and minerals which are foreground processes (i.e. based on primary data) as per the GBA GHG Rulebook (GBA, 2023), covers the modelling of EOL and recycling life cycle stage and provides guidance on calculating the process-specific GHG emissions. In the following, the general rules for the EOL allocation, functional unit, system boundaries, data collection requirements, multi-output allocation and calculation of the carbon footprint are described. Subsequently, data collection and allocation requirements for the recycling processes are provided.

The allocation method determines the modelling of emissions associated with the End-of-life and recycling processes. The GBA Rulebook explains two prevalent approaches: the Cut-off (100:0, recycled content) and Substitution (0:100, closed-loop approximation, or end-of-life approach). The Cut-off thereby is recommended due to being the more transparent approach. The Battery Pass carbon footprint working group also concludes that the Cut-off approach is the most transparent and accurate approach for End-of-life allocation. An analysis comparing the three different approaches (Cut-off, Substitution, and Circular Footprint Formula as per PEF/PEFCR) can be found in the document provided by the Battery Pass project: *"Comparison of end-of-life allocation approaches: An analysis complementing the Battery Pass Rules for calculating the Carbon Footprint of the 'End-of-life and recycling' life cycle stage"*.

The following EOL and recycling rules are specified under the Cut-off EOL allocation method. The rules are primarily addressed to companies running recycling operations (i.e. recycling providers) such that recycling process emissions can be calculated based on primary activity data. The rules are addressed to companies having to declare carbon footprints for the EOL and recycling life cycle stage based on waste collection and disposal emissions. The consumer receiving the recycled content shall report supplier-specific data for the recycled content used, based on the data collection processes provided in the subsequent sections. Specifically, the recycled pCAM/CAM and anode materials shall include the supplier-specific GHG footprint based on the general rules and primary data collection as set out in the following sections. For all other recycled materials (i.e. other than pCAM/CAM and anode materials) used in the production process, also supplier-specific data shall be used where available. Section 5.3.8 provides a general approach for the data collection for other recycled materials while the general rules of this document shall apply. The current focus is on Li-ion/NMC batteries, but the general rules apply to all technologies and corresponding input/output tables for primary activity data collection can be extended by applicants.

[7] Note that the terminology of pre-consumer (manufacturing waste) and post-consumer battery waste refers to the Battery Regulation terminology in the context of the requirements on the recycled content in batteries. This diverges from the definition of waste in the context of product carbon footprint applications: "Materials, co-products, products or emissions without economic value that the holder discards, intends to discard or is required to discard". Manufacturing waste or post-consumer batteries, for instance, have economic value.

5.1 General rules for recycled content emissions

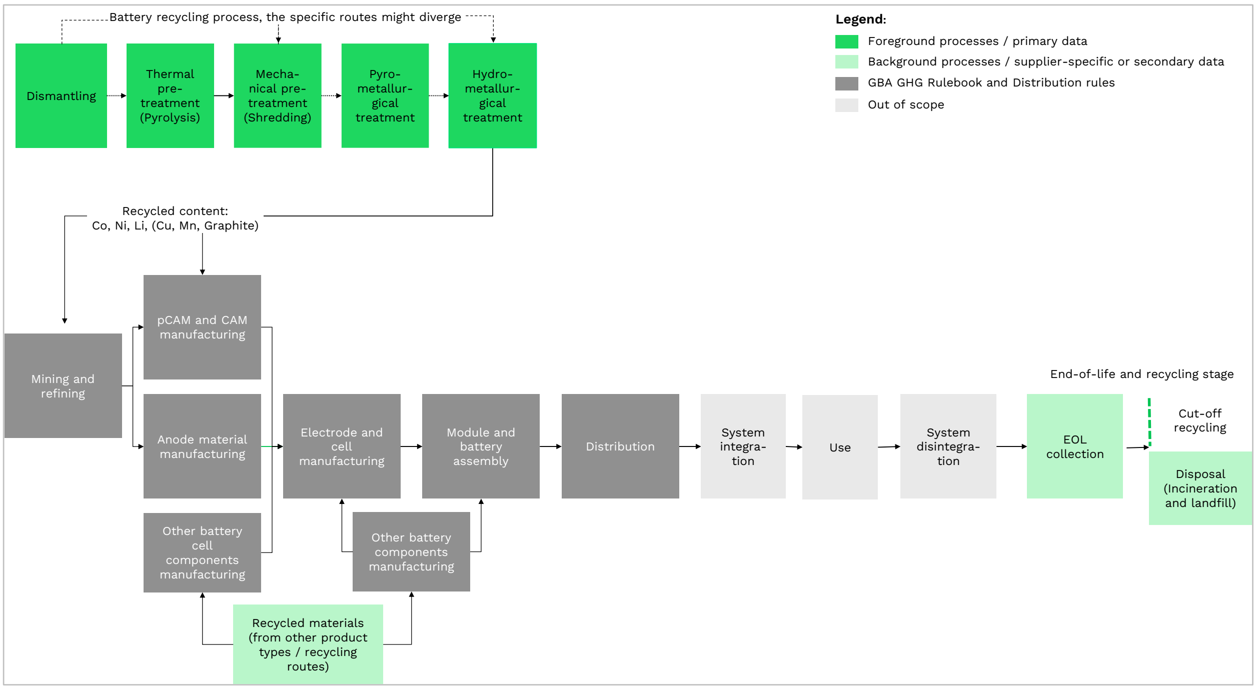
5.1.1 End-of-life and recycling allocation via the Cut-off approach

Following the cut-off approach, the processing and recycling emissions of the considered product system (battery) are allocated to subsequent product systems and not considered at EOL – only recycled content on the input side of production bears recycling emissions. Therefore, recycling emissions are accounted for as emissions associated with the recycled content in production processes. No burdens or credits are associated with the material from the previous life cycle, i.e. are set to zero before entering the recycling process. The End-of-life and recycling life cycle stage under the cut-off allocation thus includes only the EOL collection as well the waste incineration and landfilling processes following the polluter-pays-principle based on a recyclability assessment or statement of the materials (see Figure 4).

The share of recycled materials shall be reported on the input side of a process or product to enable the producer to calculate the recycled content of the battery (GBA, 2023). The amount of waste recycled shall be reported in three categories, while run-around scrap within the same plant shall not be considered (only waste treated outside of own operations):

- Pre-consumer waste (manufacturing waste, excluding run-around scrap)
- Post-consumer waste (end-of-life waste)
- Waste from unknown origin

Figure 4: End-of-life and recycling allocation in the Cut-off approach



5.1.2 Functional unit and reference flow of battery recycling processes

The recycling process requires unit flows that relate the recycling outputs to the individual cell composition, incorporating the yields of the respective recycling process. The functional unit for the individual recycling process steps shall be specified such that it refers to the characteristics of the respective process output (e.g. dismantled modules, black mass, secondary battery grade materials). The reference flow is the amount of product needed per process step to fulfill the function (measured in kilograms).

For the complete battery recycling process:

- **the functional unit shall be one kg of battery-grade material** (recovered from the needed mass of pre- or post-consumer battery packs/modules/cells for all metals and minerals in the recycling process). Battery-grade thereby is defined as the quality of the material complying to the material specifications for reutilization in batteries. For instance, the functional unit refers to the production of 1 kg $NiSO_4.6H_2O$ battery grade. The GHG emissions (in CO_2e) are calculated per the defined functional unit.
- **the reference flow shall be in kg of treated packs/modules/cells in the recycling process.**

5.1.3 Recycling-related system boundaries and processes

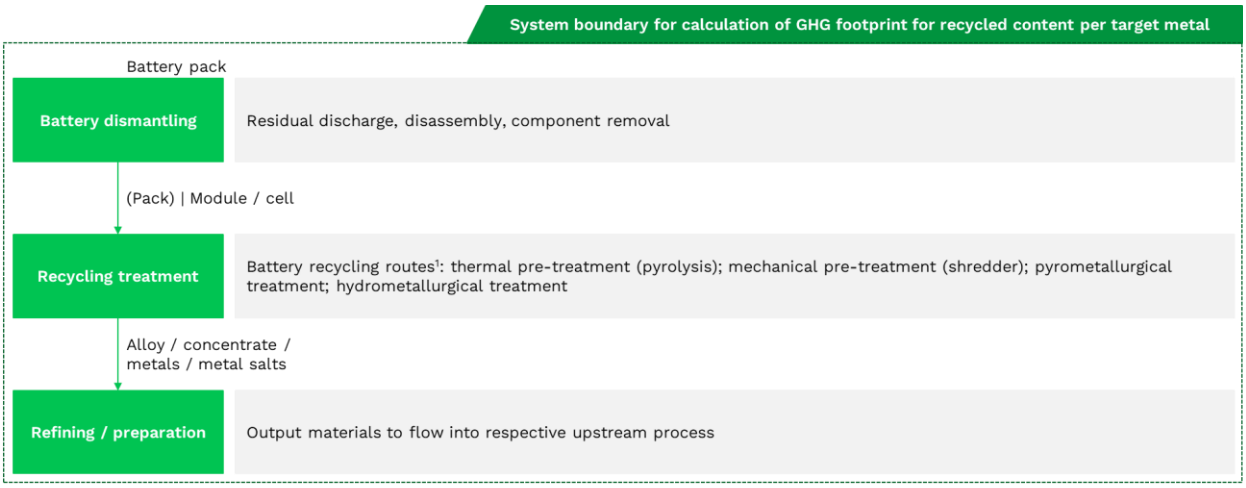
The carbon footprint calculation requires defining the system boundary for the EOL and recycling process in terms of setting a cut-off point (ISO 14044:2006). The EOL and recycling stage consists of the end-of-life collection (section 5.2), recycling treatment (section 5.3) and disposal of unrecyclable fractions (section 5.4). The system boundaries of recycling are commonly set after the waste batteries are collected (CEID 2020). Following the Cut-off approach where the recycling treatment is allocated as recycled content on the input side of production, the End-of-life and recycling stage only consists of the emissions associated with the collection of spent batteries as well as potential emissions from waste disposal (incineration and landfilling) since recycling emissions are accounted in the upstream production emissions. End-of-life collection is modelled as described in section 5.2. Disposal emissions that should be associated with the unrecyclable fraction of the considered battery are described in section 5.4.

The following umbrella process chart (Figure 5) shows the generalised process for recycled battery metals in the Cut-off approach. The GHG footprint system boundary of the recycled content thus starts with battery dismantling, and via the respective recycling treatment flows into the refining or preparation of the output materials.

The specific recycling treatment processes shall follow the general umbrella process:

1) Battery dismantling
2) Recycling treatment
3) Refining/preparation (to battery-grade recycled materials)

Figure 5: System boundaries of battery recycling as umbrella process chart



[1] The battery recycling routes vary per recycling provider. Batteries are usually dismantled into modules before mechanical treatment is applied. However, some providers mechanically treat entire battery packs. If pyrolysis is applied, it will be followed by or used in combination with mechanical treatment. Pyrolysis, mechanical and pyrometallurgical treatments are optional, but all routes usually end with hydrometallurgical treatment.

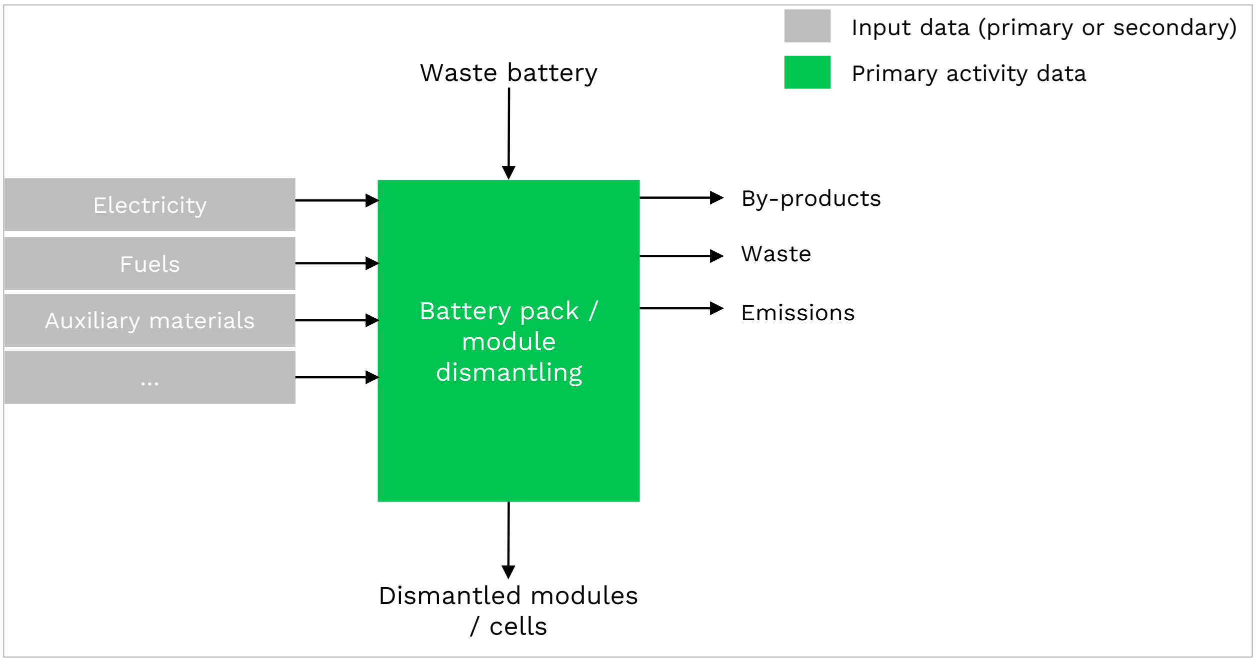
The recycling treatment processes focus on the recovery of CAM and anode materials in line with the current foreground processes of version 1.4 of the GBA GHG Rulebook. The system boundaries for other recycled materials, for instance in cell and pack components, are defined in section 5.3.8 Figure 17.

Consistency requires the end-of-life cut-off being made at a point which harmonises with the input data used for the secondary raw materials in the production stage, i.e. the recycled content needs to account for the emissions associated with the processes starting with discharging and disassembly.

Each of the above-mentioned generic recycling stages must have a reference to which all inputs and outputs are referred to, as shown in the respective following generalised flow charts (Figure 6, Figure 7, Figure 8).

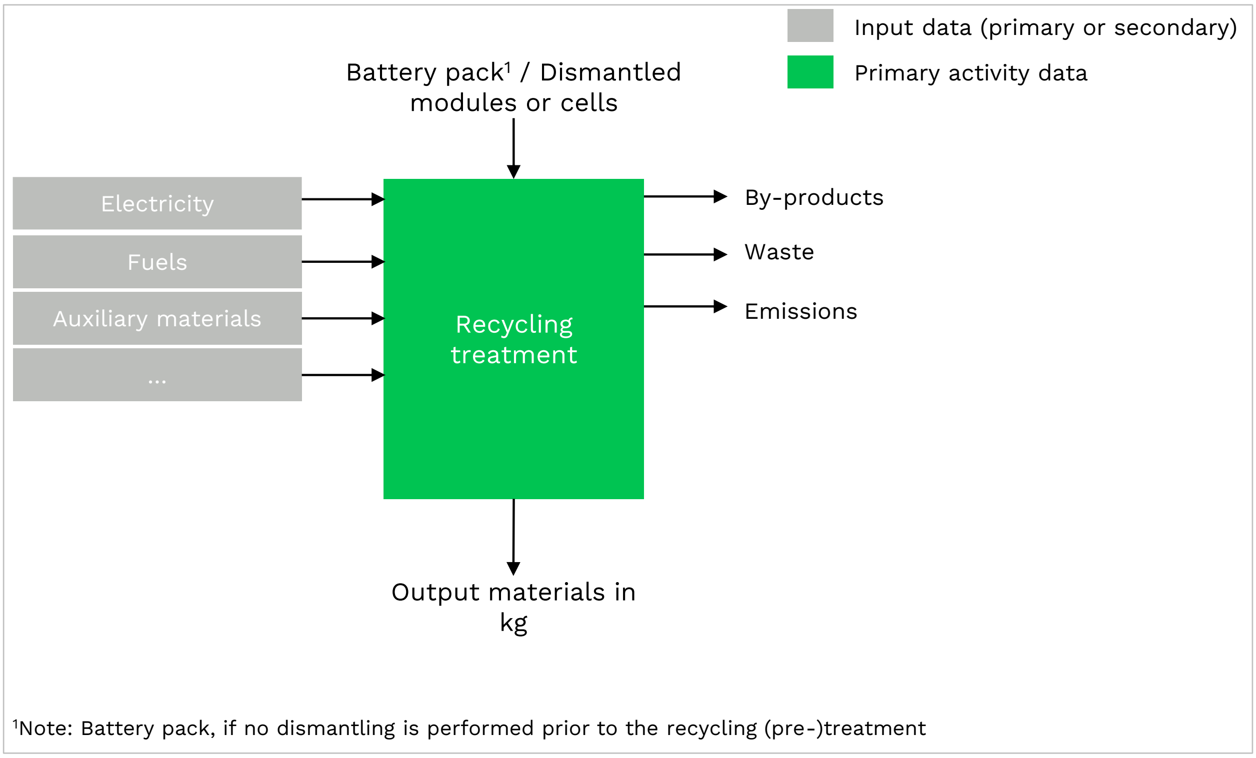
Dismantling

Figure 6: Generalised dismantling reference flow chart



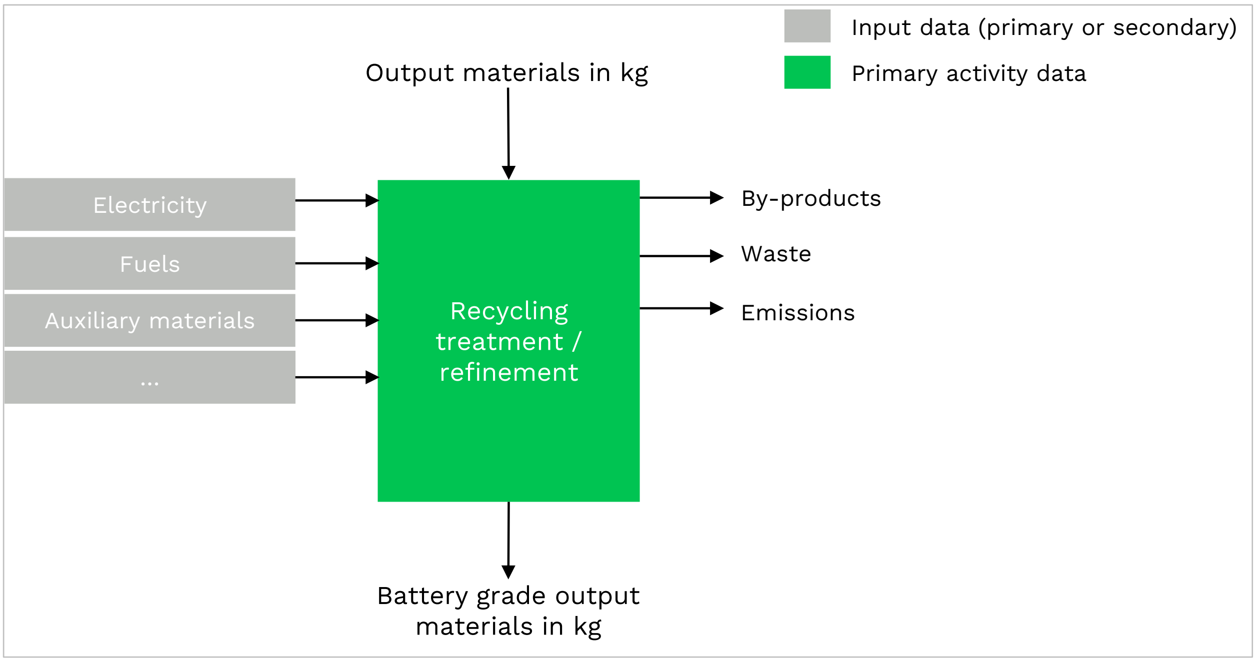
Recycling treatment (including potential pre-treatment steps)

Figure 7: Generalised recycling treatment reference flow chart



Further refinement (if recycling does not yield battery grade materials)

Figure 8: Generalised refinement treatment reference flow chart



5.1.4 Data collection requirements

The emissions arising in recycling processes vary depending on the specific cell chemistries as well as recycling routes and technologies employed (Mohr, et al., 2020). Therefore, in alignment with the foreground processes of the GBA GHG Rulebook, the user (i.e. recycler) shall collect activity data for each of these steps and calculate the carbon footprint on this basis using associated GHG emissions factors and GWP conversion factors.

The calculation of the recycling process emissions shall be based on a detailed modelling of input-output flows with company-specific activity data for the recycled battery grade materials. Only the resulting carbon footprint per material should be provided to the recipient of the recycled content. Main treatment emissions (i.e. pyro- and/or hydrometallurgical treatments or further refinement to battery grade) shall always be based on company-specific activity data. In case recyclers performing the main treatment do not operate the entire recycling processes, supplier-specific data shall be used for the steps not operated.

Guidance for modelling passive components (e.g., cell casing, battery management system, separator) and other components that potentially include recycled materials is not provided in the same detail. Nevertheless, manufacturers using recycled materials other than secondary battery grade materials shall include supplier-specific carbon footprint values as much as possible. As such, it is generally recommended to collect supplier-specific data for all materials and components, but particularly required for the pCAM/CAM and anode materials.

The data quality requirements as specified in section 3.6 of the GBA GHG Rulebook shall apply (GBA, 2023). In the European context, the data quality requirements and data needs matrix as prescribed by PEF and PEFCR must be applied (JRC, 2023; Recharge, forthcoming). In this context, the selection of datasets shall be in line with the hierarchy provided by the JRC (JRC, 2023; section 6.3). Activity data shall be used in combination with EF-compliant datasets that can be accessed through the EF reference packages. Where supplier-specific data is not available the most recent EF-compliant datasets[8] may be used.

The period for data collection is annual per default. This can be either calendar year or fiscal year. Which time period was used, shall be indicated in the data collection sheet.

Data collection and footprint calculation shall be site-specific per default. In case the battery module or pack is recycled in several locations (i.e. the recycling process chain is performed in several locations), and the carbon footprint shall represent the average product, the data shall be collected for all locations, and a weighted average shall be calculated.

If the recycling provider using these rules to calculate company-specific carbon footprints can prove that the use of site-specific footprints leads to negative environmental consequences overall, the provider may use a mass balance across plants and locations to provide a representative average over manufacturing plants. In this case, justification shall be provided. An example is that recycled materials are ordered from different world regions due to lower local footprint, effectively increasing transport emissions to the consumer. Proof shall be provided that this leads to overall negative impacts.

The input/output tables in the subsequent process-specific sections shall serve as guidance for the users of these rules and applies the data collection requirements to the processes. Additionally, data collection templates are developed to give more detailed guidance to the user in terms of which primary activity data is needed for the CF calculation and which additional information is required to facilitate the calculation.

The data collection tables and templates do not claim to be complete regarding processes or inputs and outputs and shall be amended if additional processes or inputs and outputs are required for the carbon footprint calculation.

5.1.5 Allocation in multi-output recycling processes

To determine the emissions associated with the recycled content used, it is necessary to calculate the carbon footprint based on the input-output activity data for the recycling processes producing the recycled material and include the footprint at the point of substitution where recycled materials are input back into production processes. The activity data are then multiplied with corresponding emissions factors. For battery materials, this may include the identification of the carbon footprint of the recycled content after some mixing of primary and secondary material flows has occurred.

Battery recycling processes are typically multi-output processes, i.e. yielding several valuable and functional outputs. For multi-output processes, the GHG emissions associated with the respective process step shall be partitioned between all process output products (co-product(s)) in a consistent way.

Definition of main product(s), co-product(s) and waste

Main products are defined “as products that the process is operated for and optimised to produce.” (TfS Initiative, 2022). Additionally, the economic values of the main products might be significantly higher than for the co-products, depending on the sector. In battery recycling, this generally conforms to battery-grade metal compounds. Co-products, in contrast, are defined as additional, co-occurring process outputs “with an economic value above zero, for

[8] European Platform on Life Cycle Assessment – currently, EF reference package 3.1. as most recent version: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

which demand at the specific production site is available, and evidence can be given that the co-product is used as intended” (GBA, 2023).

If process outputs do not have a net economic value or are not further processed into products, they will be treated as waste with the result that only the respective waste treatment GHG process emissions are partitioned to the respective main products and co-products. If net costs incur for the output, i.e. treatment costs exceed the revenue, this output shall be classified as waste. In the data collection, main product(s), co-product(s) and waste should be clearly differentiated by the user of these rules. The classification of outputs as co-products or waste might change over time and thus shall be done in line with the data collection requirements of this document. The modelling approach for manufacturing waste is described in section 5.1.6.

In the data collection, main product(s), co-product(s) and waste shall be clearly differentiated by the user of these rules. In the context of allocating multi-output processes, no differentiation between main products and co-products is made hereinafter.[9]

In some jurisdictions, there may be legal constraints to the definition of co-products (e.g., limits to storage durations). Proof shall be given that, in addition to fitting with the definition of co-product provided in this Rulebook, the distinction between waste and co-products is in alignment with prevailing legislation (for each 12 months reporting period). Recycling plants in the start-up phase require time to implement commercial relationships to sell co-products. A start-up period for a new recycling facility (new location, extension of capacity or exchange of entire production line) of maximum six months may be used to classify stored materials as co-products (e.g., material for which discard is not intended, but for which commercial arrangements are not yet in place).

Allocation for co-product(s)

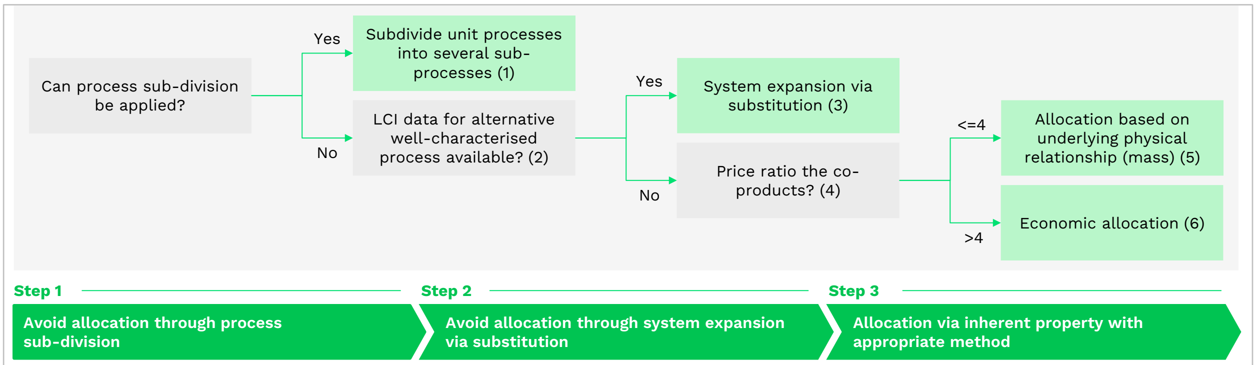
Following ISO 14044:2006 section 4.3.4.2, allocation generally shall be avoided if possible. Thus, recycling-related emissions shall be partitioned to co-product(s) in the following hierarchy:

- Subdivision of a unit process into several sub-processes
- System expansion by eliminating the co-product from the product system for which the carbon footprint shall be calculated by subtracting the GHG emissions of a functionally equivalent product produced by a well-characterised and representative alternative process, (PE International, 2014; Santero and Hendry, 2016; GBA, 2023)
- Allocation based on a relevant underlying physical relationship (i.e. mass)
- Allocation based on some other relationship (i.e. economic value)

For the application of this hierarchy, the user of these rules should follow the decision steps including the notes in Figure 9.

[9] In the activity data collection it shall be distinguished between main products and co-products to facilitate the assignment of the main products from the respective process steps to the functional unit of the subsequent recycling treatment steps. For the allocation of emissions to the respective process output products, the term co-product is used for all products (main products and co-products) resulting from the process.

Figure 9: Decision hierarchy and steps to solve multi-functionality/multi-output problems



(1) The end-of-life and recycling life cycle stage processes are to be divided into separate processes (i.e. collection, dismantling, pre-treatment, recycling treatment, disposal). However, it may not be possible to further sub-divide some multi-input/multi-output processes such as hydrometallurgical treatment.

(2) Well-characterised processes are those that do not require allocation amongst co-products, or for which allocation amongst co-products is clear and consistent on a global basis. The process is considered representative, when it is of superior weight, influence or prevalence on the market.

(3) System expansion via substitution may only be used if LCI data of a well-characterised representative alternative process is available for the material assumed to be substituted to calculate the credit.

(4) The price ratio of the co-products shall be calculated by dividing the highest by the lowest price of the specific output products at the point of separation and shall be based on stable market prices. In cases of strong price fluctuations, companies should use the average market price over the last 10 years to dampen price fluctuations.

(5) Following ISO 14044, allocation based on physical properties, i.e. mass of the process output product, should be prioritised. Mass allocation (mass of process output product) shall be applied if the ratio of economic price of the co-products is <=4.

(6) If the price ratio of the co-products is >4, economic allocation shall be applied by dividing the economic value (price x mass) of the respective product by the sum of economic values of all process products considering stable average market prices as described in note (4).

Step 1: Subdivision

According to the PEF methodology, subdivision means breaking down multi-functional (multi-output) processes to identify and isolate the inputs associated with each process output (EC, 2021). To avoid allocation, the user of these rules shall assess whether process subdivision is applicable. In battery recycling processes, subdivision is often not possible as these are integrated multi-input processes producing several outputs (e.g. hydrometallurgical treatment). Where process subdivision is possible, inventory data should be collected for those unit processes directly attributable to the products of concern at their point of separation. Process subdivision requires data being available at sub-process level, e.g. through metering at the production line. On aggregated process level, the data collection shall always be done for each of the respective recycling process steps (dismantling, pre-treatment, main treatment) separately – as provided in section 5.3.

Figure 10 provides an exemplary data collection for the hydrometallurgical treatment in case process subdivision can be applied. The example shows that only input and output data are collected for the unit processes that have been subdivided (and subsequently modelled using corresponding emissions factors). The incoming emissions from previous processes (e.g. the black mass from mechanical pre-treatment) shall be allocated to all process outputs of the sub-divided process steps (in step 7).[10]

[10] Note that in attributional carbon footprint accounting, allocation cannot fully be avoided in process sub-division as upstream emissions from previous process steps have to be included in the sub-divided process.

Figure 10: Exemplary data collection for the subdivision of the hydrometallurgical treatment

Collect activity data for the carbon footprint based on unit process-specific inputs and outputs (steps 1-6). Common input (i.e. black mass) shall be allocated to all outputs of all steps after the process-specific emission have been calculated step 7.

1) Leaching to remove graphite from black mass

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Graphite	kg	
Wastewater | Waste | Direct Emissions	multiple	

2) Precipitation to remove residues

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Residue	kg	
Wastewater | Waste | Direct Emissions	multiple	

3) Precipitation to extract Manganese compound

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Mangenese sulfate (MnSO4)	kg	
Wastewater | Waste | Direct Emissions	multiple	

4) Solvent extraction to extract Cobalt compound

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Cobalt sulfate (CoSO4)	kg	
Wastewater | Waste | Direct Emissions	multiple	

5) Solvent extraction to extract Nickel compound

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Nickel sulfate (NiSO4)	kg	
Wastewater | Waste | Direct Emissions	multiple	

6) Precipitation to extract Lithium compound

Material	Unit	Data
Input		
Electricity | Fuels | Auxiliaries | Water | Reagents | Additives	multiple	
Output		
Lithium carbonate (Li2CO3)	kg	
Wastewater | Waste | Direct Emissions	multiple	

7) Allocation of Black Mass Scope 3 upstream emissions to all final process output products

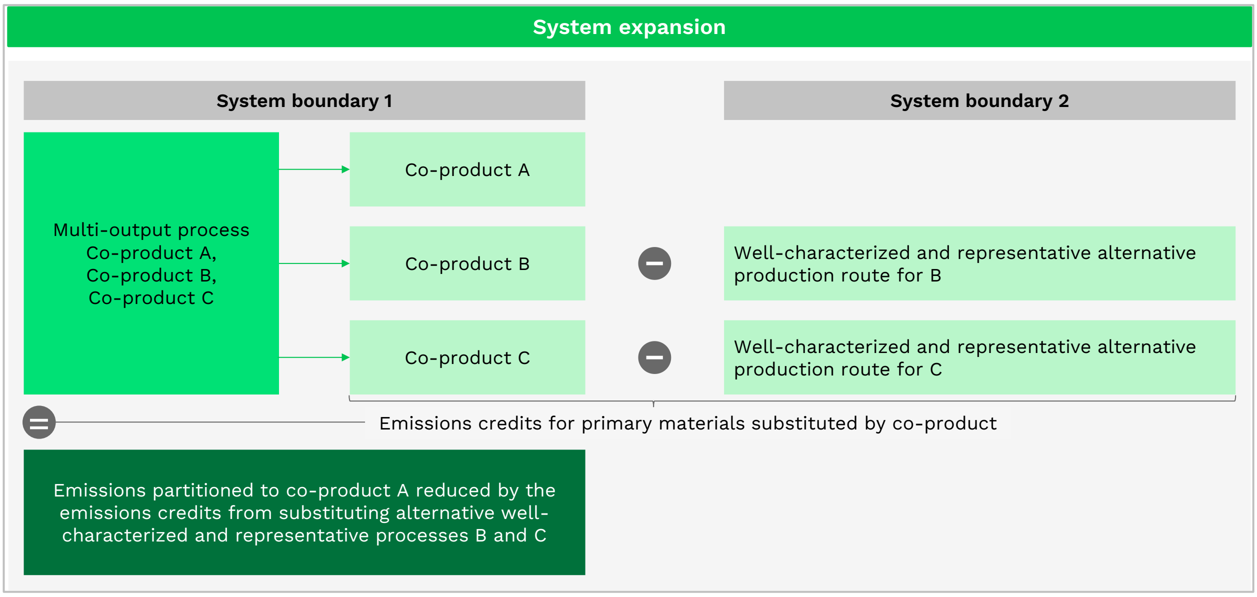
Step 2: System expansion for products with well-characterised and representative alternative process

If a process cannot be further subdivided, to avoid allocation using system expansion via substitution, data for an alternative production route with a well-characterised and representative process is needed (Santero and Hendry, 2016; TfS Initiative, 2022; GBA, 2023). System expansion should only be applied in cases where a well-characterised and representative alternative production route is available (i.e. the alternative production route does not require allocation amongst co-products or allocation amongst co-products is clear and consistent on a global scale; and is of superior weight, influence or prevalence in the market) (GBA, 2023).

Therefore, as a general rule, the user shall apply system expansion via substitution only for co-products that substitute materials for which LCI data for well-characterised and representative alternative routes are available. The respective alternative route shall be a dedicated and dominant[11] production process based on sector consensus (TfS Initiative, 2022; PACT, 2023). This requires direct knowledge of the function and eventual use of the co-product (GHG Protocol 2011).

[11] Dedicated means identifiable production process on the market specific to the displaced product. Dominant means that the production process is a prevalent/the main process on the market.

Figure 11: Avoiding allocation of emissions to products and co-products – system expansion via substitution



System expansion substitution proceeds as follows: the product, which is used in another product system and therefore replaces primary material, is credited with the carbon footprint of the substituted material (see Figure 11). Hence, an avoided process in the form of a well-characterised alternative production route that produces a product functionally equivalent to the co-product is subtracted from the recycling process system. Therefore, if co-product(s) of the recycling process system require(s) further treatment to achieve functional equivalence, the resulting process emissions should be taken into account before calculating the credits from system expansion. This includes the emissions from the transportation to the location of intended use and further processing emissions from co-products.

For example, sodium sulfate is increasingly recovered from hydrometallurgical processes and further treated in crystallisation or electrodialysis processes to obtain valuable products that replace virgin materials (e.g., fertiliser). Therefore, if economic value and use in a different product system are verifiably documented, the credits for sodium sulfate should be calculated only after accounting for emissions from transport to the processing site and further treatment. For including transport emissions, the respective buyer-specific transport distances shall be applied. Please refer to section 4.2.4 of the GBA GHG Rulebook and section 4.2.1 of this document.

To avoid counting the recycling benefit over two separate lifecycles (double counting), individual credits from system expansion substitution shall only be claimed once in the product system of the recycling process, i.e. producing the co-product, and not in a different product system using the co-product. This means, if the multi-output process subtracts credits for producing a co-product, then the co-product sold bears the footprint of the reference production system (TfS Initiative, 2022). In circumstances where the special market situation requires it (e.g., for reputational reasons), the user of the rulebook shall request from the user of the co-product from recycling (in different product systems) a confirmation that the used co-product is accounted with the carbon footprint of the substituted primary material (having been used as basis for credit).

To properly account for the substituted material, primary data for the replaced virgin materials shall be used. In case these are not available, secondary datasets for the substituted primary material(s) shall be applied (EF-compliant datasets to be prioritised; if this data is not available, datasets by industry associations should be used). In each case, data for material(s) with the same functionality and inherent properties (e.g., quality/purity) shall be used. Additionally, the data from the same geographical region shall be used to not overestimate the credits.

Evidence shall be given in the verification of the GHG footprint (e.g., by contracts or supplier agreements) that technically the chosen material that is assumed to be substituted is appropriate and the co-product is used for the intended application. The appropriateness of the selection of the product from the alternative production route shall be verified for each carbon footprint. A third party shall verify the economic value of the co-product with specific properties (e.g., purity/grade, net calorific value, water content, etc.) at the facility gate, as well as the share of the co-product for which the price is paid.

Step 3: Allocation based on inherent properties for products with no well-characterised and representative alternative route

Even though allocation shall be avoided, this is not always possible. In case the process cannot be further subdivided and no well-characterised and representative alternative route is available to perform system expansion, allocation based on inherent properties shall be applied. This is the case for e.g., base metals, where co-products occur within the production process, such as copper, molybdenum, nickel, lead or zinc (Santero and Hendry, 2016).

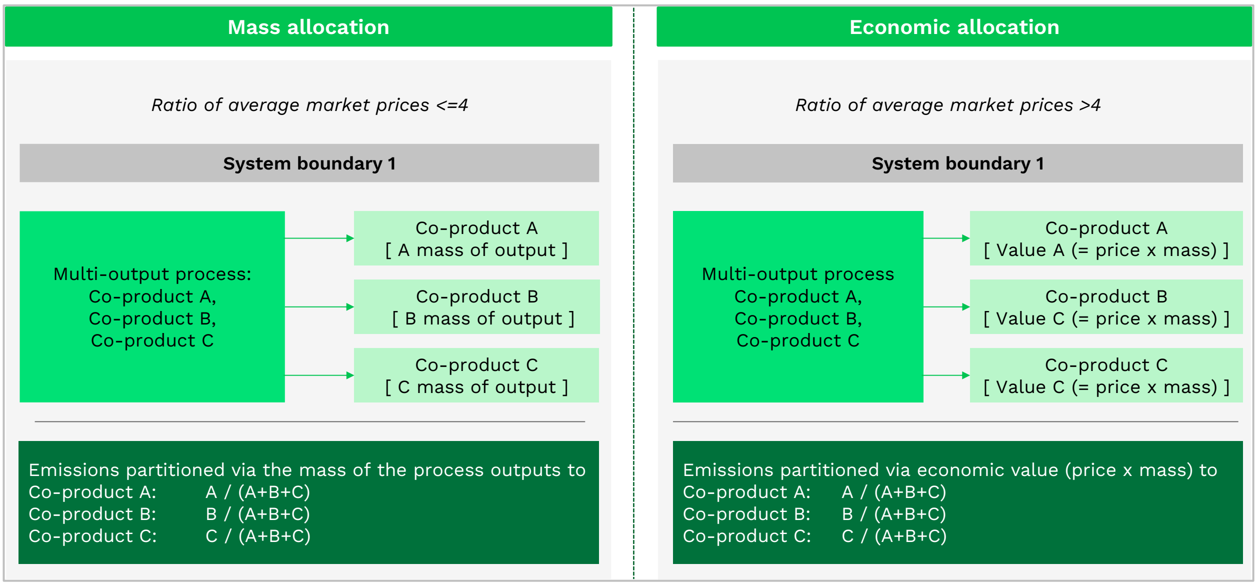
As described in the allocation hierarchy, to determine the applicable type of allocation, the ratio of the market prices of all co-product(s) needs to be identified. If the share of a co-product is very small (in mass or volume below or equal to 3%), it can be neglected in the determination of the price ratio. If there are more than two co-products, the highest and lowest price per unit of the co-products shall be used to determine the price ratio by division of the prices (TfS Initiative, 2022). The price for the specific product outputs at the point of separation in the respective process shall be used (e.g. shredding fractions such as black mass). This ratio implies that product(s) with significantly higher economic value can be considered the driver of the process without which the production would not take place. The calculation of the price ratio shall be based on stable, and in case of strong price fluctuations, average market prices.

When the ratio of the price of the products coming out of the process is greater than four, economic allocation shall be applied. Thereby, the average prices for the materials as described below shall be used (not revenues or costs). The economic allocation factor applicable for the allocation is obtained by dividing the economic value (mass multiplied by average market price) of one co-product by the sum of economic values of all co-products (see Figure 12). This factor is then to be applied to all input and output streams of the considered process to thus allocate shares of the GHG emissions of the process to the different co-products arising from the process (GBA, 2023).

For calculating both the price ratio and the products' economic values, the GBA GHG Rulebook applies: "The relative economic value of co-products should be calculated on the basis of stable market prices. For metals, 10-year average global market prices, e.g., as published by the World Bank (The World Bank, 2022) shall be applied as recommended by Santero & Hendry (2016) to avoid the impact of high price-volatility in global markets. The used market prices shall reflect the specific conditions in terms of e.g., purity or other properties which have an impact on the global market price." (GBA, 2023). In case specific metal compound prices are available for 10-year averages, these may be used instead of commodity prices.

When the ratio of the price of the products coming out of the process is lower than or equal to four, allocation based on mass of the process output products[12] shall be applied. As displayed in Figure 12, the mass-based allocation factor for the respective materials is obtained by dividing the product mass of one co-product by the sum of masses of all co-products. This factor is then to be applied to all input and output streams of the considered process to thus allocate shares of the GHG emissions of the process to the different co-products arising from the process (GBA, 2023).

Figure 12: Allocation of emissions to products and co-products – mass allocation versus economic allocation



[12] Process output product refers to the product of the respective process step being compounds or fractions. Note that it does not refer to metallic mass in the output products. As an example, it refers to the mass of Nickel sulfate hexahydrate (NiSO4.6H20), not the mass of the Nickel content in the compound.

Example of mass and economic allocation in hydrometallurgical treatment:

The following exemplary multi-output allocation calculations for the hydrometallurgical recovery showcase the differences in the resulting allocation factors and provide guidance on selecting and calculating the allocation factor. The two examples are given based on inventories from Recharge (forthcoming) for (A.1-A.2) a NMC721 battery and Mohr et al. (2020) for (B.1-B.2) a NMC111 battery. Prices are global 10-year average prices for the commodity metals as proxies taken from World Bank (2022) and US Geological Service (2023). As the price ratio between the lowest and highest market price averages are above 4, economic allocation shall be applied. To obtain the economic allocation factor, the 10-year average prices are multiplied with the output products' masses.

Figure 13: Mass allocation factors in hydrometallurgical recycling based on NMC 721 and NMC111 inventories

Exemplary

A.1 **Mass allocation** in hydrometallurgical treatment: NMC721 inventory [Recharge (forthcoming)]

	Main products and co-products	Product mass *kg / kg battery*	Mass allocation factor
Main products	Lithium carbonate (Li2CO3)	0.0226	**5%**
	Manganese sulfate (MnSO4. H2O)	0.0426	**10%**
	Cobalt sulfate (CoSO4.7H2O)	0.0838	**19%**
	Nickel sulfate (NiSO4.6H2O)	0.253	**59%**
Co-products	Aluminium ingot	0.00893	**2%**
	Copper mix	0.0212	**5%**
	Sum	**0.432**	**100%**

B.1 **Mass allocation** in hydrometallurgical treatment: NMC111 inventory [Mohr et al. (2020)]

	Main products and co-products	Product mass *kg / kg treated cell*	Mass allocation factor
Main products	Lithium hydroxide (LiOH)	0.082	**10%**
	Manganese sulfate (MnSO4.H2O)	0.168	**20%**
	Cobalt sulfate (CoSO4.7H2O)	0.173	**20%**
	Nickel sulfate (NiSO4.6H2O)	0.172	**20%**
Co-products	Aluminium	0.054	**6%**
	Copper	0.213	**25%**
	Sum	**0.862**	**100%**

Source: Inventories from A.1 Recharge (forthcoming) B.2 Mohr et al. (2020).

Figure 14: Economic allocation factors in hydrometallurgical recycling based on NMC 721 and NMC111 inventories

Exemplary

A.2 **Economic allocation** in hydrometallurgical treatment: NMC721 inventory [Recharge (forthcoming)]

	Main products and co-products	Product mass *kg / kg battery*	Market price (10-y average) *USD / kg*	Economic value = mass x price *USD*	Economic factor
Main products	Lithium carbonate (Li2CO3)	0.0226	68.03 [a]	1.54	**17%**
	Manganese sulfate (MnSO4.H2O)	0.0426	2.90 [a]	0.12	**1%**
	Cobalt sulfate (CoSO4.7H2O)	0.0838	40.92 [a]	3.43	**38%**
	Nickel sulfate (NiSO4.6H2O)	0.253	14.89 [b]	3.77	**42%**
Co-products	Aluminium ingot	0.00893	1.97 [b]	0.02	**0.2%**
	Copper mix	0.0212	6.76 [b]	0.14	**2%**
	Price ratio highest vs. lowest		**14**		**100%**

B.2 **Economic allocation** in hydrometallurgical treatment: NMC111 inventory [Mohr et al. (2020)]

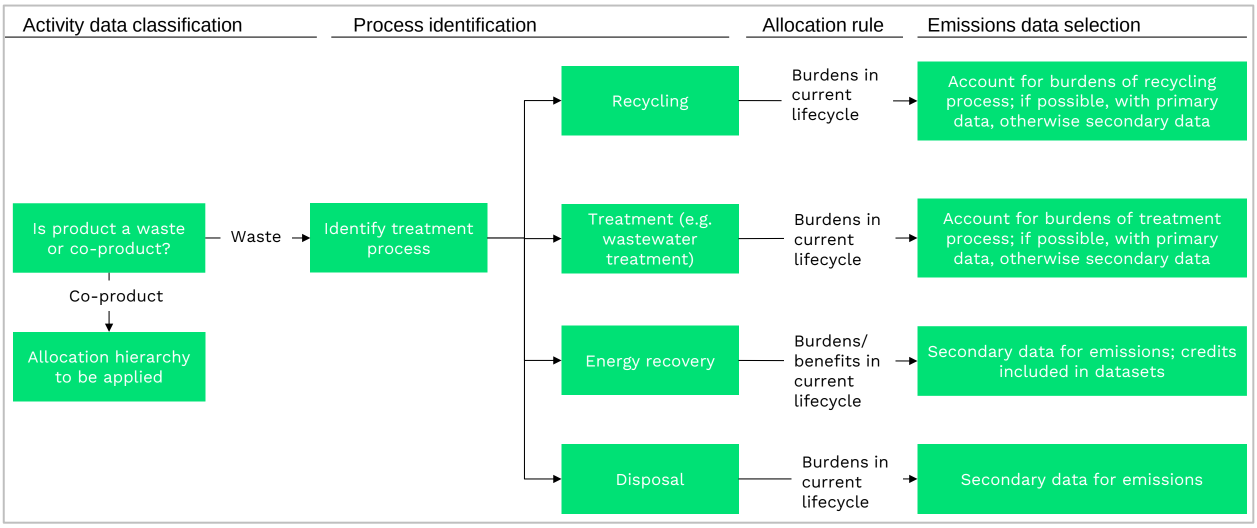
	Main products and co-products	Product mass *kg / kg battery*	Market price (10-y average) *USD / kg*	Economic value = mass x price *USD*	Economic factor
Main products	Lithium hydroxide (LiOH)	0.082	68.03 [a]	5.58	**32%**
	Manganese sulfate (MnSO4. H2O)	0.168	2.90 [a]	0.49	**3%**
	Cobalt sulfate (CoSO4.7H2O)	0.173	40.92 [a]	7.06	**41%**
	Nickel sulfate (NiSO4.6H2O)	0.172	14.89 [b]	2.57	**15%**
Co-products	Aluminium	0.054	1.97 [b]	0.11	**1%**
	Copper	0.213	6.76 [b]	1.44	**8%**
	Price ratio highest vs. lowest		**14**		**100%**

Sources: Inventories from A.2 Recharge (forthcoming) and B.2 Mohr et al. (2020). 10-year average commodity prices are taken from a. United States Geological Services (USGS) (2023) and b. World Bank (2022). Note that prices for metal commodities (e.g. Nickel) have been used as specific metal compound prices are only accessible from specialised market data service providers and therefore impractical.
Notes: **All 10-year-average prices refer to prices for 100% metal content**. As lithium carbonate and manganese prices refer to differing metal contents, these were calculated stoichiometrically to reflect 100% metal content. The 10-y-average Lithium Carbonate price from USGS is 12.93 USD (Li-content 19%). The 10-y-average Manganese price from USGS is 1,28 USD (Mn-content 44%).

5.1.6 Manufacturing waste allocation

The allocation of manufacturing waste (i.e. waste occurring during the production process) shall follow a consistent application of these rules when collecting the activity data and attributing related carbon emissions. In general, waste shall be modelled by allocating the waste burdens (e.g. from incineration or landfilling) to the process output products for which the carbon emissions are collected and calculated. The emissions from treating manufacturing scrap, which is material that is recovered in further operations (e.g. recycling), shall also be attributed with the burdens in the current life cycle. Figure 15 shows the modelling approach for manufacturing waste. First, the collected activity data has to be classified in terms of whether the process output is waste or a co-product. In addition to the definition of co-product provided in this Rulebook (net economic value above zero, see section 5.1.5), the distinction between waste and co-products shall be in alignment with prevailing legislation and therefore might change over time. Second, if the classification yields that the output is waste, the treatment process shall be identified. Third, as a general rule, process emissions shall be allocated to the process output products in the current lifecycle. Fourth, emissions data for the identified process shall be multiplied with the collected activity data.

Figure 15: Modelling approach for pre-consumer / manufacturing waste



5.1.7 Calculation of the carbon footprint

The collected primary activity data shall be used in combination with EF compliant datasets for the emissions factors. The resulting emissions are attributed to the functional unit by adding up the emissions of all attributable processes along the specific recycling route operated by the user of these rules. The impact category shall be Global Warming Potential (GWP), also referred to as Climate Change. To transform other GHG emissions into carbon emissions, the GWP impact category is based on the IPCC GWP factors published in the 6th Assessment Report in table 7.15 (IPCC 2021).

A general equation to calculate the carbon footprint based on activity data, emissions factors and GWP impacts is as follows (with units indicated below):

$$Carbon\ footprint = Activity\ data\ x\ emissions\ factor\ x\ GWP\ 100\ factor$$

$$(kg\ CO2\ eq.)\ =\ (amount\ of\ unit)\ x\ (kg\ GHG/unit\ of activity)\ x\ (kg\ CO2e/kg\ GHG)$$

5.2 End-of-life collection

The carbon footprint shall include the end-of-life collection of spent batteries. Related emissions result from the transport from a collection place where the spent battery is disassembled from the used system to the end-of-life treatment.

The transport from collection place to the end-of-life treatment for unrecyclable fractions is included in the landfill and incineration EF-compliant datasets (see section 5.4). For modelling the transport-related emissions to the recycling treatment, the user of the rules shall specify the transport and vehicle type as well as transport distance and utilisation ratio. The data collection and partitioning of end-of-life transport-related emissions follows the approach as outlined in section 4 (Distribution rules).

In case specific values are not available, the following values shall be used (Recharge, 2018):

- **Transport to the EOL recycling**
  Intracontinental supply chain: 200 km by truck (28-32 t, EURO 5; UUID 0aa65e8b-70c8-4b7f-b1d7-91a6403d2b5a) with utilisation ratio 64%

5.3 Recycling processes – data collection guidance

Today, most battery recycling processes consist of a combination of pyrometallurgical and/or hydrometallurgical processes including pre-treatment such as dismantling and/or pyrolysis and mechanical shredding (Wagner-Wenz, et al., 2022). Battery pack dismantling includes the electrical deactivation of the spent battery as well as the disassembly of the battery pack into modules or cells. Alternatively, pyrolysis (high temperature treatment >200°C) could be applied to deactivate the battery. Subsequently, three process technology types are commonly applied, which are combined in varying steps: mechanical, pyrometallurgical, and hydrometallurgical processes. Current industrial recycling treatment processes for lithium-ion batteries involve pyrometallurgical (high temperature) and/or hydrometallurgical (chemical) separation methods for the contained metals. However, these routes vary strongly depending on the recycling provider (see Figure 16). In the following sub-sections, the generic data collection and allocation requirements for the major process steps of these routes are described.

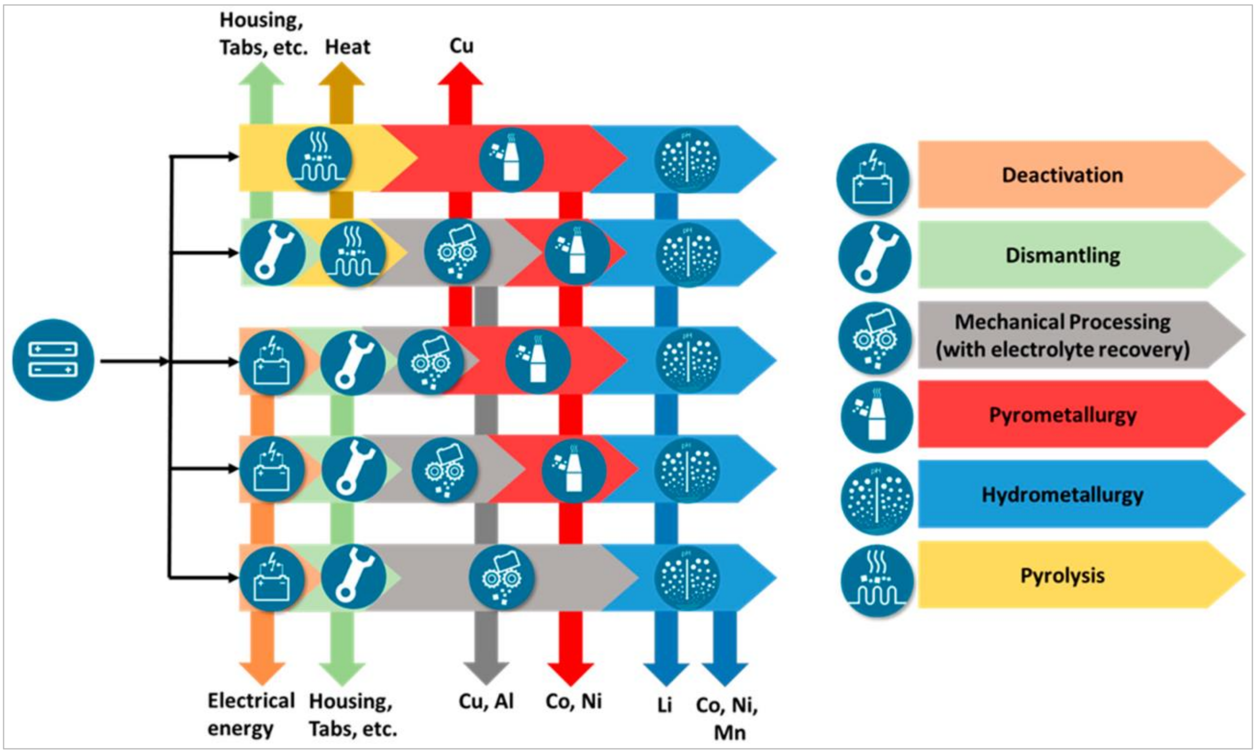
The user of these rules shall include each step of the recycling process chain applicable to the respective operation that leads to recycled battery materials in line with the system boundaries (section 5.1.3). The user shall outline the process route operated in the documentation. Where a battery recycling provider follows a different route than displayed in Figure 16, the generic data collection shall be extended to include new processes and routes into the recycling value chain. Co-production is a special case being discussed in section 5.3.7.

Depending on the specific route and combination of treatment processes, the recycled output materials and their quality differ as the various metallurgical recycling steps may not entirely cover refining to battery-grade materials. Additional refining steps should be modelled and documented to represent the functional unit. Waste occurring in the recycling treatment process chain needs to be accounted for in the respective step.

The recycling provider (i.e. recycled content provider) using these rules to calculate the recycling emissions shall include all relevant process steps and calculate the carbon footprint for the respective steps separately, which on an aggregated level form the overall carbon footprint of the recycling process. Additionally, the user shall report overall recycling efficiencies of the process. The recycling efficiencies (yield) of the overall process need to comply with the recycling efficiencies minimum levels of recovered materials set out in the EU Battery Regulation (see Annex 0).

Furthermore, the respective user shall calculate the transport between the different process steps up to the recycled material that flows into the upstream production process with the respective transport means, which is described in the rules on transport-related emissions for distribution (please refer to section 4 of this document).

Figure 16: Different recycling process routes for waste batteries (Doose et al. 2021)



5.3.1 Discharge and dismantling (if required)

Process description

Usually, the first process step includes the deactivation of the spent battery system having been dismantled from the final product (if applicable). The dismantling from the final product is not included in the system boundary. The deactivation of the battery is followed (but not compulsory) by dismantling the battery system to modules or, rarely, to individual cells.

The deactivation frequently proceeds by full electrical discharge and subsequent short circuiting or by pyrolysis of the battery systems. If pyrolysis is the first processing step, refer to section 0. Discharge is vital prior to disassembly to guarantee stabilisation and security as the energy content in the battery can cause adverse chemical reactions (e.g., short circuiting) and due to safety reasons in currently mostly manual dismantling processes. Electrical discharge is followed by a dismantling procedure, where passive components such as casing, connection and sealing materials of the battery pack are removed before further treatment and the battery pack is separated into modules (and in some cases even cells). The removed components are typically introduced to conventional recycling methods for aluminium, iron, copper, polymers, and others.

Data collection requirements

The user of this rulebook shall make reference to which inputs and outputs are referred to, as shown generally in Figure 6. No emissions credits shall be given for the discharged electricity in the deactivation process. If it is demonstrated that the electricity is reutilised in the same production site and therefore replaces procured electricity, this may be reflected in the electricity input for the CF calculation (only newly procured/produced energy is accounted for).

The data collection shall cover all related operational processes during the discharging and dismantling (prior to further treatment) to obtain at the end the dismantled modules or cells to be sent to the recycling treatment process steps. The following table includes a generalised minimum list of input and output parameters the use of these rules shall collect. The user shall state the exact unit, as well as give additional information in the specification field (for instance for the conversion of unit metrics).

Allocation

In the dismantling process, economically valuable components are dismantled from the battery (e.g. BMS, casing, connectors). If the conditions of system expansion are not met (alternative well-characterised and representative routes), allocation shall be applied. Since it is likely that the economic value at EOL of some of these components is significantly higher than other co-products (e.g. copper scrap compared to aluminium scrap), economic allocation as presented in section 5.1.5 may apply. The user of the rulebook shall assess the applicability of economic allocation. Thereby, the price of the components shall be taken as the basis. Only if these are not available, the value of the embedded materials may be used.

For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 3: General input-output table for dismantling process

Material	Unit	Data	Specification
Input			
Spent battery	kg		
Electricity	kWh		
Fuels	kg		
Auxiliary materials	kg		
Water	l		
Output			
Modules/cells	kg		
Co-products	kg		
Waste	kg		e.g. dust
Direct GHG emissions	kg		

5.3.2 Thermal pre-treatment – pyrolysis (if required)

Process description

Thermal pre-treatment offers a controlled deactivation, discharge and decomposition to remove carbon and organic components (Makuza, et al., 2021). Pyrolysis is the process of heating the battery material above its decomposition temperature in an oxygen-free environment to facilitate the thermal decomposition of organic compounds, which can be used as fuel or chemical feedstock. The active cathode material can withstand the pyrolysis temperature and remains as a solid residue, which is then further processed during the subsequent recycling steps.

Data collection requirements

The data collection shall cover all related operational processes during thermal pre-treatment required to reach the next recycling treatment process step. Combined thermal-mechanical pre-treatment processes exist, yielding pyrolysed black mass. Both pre-treatments as described in these rules may be modelled in combination using the relevant input-output tables. A separate data collection sheet provides a combined data template. Off-gas treatment needs to be accounted for in the process activity footprint calculation. The same applies to wastewater treatment. Where electrolytes and graphite evaporate in the thermal pre-treatment, direct emissions shall be included.

The following table includes a generalised minimum list of input and output parameters the use of these rules shall collect. The user shall state the exact unit, as well as give additional information in the specification field (for instance for the conversion of unit metrics).

Allocation

Typically, metal fractions are produced as co-products. As there is likely no well-characterised and representative alternative for metals, metal fraction co-products shall be allocated either economically or via final product output mass. For other materials, these co-products may be given system expansion credits if the conditions of the allocation rules in section 5.1.5 apply (particularly alternative well-characterised and representative routes, verification of economic value). If these alternative routes cannot be identified, economic or mass allocation applies.

For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 4: General input-output table for thermal pre-treatment

Material	Unit	Data	Specification
Input			
Spent battery / dismantled modules	kg		
Electricity	kWh		
Fuels	kg		
Auxiliary Materials	kg		
Industrial gases	m^3		
Water	l		
Output			
Solid battery residue	kg		(for further treatment)
Co-products – Metal fractions	kg		
Co-products – Other	kg		
Off-gases for further treatment	kg		
Waste	kg		
Direct GHG emissions	kg		Graphite and electrolyte, if thermally lost

5.3.3 Mechanical pre-treatment / shredding (if required)

Process description

Mechanical treatment includes mechanically crushing/shredding (potentially with gas treatment under inert atmosphere) dismantled battery modules or cells (comminution), followed by air classification, sieving and magnetic separation. This yields black mass and, through some segregation processes, other co-products such as polymer flakes from separators, aluminium and copper fractions from foils or ferrous/non-ferrous metal fractions from the casing. Additionally, one possible route for graphite treatment might be separation before the black mass is produced (see the example of graphite treatment in the box below which shall serve as the basis for deciding on treating co-products). Drying can be a part of the mechanical treatment, yielding electrolyte as a co-product. The electrolyte treatment processes (especially if thermally treated) could lead to direct carbon dioxide emissions that need to be included in the CF calculation. The off-gas emerging from this process step is cleaned via condensing and an activated carbon filter which needs to be replaced and reprocessed periodically (Mohr, et al., 2020). The degree of mechanical processing varies and thus determines the amount of recovered materials as the amount and quality of recovered materials increases with more complex mechanical treatment. Subsequently, the black mass is pyrometallurgically processed before it goes into a final hydrometallurgical step or directly introduced into hydrometallurgical treatment.

Potentially, entire battery packs are mechanically processed. This yields additional co-products such the fractions from the battery/cell casing and wiring.

Example graphite treatment:

The example of graphite highlights that battery recycling process outputs can vary strongly depending on the technical design. It shall serve as basis for classifying and accounting for typical co-products/waste from the respective recycling process steps (such as electrolyte). The recovery of graphite can follow four routes:

(1) Separated in mechanical pre-treatment

Graphite might be separated before the black mass is produced in the mechanical pre-treatment. Depending on the economic value (potentially as energy carrier substitute) and local waste legislation, the user of these rules shall determine whether graphite is to be treated as a co-product or waste.

(1 a) Sold as co-product

If the net economic value of graphite removed in the mechanical pre-treatment is above zero and local legislation does not classify it as waste, the allocation hierarchy in section 5.1.5 applies.

(1 b) Incinerated (as waste)

If the classification yields that the removed graphite is waste, the waste modelling approach in section 5.1.6 applies and burdens of further treatment shall be allocated to the output products of the mechanical pre-treatment step.

(2) Thermally recovered in pyrometallurgical or thermal pre-treatment

The according carbon emissions from thermal treatment shall be accounted as direct process emissions with the carbon content of the graphite.

(3) Recovered in hydrometallurgical treatment

If black mass still contains graphite, and this graphite is recovered as a co-product, the allocation rules as defined in section 5.3.5 apply as a co-product in the hydrometallurgical treatment. However, in case the graphite is not valorised, case 1b is applicable.

For all described routes, the quality of outgoing graphite shall be documented in the data collection as it is important for accounting associated impacts.

Data collection requirements

Depending on the overall process design (i.e. no thermal pre-treatment prior to mechanical pre-treatment), the black mass might require pyrolysis/thermal treatment (e.g., roasting) prior to hydrometallurgical processes to remove the organic components and to concentrate the metal content (Brückner, et al., 2020). In this case, please refer to and adapt accordingly the data collection in section 5.1.4. Combined thermal-mechanical pre-treatment processes exist, yielding pyrolysed black mass. Both pre-treatment as described in these rules may be modelled in combination using the relevant input-output tables. A separate data collection sheet provides a combined data template.

It is important to calculate GHG-relevant process emissions such as during the off-gas treatment. In case off-gases occur, their treatment needs to be accounted for in the process activity footprint calculation. This applies to other processes that might be required during mechanical pre-treatment.

Allocation

Mechanical pre-treatment separates battery materials into black mass and several other co-products. Typically, metal fractions are produced as co-products. As a first step, it shall be assessed whether process subdivision can be applied at the points of separation for the respective co-products, in line with section 5.1.5. As a second step, it shall be evaluated whether system expansion applies for eliminating co-products from the system boundary. Since there is likely no well-characterised and representative alternative for metals, metal fraction co-products shall be allocated either economically or via mass, depending on the price differential as described in section 5.1.5. For other materials such as polymer flakes, graphite or electrolytes, these co-products may be given system expansion credits if the conditions of the allocation rules in section 5.1.5 apply (particularly well-characterised and representative alternative routes, verification of economic value). If these alternative routes cannot be identified, economic or mass allocation applies. When the price ratio between all process output products exceeds four, economic allocation shall be applied. This is likely the case but depends on the composition of the treated battery, which is why the user of the rulebook shall assess the applicability of economic allocation in line with the allocation requirements.

For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 5: General input-output table for mechanical pre-treatment/shredding

Material	Unit	Data	Specification
Input			
Dismantled modules/cells | Battery pack	kg		
Electricity	kWh		
Fuels	kg		
Auxiliary Materials	kg		
Industrial gases	m^3		
Water	l		
Output			
Black mass	kg		
Co-products – Metal fractions	kg		E.g., copper, aluminium, steel
Co-products – Other	kg		E.g., polymer flakes, electrolyte, graphite
Off-gases for further treatment	kg		
Waste	kg		
Direct GHG emissions	kg		

5.3.4 Pyrometallurgical treatment (if required)

Process description

Pyrometallurgical processes (e.g., smelting in blast furnace or electric arc furnace) are well established for extracting materials from metal fractions and can achieve high recovery yields for cobalt, nickel, and copper. These extract metal by heating the battery/module/cell scrap with products of a metallic alloy, slag and gases in the processes. However, challenges regarding the recovery of other materials exist as lithium, manganese, and graphite are lost into the slag depending on the battery composition (Rinne, et al., 2021). To be able to recover lithium and manganese, pyrometallurgical processes have to be combined with hydrometallurgical processes for recovering the lithium- and manganese-containing slag or cobalt-, nickel-, copper-containing alloy/matte. Overall, a relatively small total recovery of the battery materials can be expected in this case due to graphite, polymers, and electrolyte being burned, although a very high recovery of nickel, cobalt, and copper is possible.

Pyrometallurgy includes high-temperature processes such as roasting or smelting for recovering and refining metals. Roasting describes processes that include a gas–solid reaction (oxidising roasting) to purify the ore or secondary material. Smelting describes processes that extract a metal from an ore or secondary material using heat and a chemical reducing agent to decompose the secondary material. This drives off other elements as off-gases or slag and leaves the metal base as alloy/matte for further processing and refinement (Brückner, et al., 2020). The reducing agent is commonly a source of carbon, potentially originating from the battery itself. In this process, untreated battery modules/cells can be directly fed into the furnace. After the reduction smelting process, the metals are concentrated into a molten alloy (Makuza, et al., 2021).

The pyrometallurgical process yields a cobalt, copper, and nickel-containing alloy (metallic phase) or matte (sulfidic phase). Additionally, an aluminium-, manganese- and lithium-containing slag (oxidic phase) as well as a fly ash are produced. These processes often only produce intermediates that require further hydrometallurgical refining. Thus, to recover the individual metals, the alloy is introduced to hydrometallurgical processes. The fly ash is usually used as an outlet for undesirable elements such as fluorine and hence, it is disposed of (Brückner, et al., 2020).

Data collection requirements

The data collection shall cover all related operational processes during the pyrometallurgical process required to reach the next recycling treatment process step. It is important to calculate GHG-relevant process emissions such as during the reduction process. In cases where cokes or graphite is used as reducing agent, these can be very important contributions to the carbon footprint. Furthermore, off-gas treatment needs to be accounted for in the process activity footprint calculation. The same applies to wastewater treatment. An additional important specification to be stated is the quality of output metals and the yield. This is an important factor for cross-checking the recycling balance over the whole process chain. The grade/purity level of the output metals shall be reported (assay data) as well as the recycling yield.

Allocation

If recycling providers co-produce with primary materials, sulphuric acid from SO_2 scrubbing and recovered heat (as steam or thermal energy) are co-products from the process (see also section 5.3.8). Where the conditions of the allocation rules in section 5.1.5 apply (particularly well-characterised and representative alternative route as well as verification of economic value), these shall be allocated via system expansion credits. The credits for co-products shall be calculated only after accounting for emissions from transport to the processing site and further treatment. For including transport emissions, the respective buyer-specific transport distances shall be applied. The user of these rules shall clearly classify co-products and provide justification in the technical documentation. If system expansion is not applicable, economic or mass allocation shall be applied depending on the price differential of the co-products.

For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 6: General input-output table for pyrometallurgical treatment

Material	Unit	Data	Specification
Input			
Black mass | solid battery residue	kg		
Reducing agents	kg		C content and type of reductant
Auxiliaries / Additives	kg		e.g., limestone, sand
Bulk chemicals	kg		e.g., NaOH, Na_2SO_4, NaCl
Electricity	kWh		
Fuels	kg		
Water	l		
Output			
Slag or alloy/ Matte for further treatment in hydro	kg		Assay data for metal fractions and quality (% of metal content), including recycling yield
Co-products – Other	kg		e.g., sulphuric acid from SO_2 scrubbing; recovered heat (as steam or thermal energy)
Chemical waste	kg		e.g., SO_2, Cl
Wastewater	l		
Off-gases for further treatment	kg		
Solid waste	kg		e.g., fly ash
Direct GHG emissions	kg		Calculated based on reductants (stoichiometry), graphite carbon content

5.3.5 Hydrometallurgical treatment

Process description

The flowsheets of hydrometallurgical processes can vary significantly. Yet, in general, hydrometallurgical treatment uses chemical solutions to leach and extract target metals from battery waste and proceeds in three steps: (1) leaching, (2) purification as well as (3) precipitation (Mn, Li) and crystallisation (Co, Ni) or electrowinning in some cases (Liu, et al., 2019).

In leaching, the metals in the slag or black mass are dissolved using a leaching media (salt, base or acid, e.g., sulfuric acid solution). In the purification step, metals are separated and purified through selective chemical reactions such as solid-liquid (ion exchange) and liquid-liquid (e.g., solvent extraction) reactions. The third step consists of recovering the metals from the solution into solid products in the form of metals, metal salts or compounds through crystallisation or ionic precipitation (Brückner, et al., 2020). Cobalt and nickel can be recovered in solvent-based reactions, as well as crystallised to $CoSO_4$ and $NiSO_4$ via water evaporation under vacuum. Manganese is oxidatively precipitated as MnO_2. Lithium is subsequently recovered as a lithium compound (e.g. Li_2CO_3). The lithium filtrate may also be crystallised (LiOH) while producing sodium sulfate (Na_2SO_4). The wash waters and effluents are neutralised to produce neutral wastewater and to precipitate the remaining metals as hydroxides (Rinne, et al., 2021). Depending on the specific flowsheets and input materials used, different product compositions can occur.

A distinction can be made between three routes.

(1) The first includes complex hydrometallurgical flowsheets and results in the recovery of battery grade materials, i.e., $NiSO_4$, $CoSO_4$, $MnSO_4$, $LiOH/Li_2CO_3$. For the calculation of the process carbon footprint, the input / output Table 7 applies.

(2) The second is the production of intermediates by leaching and precipitation with the aim of producing cobalt and nickel and a separate lithium product for further processing in existing refineries. For instance, Mixed Hydroxide Precipitate (MHP, an intermediate nickel product containing both nickel and a small amount of cobalt) is an intermediate product from recycling which would require further treatment and refinement to achieve battery grade. If a recycling provider follows this route, the provider shall adapt Table 7 for calculating the GHG emissions of the intermediate production and include the refinement process in the calculation as described in section 0.

(3) The third is a combination of (1) and (2) where battery grade materials ($NiSO_4$ and $CoSO_4$) are produced and non-battery grade intermediates ($MnCO_3$ and Li_2SO_4). Table 7 can be applied with the specification that $MnCO_3$ and Li_2SO_4 are to be classified as co-products in the data collection. If these co-products are further treated to battery grade materials, the refinement process shall be included in the carbon footprint calculation.

Data collection requirements

Table 7 presents a generalised input output table which shall be extended by the user to accommodate the complexities of the recycling process at hand. A separate data collection template includes a more comprehensive list of input and output materials which can accommodate both alternative routes. The user shall adapt this to match the complexities of the respective flowsheets.

The data collection shall cover all related operational processes during the hydrometallurgical process required to reach the final recycling treatment process step (or additional refinement step). It is important to consider process emissions in the hydrometallurgical process where limestone is used for neutralisation and $CaCO_3$ is reacting with acid solution generating GHG emissions. All relevant process emissions shall be included, for example potential sodium sulfate crystallisation as well as wastewater treatment which shall be accounted for in the process activity footprint calculation (see input/output Table 7). In case lithium is recovered in a separate process step compared to the other battery metals, the user may collect the data for this process step separately as displayed in Table 8. Burdens of this separate process shall be attributed to the lithium product, which shall bear emissions from the previous process step (allocated via final product mass to the co-products).

The indirect environmental impacts (scope 3) from the production of chemical reagents could be significant, particularly if the chemical consumption is high (Rinne, et al., 2021). Therefore, chemical inputs and outputs shall include supplier-specific CF data as far as possible. Where this is not possible, EF-compliant databases shall be used. As a carbon emissions factor is not available for many chemicals, proxies per the following categorisation shall be used. To avoid some of the chemicals being excluded through a carbon factor not being available, it is recommended to group the chemicals according to their purpose in frothers, dispersants, and flocculants and take the biggest contributor (mass) as a proxy for all categorised chemicals in case no supplier-specific or EF-compliant carbon footprint is available for these. Other bulk chemicals or auxiliaries like neutraliser (e.g., quicklime (CaO)), need to be collected separately.

For all hydrometallurgical flowsheets, the grade/purity level of the output metals shall be reported (assay data) as well as the recycling yield. This is an important factor for cross-checking the recycling balance over the whole process chain.

Allocation

Recycling processes are multi-output processes, i.e. having several valuable and functional outputs. For multi-output processes, the GHG emissions associated with the process shall be partitioned between the co-product(s) in a consistent way as per the generally defined allocation rules. In battery recycling, the target process outputs generally conform to battery-grade metal compounds (metal salts). Hydrometallurgical treatment yields a variety of co-products which varies depending on the complexity of the respective flowsheet.

Generally, the target process output products are battery-grade nickel, cobalt, manganese and lithium compounds. Typically, sodium sulfate crystals, copper and graphite/carbon filter cake are produced as co-products.

Following the multi-output allocation hierarchy (section 5.1.5), it first has to be examined whether process sub-division applies. If sub-division can be applied, hydrometallurgical processes shall be further sub-divided into sub-process level under the conditions and guidance set out in section 5.1.5.

Where sub-division is not applicable, system expansion shall be investigated. If this is not applicable, allocation shall be applied. Even though nickel, cobalt, manganese and lithium compounds have alternative production routes, e.g., nickel sulfate and cobalt sulfate, these are not well-characterised and representative. There is no dominant route on the market producing these materials (see for instance GBA GHG Rulebook section 5.1.1. and 5.1.2.).[13] For co-products where the conditions of the allocation rules in section 5.1.5 apply (e.g. sodium sulfate), system expansion substitution shall be applied. The credits for sodium sulfate – and other co-products – shall be calculated only after accounting for emissions from transport to the processing site and further treatment. For including transport emissions, the respective buyer-specific transport distances shall be applied. The user of these rules shall clearly classify for which co-products system expansion is applied and provide justification in the technical documentation. As there is likely no well-characterised and representative alternative process for copper, this potential co-product shall be partitioned via allocation in line with the allocation method applied to the co-products.

As the criterion for applying system expansion to other process output products is not met, allocation shall be applied. If the price differential between output products surpasses four – as is likely given the example shown in Figure 14 – economic allocation shall be applied. Only if the price differential is below four, mass allocation shall be applied for these outputs. The user of these rules shall determine the price differential based on the specific outputs of the process

[13] Note that the identification of well-characterised and representative alternative routes for the applicability of system expansion requires knowledge of production processes that yield materials of the same quality and composition as those of the recycled product. It is recommended to refer to the relevant sections for the upstream processes in this rulebook.

and apply the allocation classification. Allocation shall always be done at the point of separation If this is ruled out, the applicability of system expansion needs to be checked.

For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 7: General input-output table for hydrometallurgical treatment

Material	Unit	Data	Specification
Input			
Black mass | slag | alloy | matte	kg		
Electricity	kWh		
Fuels / steam	kg		e.g., coke
Water	l		
Bulk Chemicals	kg		e.g., H_2SO_4, SO_2, NaOH, Na_2CO_3, diluents etc.
Auxiliary gases	Nm^3		e.g., compressed air, oxygen, nitrogen
Reagents / additives / auxiliaries	kg		e.g., lime (CaO), limestone, carbon activated carbon filter, silica sand
Output			
Cobalt compound ($CoSO_4$)	kg		Assay data
Nickel compound ($NiSO_4$)	kg		Assay data
Manganese compound ($MnSO_4$)	kg		Depending on complexity of process flow, Assay data
Lithium compound (LiOH / Li_2CO_3)	kg		Assay data
Co-products – Metal fractions	kg		e.g., $MnCO_3$ or Li_2SO_4 (if not battery grade), copper, Assay data required
Co-products – Other	kg		e.g., sodium sulfate (crystals), electrolyte, graphite
Water for further treatment to recover materials	l		e.g., lithium content - if lithium is extracted in aggregated process and no further materials can be recovered, this can be neglected
Wastewater	l		Incl. solid suspension, fluoride, other emissions to water
Waste	kg		e.g., inert waste residue for landfill, waste gypsum, chemical waste
Direct GHG emissions	kg		

Table 8: Lithium recovery in case of separate process step

Material	Unit	Data	Specification
Input			
Lithium contained in water for further processing	kg		Lithium content in water
Electricity	kWh		
Fuels / steam	kg		e.g., coke
Water	l		
Bulk Chemicals	kg		e.g., H_2SO_4, HCl, NaOH, $NaCO_3$, $CA(OH)_2$, $CaCl_2$ etc.
Auxiliary gases	Nm^3		e.g., compressed air, oxygen, nitrogen
Output			
Lithium hydroxide (LiOH) Crystals	kg		Assay data
Lithium Carbonate (Li2CO3)	kg		Assay data
Co-products - Other	kg		e.g., sodium chloride (NaCl) crystals
Wastewater	l		Incl. solid suspension, fluoride, other emissions to water
Waste	kg		e.g., inert waste residue for landfill, waste gypsum
Direct GHG emissions	kg		

5.3.6 Refining / preparation to battery grade (if required)

The recovered recycled material quality must comply with quality/grade requirements for each battery input. Where the battery recycling process does not yield recycled materials of sufficient quality (i.e. battery grade), further refinement or preparation to battery-grade materials is required. The respective activities shall be included in the carbon footprint calculation. Hydrometallurgical unit operations often occur as refining steps at the end of a process chain because of their ability to produce high-quality products (Brückner, et al., 2020). Where additional hydrometallurgical steps are added for intermediates, please refer to section 5.3.5. If pyrometallurgical roasting is applied to purify the secondary material alongside primary materials, please refer to section 5.3.4. Additionally, please refer to the respective sections in the cluster-specific rules of GBA GHG Rulebook on refinement of primary nickel, cobalt and manganese sulfate as well as lithium carbonate/hydroxide (see refining in sections 5.1.1.-5.1.4.) (GBA, 2023). Fundamentally, the displayed refinement processes are similar for refining intermediate metals that originate from the hydrometallurgical treatment in battery recycling.

5.3.7 Co-production of primary and secondary materials

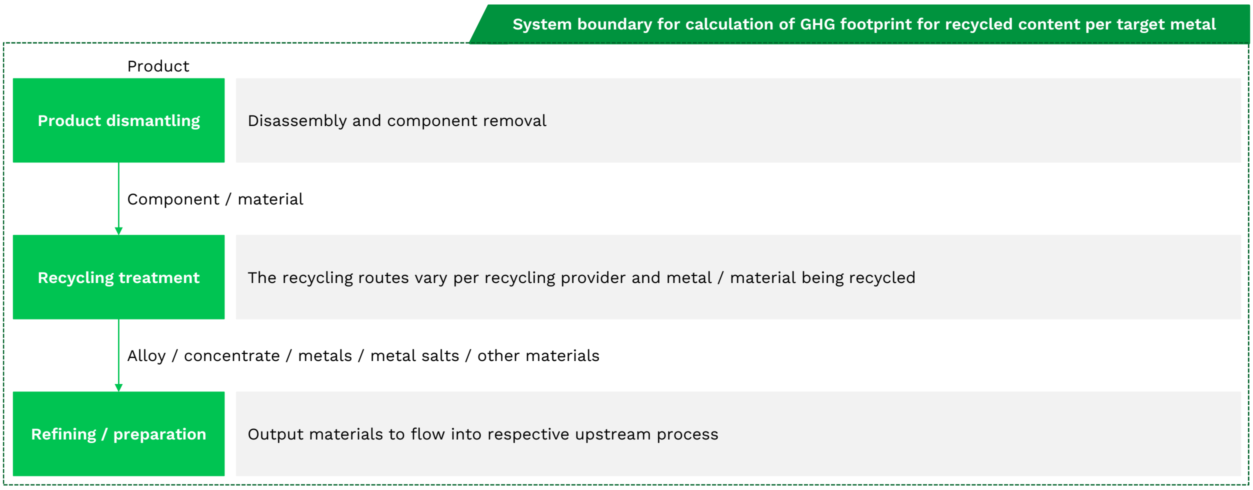
Additionally, co-production of primary and secondary materials is applied in industry. Pre-processed waste materials are refined together with primary materials. For calculating the carbon footprint of such processes, the steps from waste collection to the pre-processed waste material (i.e. black mass) shall be accounted for, including steps that clean or scrub the pre-processed materials. The user of these rules shall identify the point of substitution where the secondary materials replace primary materials. The secondary materials bearing the emissions from collection, dismantling and pre-processing are included at the respective point of substitution in upstream processes, as identified in the GBA GHG Rulebook. This corresponds to further refining as outlined above, where secondary materials are included in the respective upstream refinement steps in sections 5.1.1.-5.1.4.

If users operate co-production processes, the recycled content entering the production shall be identified and associated with the burdens of previous processing steps. Company-specific data shall be used for the pre-processing steps, if these are operated by the user. If not, supply chain-specific data shall be used. In each case, all steps of the recycling system boundaries until the point of substitution shall be considered. This requires identifying the amount of recycled content that is introduced into the refinement process. Where secondary materials are introduced in several refinement steps, a correct mass balance shall be provided for the share of recycled content.

5.3.8 Other recycling processes: generalised data collection sheet

For all materials other than pCAM/CAM and anode materials or different products systems and recycling processes, the user of this rulebook shall collect supplier-specific data from the respective recycling routes where the recycled material is procured. A generalised recycling process chart is given in Figure 17. In line with Figure 7, each of these generic recycling stages must have a reference to which all inputs and outputs are referred to.

Figure 17: System boundaries of general recycling as umbrella process chart



As the recycling processes vary significantly within types of materials but even more so between types of materials (e.g., polymers and steel), the generalised data collection sheet shall be extended and applied by the recycled material provider under the general rules laid down in section 5.1 under consideration of the sub-sections for battery materials recycling in section 5.3.

The following general data collection sheet shall be used and extended to collect primary activity data and calculate the GHG footprint of the recycled material that is used on the input side of the battery production.

The general rules in section 5.1 shall apply. For modelling electricity, please refer to the GBA GHG Rulebook chapter 4.2.2. Electricity (GBA, 2023).

Table 9: Input-output table for other recycling processes – generalised data collection

Material	Unit	Data	Specification
Input			
Product scrap	kg		e.g., end of life steel, aluminium, polymers, etc.
Electricity	kWh		
Fuels	kg		
Auxiliary Materials	kg		
Reductants	kg		
Bulk chemicals	kg		
Output			
Recycled material	kg		e.g., recycled polymers, recycled steel, recycled aluminium, etc.
Waste	kg		
Co-products	kg		
Direct emissions	kg		

5.4 Disposal emissions based on recyclability (as End-of-life and recycling emissions)

While the recycling emissions of previous batteries are associated on the input side, the emissions related to the disposal of the considered battery are assigned to the respective system boundary as emissions for the EOL and recycling stage. Hence, the system boundary of the considered product includes the waste incineration and landfilling processes following the polluter-pays-principle. This requires assumptions on the EOL treatment of the battery (e.g., information on collection rate and future recycling flowsheets and efficiencies).

The user of this rulebook (user calculating the carbon footprint of the battery system boundary) shall indicate if unrecyclable materials are included in the battery and the respective destination as of current EOL processing. This means that unrecyclable fractions shall be reported with the respective amount and whether these are landfilled or incinerated. Thereby, recyclability is defined as the ability of component parts, materials or both that can be diverted from an end-of-life stream to be recycled (ISO 22628:2002). For these rules, this shall refer to recycling technologies and processes available on the market at the point of calculating the carbon footprint. This means that no future recycling technologies shall be taken into account. Additionally, the available recycling processes shall be dominant, i.e. indicating that these are generally economically beneficial. Therefore, if no recycling process is dominantly available on the market for certain materials, these shall be classified as unrecyclable.

In the EU context, an evaluation for recyclability of the material in the battery is required and a statement on the recyclability of the materials/products shall be provided (Recharge, 2018). The statement on and evaluation of the recyclability shall follow the three criteria (as described by ISO 14021:1999, section 7.7.4) and requirements as per the PEFCR (Recharge, 2018):

1) The collection, sorting and delivery systems to transfer the materials from the source to the recycling facility are conveniently available to a reasonable proportion of the purchasers, potential purchasers and users of the product;
2) The recycling facilities are available to accommodate the collected materials;
3) Evidence is available that the product for which recyclability is claimed is being collected and recycled.

As these fractions and resulting EOL emissions are likely non-significant, EF-compliant secondary datasets for heating values and landfill emissions may be used: if waste incineration occurs, materials are to be linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. No credits for power or heat production as well as material recovery are assigned. If materials are sent to landfills, they are to be linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring versus power production).

6 Rules to comply with the Circular Footprint Formula requirements

In the context of the EU carbon footprint declaration, EU-specific methodologies are required. Based on the defined rules, these requirements can be fulfilled. Detailed guidance on the application of the Circular Footprint Formula (CFF) for the EOL and recycling life cycle stage are provided in this chapter. Thereby, it is described how the data collected under the Battery Pass rules and the GBA GHG Rulebook can be used to fulfil the requirements.

6.1 The Circular Footprint Formula for EOL and recycling allocation

6.1.1 Background and regulatory requirement

The EU Battery Regulation's Carbon Footprint Declaration will require the Circular Footprint Formula (CFF) as EOL allocation method as per reference to the PEF/PEFCR in Annex II (European Commission, 2023). The Circular Footprint Formula proposed by the European Product Environmental Footprint method combines usage of recycled materials as well as benefits and burdens associated with recycling, energy recovery and disposal at the End-of-life (EOL) (European Commission, 2019).

Additionally, the CFF is required for production waste modelling. This is mandatory for all waste occurring in the Manufacturing life cycle stage (mandatory primary activity data) and all processes where primary data are used.

To be able to fulfil the legal requirement in the European context, this chapter provides guidance on using the CFF as well as detailed rules on the calculation for batteries building on the Battery Pass rules for EOL and recycling and on the GBA GHG Rulebook for upstream emissions.

6.1.2 The Circular Footprint Formula: an overview

In comparison to other allocation methods that focus either on ingoing (Cut-off) or outgoing (Substitution) secondary materials, the CFF aims at considering both by accounting for the recycled content on the input side as well as recyclability at the EOL. Therefore, fulfilling the CFF specifications requires data collection for a wider range of parameters including, e.g., the change in material quality between life cycle stages as well as allocation factors for recycling and energy recovery processes. Furthermore, the formula refers to different life cycle stages and involves the calculation for each material.

The parameters need to be clearly defined and specified such that comparability of carbon footprints (CF) is ensured and no overestimation of credits is possible. This is particularly important as recovered materials from the EOL generally yield favourable credits that decrease the battery carbon footprint.

The CFF consists of three parts: material recovery, energy recovery and waste disposal. It is composed as follows with the parameters described below (European Commission, 2021):

Material $(1-R_1)E_V + R_1 \times (A \times E_{recycled} + (1-A)E_V \times Q_{Sin}/Q_p) + (1-A)R_2 \times (E_{recyclingEOL} - E^*_V \times Q_{Sout}/Q_P) +$

Energy $(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) +$

Disposal $(1-R_2-R_3) \times E_D$

Description of the CFF parameters as per PEF methodology:

- **A:** allocation factor of burdens and credits between supplier and user of recycled materials.
- **B:** allocation factor of energy recovery processes: it applies both to burdens and credits.
- **Q_{sin}:** quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
- **Q_{sout}:** quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
- **Q_p:** quality of the primary material, i.e. quality of the virgin material.
- **R_1:** the proportion of material in the input to the production that has been recycled from a previous system.
- **R_2:** the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R_2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R_2 shall be measured at the output of the recycling plant.
- **R_3:** the proportion of the material in the product that is used for energy recovery at EOL.
- **$E_{recycled}$ (E_{rec}):** specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
- **$E_{recyclingEoL}$ (E_{recEoL}):** specific emissions and resources consumed (per functional unit) arising from the recycling process at EOL, including collection, sorting and transportation process.
- **E_v:** specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.
- **E^*_v:** specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
- **E_{ER}:** specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.).
- **$E_{SE,heat}$ and $E_{SE,elec}$:** specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
- **E_D:** specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EOL of the analysed product, without energy recovery.
- **$X_{ER,heat}$ and $X_{ER,elec}$:** the efficiency of the energy recovery process for both heat and electricity.
- **LHV:** lower heating value of the material in the product that is used for energy recovery.

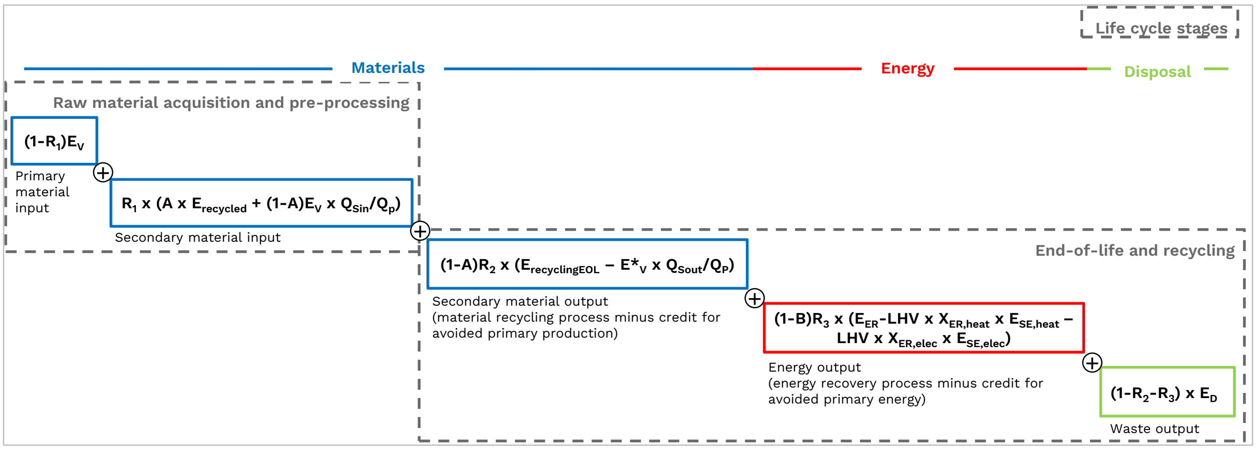
6.1.3 Application of the CFF to different lifecycle stages

The CFF combines different life cycle stages. This must be considered particularly in the case of the carbon footprint to be reported per lifecycle stage, as required by the Battery Regulation. First, a distinction can be made between end-of-life modelling of the battery and modelling of waste in different lifecycle stages.

A) End-of-life modelling of the battery

In this case, the primary and secondary material input needs to be accounted in the raw material acquisition and pre-processing stage, while the secondary material, energy and waste output should be reported in the End-of-life and recycling stage (see Figure 18).

Figure 18: The elements of the Circular Footprint Formula (own illustration based on (European Commission, 2019))



B) Waste modelling via the CFF

As per the PEF methodology, the CFF shall be applied when modelling waste that occurs in processes where primary data are used to account for the emissions. Due to remaining uncertainties about the application, guidance is awaited from the update of the PEFCR of batteries.

6.2 Rules for calculating the Circular Footprint Formula

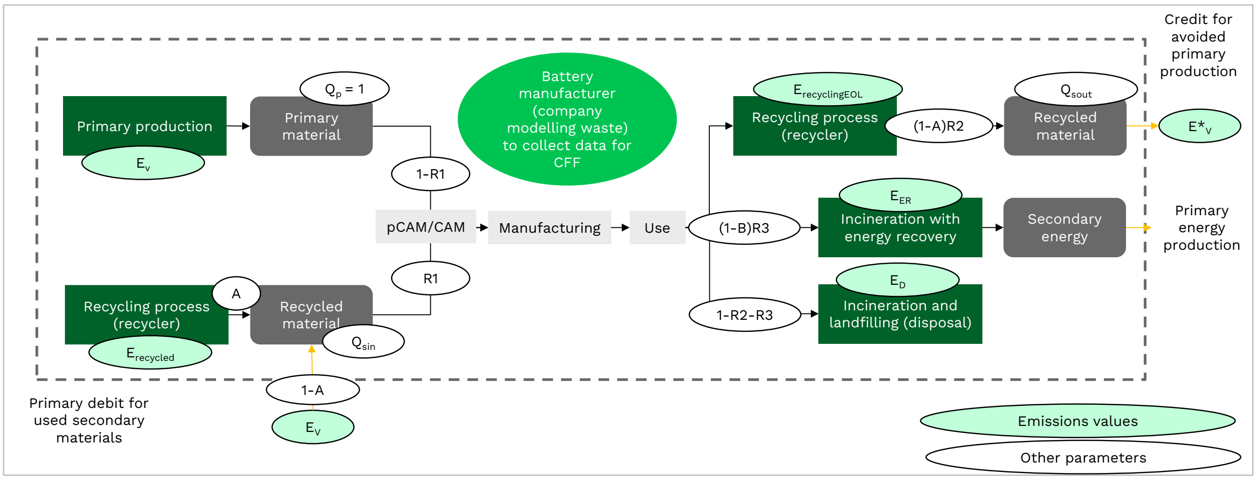
6.2.1 Modelling approach for the CFF

In the context of the carbon footprint declaration accompanying the battery's placement on the EU market, production waste (in production processes where primary data are used)[14] and the EOL shall be modelled using the Circular Footprint Formula and the accompanying rules described in the following sections. These rules are primarily addressed to economic operators/manufacturers placing the battery on the market and having to declare the carbon footprint under the PEF/PEFCR rules (for the EOL modelling) as well as companies reporting primary data for their respective production processes (for waste modelling).

In general, the PEF and CFF take a single actor life cycle assessment (LCA) perspective, i.e. the calculation is performed by one actor at a specific point in time. Applied to the CF calculation as required by the Battery Regulation, this implies that the economic operator placing the battery on the market or putting it into service is responsible for collecting data and performing the calculation. Thereby, data of the upstream processes needs to be collected "retrospectively" and for the downstream processes, i.e. the EOL taking place in the future depending on the useful life of the battery, "prospectively" (see Figure 19).

The parameters can be clustered into actual "emissions values", which are calculated by multiplying the mass of a specific process producing a material with the respective emissions factors. This results in a carbon footprint of a specific amount of CO_2e. All "Other parameters" refer to a rate or percentage and therefore range between 0 and 1 without a unit (see Figure 19).

Figure 19: CFF application for modelling EOL and recycling with data to be collected from the supply chain (refer to the section specifying the parameters below)



The battery manufacturer placing the battery on the market (CF declarant) shall apply the CFF for the EOL and recycling allocation. As per PEF/PEFCR, the user of these rules declaring the CFF values shall calculate these per material contained in the battery system boundary. Therefore, an inventory with emissions values and parameters needs to be compiled for each material (aggregated per component, see PEFCR) including the following steps:

[14] Note that the topic of pre-consumer waste modelling and allocation needs to be resolved going forward. As the current discussion on waste modelling via CFF are still ongoing, this topic has not yet been considered in the current draft version.

1) Mapping of Bill of Materials (BoM) including mass of materials;
2) Definition of “other parameters” and calculation of “emissions values” per material;
3) Calculation of CF as sum of CFs per material, in accordance with the CFF requirements.

Thereby, the cut-off threshold applies to the BoM. Processes cumulatively contributing less than 3% in terms of their greenhouse gas emissions impact may be excluded across the processes (cumulatively over all processes), referring to the overall CF of the product for which the CF is calculated as defined in this rulebook.

As according to the EU Battery Regulation, the CF needs to be “differentiated per life cycle stage” (Battery Regulation *Article 7(1)(e)*), it is important to consider which part of the formula relates to which life cycle stage (see Figure 19) and report the respective calculated values separately.

Figure 20 shows an example calculation in the form of an Excel file. The example shows how, based on a specific inventory, the CFF values and parameters need to be defined, calculated, collected and aggregated. The representation shall only inform the application of the CFF; the values shall be determined by the respective applicant.

Figure 20: Example calculation of CFF in Excel[15]

Material	Unit(output)	Amount	Parameters																			Result	Unit
			A	B	Q_{sin}	Q_{sout}	Q_p	R_1	R_2	R_3	$E_{recycled}$ (kg CO2e)	$E_{recyclingEoL}$ (kg CO2e)	E_v (kg CO2e)	E^*_v (kg CO2e)	E_{ER} (kg CO2e)	$E_{SE,heat}$ (kg CO2e)	$E_{SE,elec}$ (kg CO2e)	E_D (kg CO2e)	$X_{ER,heat}$	$X_{ER,elec}$	LHV		
Anode																							
Copper Foil (11 µm) for 1 m2	kg/kg battery	0.074	0.2	0	1	1	1	0	0.41	0	0	0.21	0.07	0.07	0	0	0	0.0001243	0	0	0	0.115086	kg CO2e
Graphite powder (estimate)	kg/kg battery	0.126	0.2	0	1	1	1	0	0	0	0	0	0.33	0.33	0	0	0	0.0002117	0	0	0	0.3345117	kg CO2e
Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	0.002	0.5	0	1	1	1	0	0	0	0	0	0.02	0.02	0	0	0	3.36E-06	0	0	0	0.0170934	kg CO2e
Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	0.002	0.5	0	1	1	1	0	0	0	0	0	0.01	0.01	0	0	0	3.36E-06	0	0	0	0.0077034	kg CO2e
Cathode																						**0.4743944**	
Manganese sulphate (estimation)	kg/kg battery	0.067	0.2	0	1	1	1	0	0.30	0	0	0.14	0.06	0.06	0	0	0	0.0001126	0	0	0	0.0784708	kg CO2e
Nickel Sulfate from electrolytnickel	kg/kg battery	0.072	0.2	0	1	1	1	0.04	0.56	0	0.28	0.28	0.34	0.34	0	0	0	0.000121	0	0	0	0.313308	kg CO2e
Lithium Carbonate mix	kg/kg battery	0.026	0.2	0	1	1	1	0	0	0	0	0.00	0.05	0.05	0	0	0	4.368E-05	0	0	0	0.0538619	kg CO2e
Cobalt sulfate	kg/kg battery	0.072	0.2	0	1	1	1	0.12	0.69	0	0.35	0.35	2.60	2.60	0	0	0	0.000121	0	0	0	1.2952907	kg CO2e
Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	0.001	0.5	0	1	1	1	0	0	0	0	0	0.01	0.01	0	0	0	1.68E-06	0	0	0	0.0085417	kg CO2e
Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	0.001	0.5	0	1	1	1	0	0	0	0	0	0.00	0.00	0	0	0	1.68E-06	0	0	0	0.0035917	kg CO2e
Carbon black (furnace black; general purpose)	kg/kg battery	0.012	0.2	0	1	1	1	0	0	0	0	0	0.03	0.03	0	0	0	2.016E-05	0	0	0	0.0318702	kg CO2e
Aluminium foil	kg/kg battery	0.045	0.2	0	1	1	1	0	0	0	0	0	0.61	0.61	0	0	0	0.0000756	0	0	0	0.6114256	kg CO2e
Electrolyte																						**2.3963606**	
Dimethyl carbonate (DMC)	kg/kg battery	0.0215	0.5	0	1	1	1	0	0	0	0	0	0.05	0.05	0	0	0	3.612E-05	0	0	0	0.0498261	kg CO2e
Ethylene carbonate	kg/kg battery	0.0215	0.5	0	1	1	1	0	0	0	0	0	0.04	0.04	0	0	0	3.612E-05	0	0	0	0.0351062	kg CO2e
Propylene carbonate	kg/kg battery	0.0215	0.5	0	1	1	1	0	0	0	0	0	0.10	0.10	0	0	0	3.612E-05	0	0	0	0.0987721	kg CO2e
Dimethyl carbonate (DMC) (for EMC)	kg/kg battery	0.0215	0.5	0	1	1	1	0	0	0	0	0	0.05	0.05	0	0	0	3.612E-05	0	0	0	0.0498261	kg CO2e
Lithium Hexaflurophosphate (LiPF6)	kg/kg battery	0.015	0.2	0	1	1	1	0	0	0	0	0	0.09	0.09	0	0	0	0.0000252	0	0	0	0.0861207	kg CO2e
Separator																						**0.3196512**	
Polypropylene Film (PP) without additives	kg/kg battery	0.045	0.5	0	1	1	1	0	0	0	0	0	0.09	0.09	0	0	0	0.0000756	0	0	0	0.094465	kg CO2e
Polyethylene foil (PE-HD) without additives	kg/kg battery	0.015	0.5	0	1	1	1	0	0	0	0	0	0.04	0.04	0	0	0	0.0000252	0	0	0	0.0361825	kg CO2e
																						3.3210536	kg CO2e

[15] Please note that the calculation displayed only includes the active materials (Cathode, Anode, Separator, Electrolyte) in 1 kg of battery. The inventory as basis for the calculation is retrieved from the PEFCR for batteries (Recharge, 2018).

6.2.2 The parameters of the Circular Footprint Formula

Table 10: Overview of default parameters for the CFF

Parameter	Most recent specifications (Joint Research Centre, 2023)
A	0.2 for metals 0.5 for plastics 0.5 for other materials *Currently under discussion, value might be modified by JRC / PEFCR TS*
B	0
Q_{Sin}/Q_P	See PEF Annex C
Q_{Sout}/Q_P	See PEF Annex C
R_1	0 per default When using company specific R_1 values other than 0, traceability throughout the supply chain is necessary and evidences shall be provided for verification.
R_2	Please refer to Table 2 of JRC 2023. The JRC table will likely be updated in the development of the delegated act and thus is not updated in this version. *Currently under discussion, value might be modified by JRC / PEFCR TS*
R_3	See PEF Annex C (only for packaging and municipal solid waste) *Currently under discussion*
$E_{recycled}$	EF-compliant default datasets Primary data allowed under specific conditions (see R_2) *Currently under discussion*
$E_{recyclingEOL}$	EF-compliant default datasets (as not available yet, default recycling scenarios provided by JRC and PEFCR) Primary data allowed under specific conditions *Currently under discussion*
E_v	EF-compliant default datasets
E^*_v	EF-compliant default datasets
E_{ER}	EF-compliant default datasets
$E_{SE,heat}$ and $E_{SE,elec}$	EF-compliant default datasets
E_D	EF-compliant default datasets
$X_{ER,heat}$ and $X_{ER,elec}$	EF-compliant default datasets
LHV	EF-compliant default datasets

Under the EU requirements, the CFF per default uses secondary data, but allows for primary data. The GBA intends to collect primary data for identified hotspots (i.e. foreground processes). Therefore, in the GBA, these primary data shall be collected.

The specifications of the GBA GHG Rulebook for cradle-to-gate emissions (in version 1.4) and the Battery Pass rules for EOL and recycling can be applied to calculate certain parameters required for the CFF, particularly E_v and R_1 (GBA GHG Rulebook), $E_{recycled}$ and Q_{sin}/Q_p. (Battery

Pass rules for EOL and recycling). Yet, additional parameters are needed to fulfil the CFF requirements.

In this section, each parameter of the formula is explained and rules for the definition and calculation are provided. In practice, these parameters need to be specified per material contained in the battery.

Emissions values

Figure 21 provides an overview on the emissions values including which data sources to use, depending on the process being in the foreground or background of the assessment. The EF-compliant datasets can be accessed via https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml.

Foreground processes are processes identified as hotspots under the GBA GHG Rulebook where primary data shall be collected.

Figure 21: Data sources for CFF emissions values

Emissions values [in CO_2 eq.]	Primary		vs. secondary data
	Foreground processes		Background processes
E_v: emissions from acquisition and pre-processing of virgin/primary material	GBA GHG Rulebook		
E^*_v: emissions from acquisition and pre-processing of virgin/primary material assumed to be substituted by secondary materials output	EF-compliant datasets		
$E_{recycled}$: emissions caused by recycling process of secondary materials input/recycled content	Battery Pass rules		
$E_{recyclingEOL}$: emissions of recycling process at EOL	Battery Pass rules[1]	EF-compliant datasets	EF-compliant datasets
E_{ER}: emissions from the energy recovery process			
$E_{SE,heat}$ and $E_{SE,elec}$: emissions from specific energy source, heat and electricity respectively, assumed to be substituted by recovered Energy	EF-compliant datasets		
E_D: emissions from disposal of waste material at the EoL			

[1] If primary data are available and physical and contractual links can be proven, this factor can be representative as of today. This reflects a conservative approach under the assumption that processes become more efficient and less emissive in the future.

E_v

"E_v" indicates the specific CO_2e emissions caused by the acquisition and pre-processing of virgin/primary materials.

Primary data shall be used for the retrospective calculation of the foreground processes following the GBA GHG Rulebook. When calculating the CFF, these values are available from the cradle-to-gate calculation. For the background processes, EF-compliant datasets can be used, unless primary data are available.

E*v

"E^*_v" indicates the specific CO_2e emissions caused by the acquisition and pre-processing of virgin/primary materials assumed to be substituted by recycled/secondary materials.

EF-compliant secondary datasets shall always be used for the prospective calculation to ensure better comparability. A common specification of the dataset to use is crucial as this parameter reflects a future process. Hence, it cannot be reliably demonstrated which material will be substituted, i.e. how it is produced. As the secondary material is assumed to be provided in the EU, the geographical scope of the EF-compliant dataset for E^*_v shall be EU-specific.

$E_{recycled}$ (E_{rec})

"$E_{recycled}$" indicates the specific CO_2e emissions caused by the recycling process of the recycled material, including collection, sorting and transportation process. These emissions values can be provided by recycled content suppliers.

Primary data shall be used for the retrospective calculation of the foreground processes following the rules in section 5. For the background processes, EF-compliant datasets shall be used, unless primary data are available.

$E_{recyclingEoL}$ (E_{recEoL})

"$E_{recyclingEoL}$" or in short "E_{recEoL}" indicates the specific CO_2e emissions caused by the recycling process at the EOL of the battery. The recycling process shall cover the collection, sorting and transportation steps, and the conversion to recycled material accounting for specific material inputs and energy demand of the recycling process.

EF-compliant secondary datasets shall be used for the prospective calculation to ensure better comparability as the economic operator will likely have a network of recyclers and it cannot be reliably demonstrated how the material will be recycled, e.g., at which recycling plant. The EF-compliant dataset used shall cover the geography "EU-28+EFTA" and be specific per material. If no dataset is available for a specific recycling process per material, datasets covering components or product groups can be used.

The ongoing discussions in EU institutions (JRC and PEFCR TS) indicate that primary data may be used under strict conditions. The criteria under which primary data may be used are still under development. This issue cannot be resolved until the discussions reach a consensus. The Battery Pass recommends using the same EF-compliant datasets to increase comparability of EOL credits given. In the case of battery recycling, there is no EF compliant dataset yet. Default scenarios will be provided by JRC and PEFCR.

The JRC rules (currently in public consultation) propose using primary data under the following specification: "company-specific activity data or company-specific datasets may be used for the waste batteries being recycled within the own premises or via a specific-recycling process if the corresponding evidence is provided in the CFB supporting study." These conditions need further clarification.

The Recharge PEFCR update (currently being developed) includes the condition that, if proof exists that the batteries go to a certain recycling process (contractual and physical links shown) and also access to the related data is prevalent, primary data shall be used for End-of-life collection and processing. If not, EF-compliant dataset to represent those processes must be used.

Default recycling scenarios containing default activity data that shall be used to model recycling emissions are provided by JRC in Annex 3. Additionally, PEFCR includes representative data for the recycling process that shall be used in the context of the PEFCR. No guidance is given for emissions values that should be used.

An additional complexity arises from allocating the $E_{recyclingEoL}$ values to the materials if modelled with the default values. For the CFF to work mathematically, $E_{recyclingEOL}$ needs to be available at material level. No guidance exists yet on how to allocate the recycling emissions from secondary datasets or default scenarios to material level.

E_{ER}-LHV x $X_{ER,heat}$ x $E_{SE,heat}$ – LHV x $X_{ER,elec}$ x $E_{SE,elec}$

This part of the formula equals the environmental impact of incineration and credits for recovered energy and is supposed to be available as combined impact in an EF secondary dataset per material. Where the respective materials are not treated by incineration with energy recovery, i.e. when R_3 = 0, this part of the formula does not need to be calculated.

Access to EF 3.1 datasets is still not available. Until these are accessible, other secondary data sources, such as industry averages could be used following the data quality requirements laid out in the GBA GHG Rulebook.

As soon as the datasets become available, the user of the rulebook shall use these datasets for the prospective calculation, but make sure that heating values of the material used and the selected secondary data set are similar or comparable.

Note that, in addition, remaining waste after energy recovery is to be modelled as disposal (unless used, e.g., as ash for cement making); EF waste-to-energy datasets consider this generally already.

An additional complexity arises from allocating the E_{ER} and LHV values to the materials if modelled with the default values. For the CFF to work mathematically, E_{ER} and LHV needs to be available at material level. No guidance exists yet on how to allocate the values for E_{ER} and LHV from secondary datasets to material level.

E_D

"E_D" indicates the specific CO_2e emissions caused by disposal of waste material at the EOL of the analysed product. This includes landfill and incineration without energy recovery.

Following section 5.4, the recyclability of the battery shall be evaluated (please refer to detailed description for parameter R_2). For the unrecyclable fraction(s), the user shall indicate which fractions are disposed (see also R_3). In case, there is no disposal, E_D equals 0 for the respective material. EF-compliant secondary datasets shall be used for the prospective calculation of E_D to ensure better comparability.

Other parameters

Figure 22: Meaning, unit, range and data sources for CFF parameters

Other CFF parameters	Range of parameters: 0	Range of parameters: 1	Data availability: Primary	Data availability: secondary data
A: allocation factor of burdens and credits between supplier and user of recycled materials	Benefits to recycling output	Benefits to recycled content	EF default values: Annex C	
B: allocation of energy recovery	100% credited to producer (default)	100% credited to user	EF default values: Annex C	
R_1: proportion of secondary material (recycled content)	100% primary material	100% secondary material	GBA GHG Rulebook	Battery Pass rules
R_2: share of material recovered at end-of-life	0% recycled at EOL	100% recycled at EOL	EF default values: Annex C	
R_3: energy recovery rate	0% to energy recovery	100% to energy recovery	EF default values: Annex C	
Q_{sin}/Q_p: quality of ingoing secondary material to primary material	0% same quality	100% same quality	GBA GHG Rulebook	Battery Pass rules
Q_{sout}/Q_p: quality of outgoing secondary material to primary material	0% same quality	100% same quality	EF default values: Annex C	
$X_{ER,heat}$ and $X_{ER,elec}$: efficiency of the energy recovery process for both heat and electricity	0% efficiency	100% efficiency	EF default values: Annex C	

A

"A" allocates between burdens/benefits of recycled content and End-of-life recycling and therefore is similar to either one of the other allocation procedures depending on the material and the market situation of the material. Hypothetically, if A is set to 1, the CFF approximates the Cut-off approach. Similarly, if A is set to 0, the CFF approximates the Substitution approach. The PEF methodology defines an A value of 0.2 for high quality secondary materials (i.e. metals), which are more demanded than produced. Thereby, the PEF A value implies that their market price is close to or the same as the one for primary materials, which is the case for many metals. For materials, where the opposite is the case and the market price is low compared to primary materials, an A value of 0.8 is defined by PEF as default. Where the market situation is more balanced or unknown the A value should be set to 0.5 (e.g., plastics). No values besides those mentioned, or rules to calculate situation-specific values, are indicated by PEF/PEFCR, but might be changed in the future.

For better comparability of carbon footprints, the user of the rulebook shall use the values indicated in the applicable PEFCR or PEF Annex C (European Commission, 2020). In case these are updated, the updated factors shall be used.

The specification of default A values for the calculation of the battery carbon footprint is still under discussion in the European Institutions.

B

"B" allocates between burdens and benefits of energy recovery processes. The parameter is equal to 0 per default, which indicates that 100% of generated and externally used energy is credited to the producer and debited to the user of the secondary energy. This means that there are both waste-to-energy burdens and avoided primary production benefits. Guidance on calculating or defining a B factor different than 0 could not be found. Therefore, as indicated in the PEF Annex C, the B factor shall be set to 0 per default.

R_1

"R_1" indicates the share of the respective material in the input to the production that has been recycled from a previous system, i.e. the recycled content per material employed.

Primary data shall be used at least for the share of secondary nickel, cobalt, lithium and lead in active components, as this is a reporting requirement as per the Battery Regulation. Additionally, verification for these values shall be provided. As per JRC 2023, evidence of the traceability throughout the supply-chain must be provided in the accompanying documentation. For all other materials, users may use primary data, if verification is provided. If no primary data is available or verifiable R_1 shall be 0 per default.

Ongoing discussion might lead to changes in the default values of the parameters.

R_2

"R_2" indicates the share of the respective material in the product that will be recycled (or reused) in a subsequent system, i.e. recycling rate per material. As this parameter significantly determines the credits for material recovered at the future EOL, it needs to be defined and specified diligently.

The user of the rulebook shall follow the PEF/PEFCR requirement to evaluate the recyclability of the material and provide evidence, before selecting the appropriate R_2 value. The statement on the recyclability shall be provided together with an evaluation for recyclability that includes evidence per material for the following three criteria (as described by ISO 14021:1999, section "Evaluation methodology") (Recharge, 2018):

1) The collection, sorting and delivery systems to transfer the materials from the source to the recycling facility are conveniently available to a reasonable proportion of the purchasers, potential purchasers and users of the product;
2) The recycling facilities are available to accommodate the collected materials;
3) Evidence is available that the product for which recyclability is claimed is being collected and recycled.

As per the PEFCR, points 1 and 3 can be proven by recycling statistics (country specific) derived from industry associations or national bodies. Approximation to evidence at point 3 can be provided by applying for example the design for recyclability evaluation outlined in EN 13430 Material recycling (Annexes A and B) or other sector-specific recyclability guidelines if available.

Ongoing discussion might lead to changes in the default values of the parameters. Therefore, the specification in this chapter might change.

R_2 values shall be calculated by multiplying the statistical collection rate of batteries (e.g., PEFCR assumes 95% for EVs) with the material recovery yield (e.g., 90% of cobalt per battery as per Battery Regulation by likely 2027) and excluding exports.

The material recovery yield shall be based on primary data if available (i.e. when contracts with recyclers are already in place). The value must be representative as of the day of calculation taking the conservative approach under the assumption that processes become more efficient in the future. Thereby the R_2 shall consider inefficiencies in the collection and be measured at the output of the recycling plant (European Commission, 2021).

- If no company-specific values are available and the criteria for the evaluation of recyclability are fulfilled, application-specific R_2 values from Annex C shall be used [to be listed by PEFCR];
- If an R_2 value is not available for a specific country, then the European average shall be used;
- If an R_2 value is not available for a specific application, the R_2 values of the material shall be used (e.g., materials' average);
- In case no R_2 values are available, R_2 shall be set equal to 0.

R_3

R_3 indicates the share of the respective material in the product that will be used for energy recovery at EOL. The difference ($1-R_2-R_3$) will yield the share of fraction being disposed of.

For better comparability of carbon footprints, the user of the rulebook shall use the default values. As the default values provided by PEF Annex C are currently only applicable to Municipal Solid Waste, R_3 should be calculated using official statistics for share of waste incinerated versus landfilled. EUROSTAT provides data on energy recovery for batteries and accumulators.

Q_{sin}/Q_p

"Q_{sin}/Q_p" indicates the quality ratio of the ingoing secondary material. These shall be determined at the point of substitution per application or material and be based on either economic aspects or physical aspects.

As all secondary materials used in the battery need to be battery-grade materials, it shall be assumed that the quality of the ingoing secondary materials is equal to the quality of primary materials. Therefore, the ratio shall be set to 1 per default.

Q_{sout}/Q_p

"Q_{sout}/Q_p" indicates the quality ratio of the outgoing secondary material. Equally to "Q_{sin}/ Q_p", these shall be determined at the point of substitution per application or material and be based on either economic aspects or physical aspects.

As this is unknown at the point of time when calculating the carbon footprint, EF default values indicated in Annex C (European Commission, 2020) shall be used for better comparability.

7 Outlook

Due to the scope of these rules "version 1.1" focusing on battery recycling processes (and particularly lithium-ion batteries), further work could include:

a. **Extension of current version**
   - Extension of NMC-based battery recycling to other chemistries and technologies and the respective recycling process data collection (e.g. LFP)
   - Data collection for other recycled materials (e.g., polymers, steel etc.) as the Circular Footprint Formula is required to be calculated for each material and the Battery Regulation demands electronic components to be based on company-specific data

Additionally, future changes in technologies will need to be reflected once they have matured:

b. **Inclusion of not yet market-ready technologies and processes**
   - Extension to potentially evolving dominant battery chemistries (e.g. sodium-ion)
   - Inclusion of novel recycling routes (e.g. direct recycling) corresponding to section 5.3

The Battery Pass intends to refer to other initiatives potentially covering some of the aspects above where these cannot be included.

ANNEX

A.1 Relevant standards and approaches for Distribution as well as End-of-life and recycling stages

A.1.1 Distribution-relevant standards

To account for distribution emissions, the most relevant standards are the Product Environmental Footprint (PEF) methodology as well as the PEFCR for batteries by Recharge.

a. Product Environmental Footprint methodology (European Commission, 2021)

As per the Commission Recommendation (EU) 2021/2279 on the use of the Environmental Footprint methods, the Distribution stage includes transport **from factory gate to warehouse/retail, storage at warehouse/retail and transport from warehouse/retail to consumer** home.

Examples of processes to include:

a. energy inputs for warehouse lighting and heating;
b. use of refrigerants in warehouses and transport vehicles;
c. fuel use by vehicles;
d. roads and trucks.

The PEF section 4.2.3 Distribution refers to section 4.4.3 Transport and logistics to model transport-related emissions. Accordingly, parameters to be taken into account when modelling transport activities comprise:

1) **Transport type:** the type of transport, e.g. by land (truck, rail, pipe), water (boat, ferry, barge), or air (airplane).
2) **Vehicle type:** the type of vehicle by transport type.
3) **Loading rate (= utilisation ratio):** environmental impacts are directly linked to the actual loading rate, which therefore shall be considered. The loading rate affects the vehicle's fuel consumption.
4) **Number of empty returns:** the number of empty returns (i.e. the ratio of the distance travelled to collect the next load after unloading the product to the distance travelled to transport the product), when applicable and relevant, shall be taken into account. The kilometres travelled by the empty vehicle shall be allocated to the product. In default transport datasets this is often already taken into account in the default utilisation ratio.
5) **Transport distance:** transport distances shall be documented, applying average transport distances specific to the context being considered.

Within EF-compliant datasets concerning transport-related emissions,[16] the fuel production, the fuel consumption by the transport vehicle, the infrastructure needed and the amount of additional resources and tools needed for logistic operations (e.g. cranes and transporters) are included.

[16] Available at https://lcdn.thinkstep.com/

To allocate the impacts from transport to the product, secondary datasets using emission factors per transported mass are coupled with transport distances and vehicle types. Hence, EF compliant datasets for truck transport **are nominated in tkm (tonne-km) expressing the environmental impact for 1 tonne (t) of product that is transported for 1 km in a truck with a certain load**. The transport payload (= maximum mass allowed) is indicated in the dataset. The transport emissions are allocated based on the transported product's mass, resulting in emissions being partitioned to the mass share of the product under study. For example, a truck of 28-32 t has a payload of 22 t; the LCA dataset for 1 tkm (fully loaded) expresses the environmental impact for 1 t of product that is transported for 1 km within a 22 t loaded truck. In case the product is 1 t, the share of emissions is 1/22 of the truck's full emissions. When a full freight's mass is lower than the truck's load capacity (e.g. 10 t), the transport of the product may be considered volume limited. In this case, the environmental impact shall be calculated using the real mass loaded.

In EF-compliant datasets, **the transport payload should be modelled in a parameterised way through the utilisation ratio**. The utilisation ratio is calculated as the mass of the real load divided by the mass of the (maximum) payload and shall be adjusted when the dataset is used. For instance, in case the truck is fully loaded for delivery but half empty upon its return, the utilisation ratio is: 22 t real load / 22 t payload * 50% km + 11 t real load / 22 t payload * 50% km = 75%.

Studies using the PEF **shall specify the utilisation ratio to be used for each truck transport modelled**, as well as clearly indicate **whether the utilisation ratio includes empty return trips**.

- **If the load is mass limited:** a default utilisation ratio of 64% shall be used.[17] This utilisation ratio includes empty return trips and thus shall not be modelled separately.
- **Bulk transport** (e.g., gravel transport from mining pit to concrete plant) shall be modelled with a default utilisation ratio of 50% (100% loaded outbound and 0% loaded inbound), unless specific data is available.

To model the transport distances, the PEF suggests default scenarios in case company-specific data are not available in sections 4.4.3.4. et seq (EC, 2021).

<u>1) From supplier to factory</u>

For suppliers located **within Europe, if no specific data are available** to perform the PEF study, then the following default data shall be used:

a. 130 km by truck (>32 t, EURO 4);
b. 240 km by train (average freight train); and
c. 270 km by ship (barge).

For suppliers located **outside of Europe, if no specific data are available** to perform the PEF study, then the following default data shall be used:

a. 1,000 km by truck (>32 t, EURO 4), for the sum of distances from harbour/airport to factory outside and inside Europe;

[17] Eurostat indicates that 21% of the km truck transport is driven with an empty load and 79% is driven loaded (with an unknown load). In Germany only, the average truck load is 64%.

b. 18,000 km by ship (transoceanic container) or 10,000 km by plane (cargo);
c. if producer's country (origin) is known, the adequate distance for ship and airplane should be determined using specific calculators;[18]
d. in case it is not known whether the supplier is located within or outside Europe, transport shall be modelled as if the supplier was located outside of Europe.

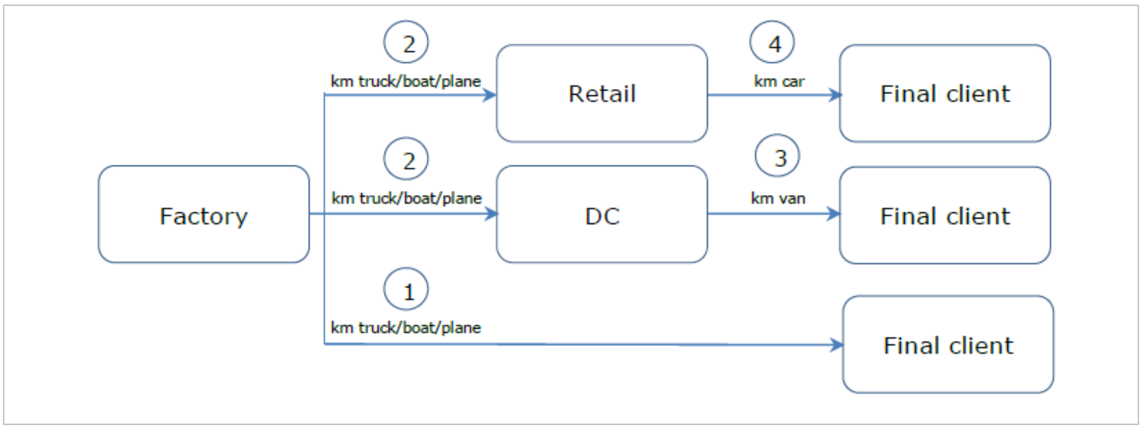
2) From factory to final client

The transport from factory to final client (including consumer transport) shall be included in the Distribution stage. The final client of the product shall be defined. The final client may be a consumer (i.e. a person who purchases goods and services for personal use) or a company that uses the product for final use. Re-sellers and importers are intermediate clients and not final clients.

Where no specific information is available, the default scenarios outlined below shall be used. The following values shall be determined by the user of the PEF method (specific information shall be used, unless it is unavailable):

- ratio between products sold through retail, distribution centre (DC) and directly to the final client;
- for factory to final client: ratio between local, intracontinental and international supply chains;
- for factory to retail: distribution between intracontinental and international supply chains.

Figure 23: Default transport scenario as per PEF recommendation



The following is the default transport scenario **from factory to client** represented in Figure 23.

1) X% **from factory to final client**:
X% local supply chain: 1,200 km by truck (>32 t, EURO 4)
X% intracontinental supply chain: 3,500 km by truck (>32 t, EURO 4)
X% international supply chain: 1,000 km by truck (>32 t, EURO 4) and 18,000 km by ship (transoceanic container). Note that for specific cases, plane or train may be used instead of ship.

[18] For instance: https://co2.myclimate.org/en/flight_calculators/new and https://www.searates.com/services/distances-time/

2) X% **from factory to retail/distribution centre** (DC):
   X% local supply chain: 1,200 km by truck (>32 t, EURO 4)
   X% intracontinental supply chain: 3,500 km by truck (>32 t, EURO 4)
   X% international supply chain: 1,000 km truck (>32 t, EURO 4), and 18,000 km by ship (transoceanic container). Note that for specific cases, plane or train may be used instead of ship.
3) X% **from DC to final client**:
   100% local: 250 km round trip by van (lorry <7.5 t, EURO 3, utilisation ratio of 20%).
4) X% **from retail to final client**:
   62%: 5 km, by passenger car (average)
   5%: 5 km round trip, by van (lorry <7.5 t, EURO 3 with utilisation ratio of 20%)
   33%: no impact modelled.

3) From EOL collection to EOL treatment

The transport from where products at their EOL are collected to where they are treated may already be included in the landfill, incineration and recycling EF-compliant datasets.

However, there are some cases where additional data may be needed.

b. Recharge PEFCR for batteries (Recharge, 2018)

Recharge argues that, "In general transportation has a negligible impact on the environment in the life cycle of a rechargeable battery." Therefore, the default values as per PEF/PEFCR are applied. Additionally, it is stated that, by default, there is no waste of products during the Distribution and Retail stage for batteries. The storage of the batteries at different stages of their life cycle is not specified in the PEFCR for batteries.

The transport from factory to final client (including consumer transport) shall be modelled within this life cycle stage. The final client is defined as the user (use phase).

A.1.2 EOL and recycling-relevant standards

In accounting for EOL and recycling emissions, three main approaches can be differentiated:

- the Cut-off approach,
- the Substitution approach, and
- the Circular Footprint Formula (CFF).

The Cut-off approach is also known as 100:0 or recycled content approach (RE:SOURCE, 2020). The burdens arising from the recycling at EOL are "cut-off" and shifted to the life cycle that uses the recycled materials (GBA, 2023). The impact of recycled materials on the input side starts with the recycling treatment to produce the materials which are used in the product system. Therefore, scrap input in the recycling process has no embedded burdens or credits from previous life cycles and no credit is received for making materials available for recycling at the End of life (GBA, 2023). Hence, after the recycling process, the secondary materials have embedded emissions equalling the recycling process emissions. The method incentivises the use of recycled materials as long as the recycling process has a lower environmental impact than virgin material (RE:SOURCE, 2020). This approach is recommended by the GBA Rulebook due to its transparency (GBA, 2023). It is also in compliance with the ISO standards 14040, 14044 and 14067 and the GHG Protocol recommends this method when the investigated product contains recycled content but there is unknown amount of recycling after use, and the company doing the life cycle assessment has control over how much recycled material to use (RE:SOURCE, 2020).

The Substitution approach is also referred to as 0:100, closed-loop approximation or End-of-life approach (RE:SOURCE, 2020). The method uses system expansion via substitution to evaluate the impact of recycling on the acquisition of virgin material. This approach is only applicable for closed-loop systems, as it assumes that recycled material substitutes for an equivalent amount of virgin material with same inherent properties (GHG Protocol, 2011). As credits are given to account for the assumed material substitution, burdens equivalent to this credit should be assigned to scrap used as an input to the production process (GHG Protocol, 2011).

However, the above two methods are neither compliant with PEF/PEFCR, nor with the application of PEFCR to lithium-ion batteries done by Recharge, as these require use of the Circular Footprint Formula (CFF) (Recharge, 2018). While the Cut-off approach favours ingoing secondary materials and the Substitution approach favours outgoing secondary materials, the CFF was developed to accommodate both by including the recycled content as well as recyclability (Eberhardt et al., 2020). Therefore, it introduces additional parameters such as the change in material quality between life cycle stages as well as allocation factors for recycling and energy recovery processes that are aiming to integrate the balance of supply and demand.

The CFF is complex to apply as it needs to be modelled on a per material basis. Additionally, the allocation factors and most of the parameters are not known at the point of market placement and would need to be based on assumptions or averages, which does not meet the ambition of the Battery Pass project and the GBA Rulebook to calculate the carbon footprint prioritising primary data. A deep dive assessment of the three main EOL allocation methods is provided in the Battery Pass document: "*Comparison of end-of-life allocation approaches: An analysis complementing the Battery Pass Rules for calculating the Carbon Footprint of the 'End-of-life and recycling' life cycle stage*".

B.1 Recycled content, recycling efficiencies and material recovery targets (European Commission, 2023)

To align the ambitions of the Battery Regulation with the approach to model the life cycle stage End-of-life and recycling, other relevant goals of the Battery Regulation need to be considered. The Battery Regulation implements sustainability requirements for batteries placed on the European market: this includes targets for recycled content, recycling efficiencies, and material recovery. While recycled content targets apply to economic operators placing the battery on the market, recycling process outcome targets apply to recyclers (please refer to below for recycled content, recycling efficiencies and material recovery targets).

Recycled content targets (Article 8): From 18 August 2031, economic operators need to demonstrate that the minimum share per manufacturing plant per year is:

a. 16% cobalt;
b. 85% lead;
c. 6% lithium;
d. 6% nickel.

From 18 August 2036, this minimum share needs to increase to:

a. 26% cobalt;
b. 85 % lead;
c. 12% lithium;
d. 15% nickel.

Annex XII Part B and C introduce **minimum recycling efficiencies and minimum levels of recovered materials**

- **Minimum recycling efficiencies**
  1) No later than 31 December 2025
     a. recycling of 75% by average weight of lead-acid batteries;
     b. recycling of 65% by average weight of lithium-based batteries;
     ba. recycling of 80% by average weight of nickel-cadmium batteries;
     c. recycling of 50% by average weight of other waste batteries.
  2) No later than 31 December 2030
     a. recycling of 80% by average weight of lead-acid batteries
     b. recycling of 70% by average weight of lithium-based batteries

- **Minimum levels of recovered materials**
  1) No later than 31 December 2027
     a. 90% for cobalt;
     b. 90% for copper;
     c. 90% for lead;
     d. 50% for lithium;
     e. 90% for nickel.
  2) No later than 31 December 2031
     a. 95% for cobalt;
     b. 95% for copper;
     c. 95% for lead;
     d. 80% for lithium;
     e. 95% for nickel.

References

Glossary, introduction (section 1), regulatory requirements (section 2), Battery Pass approach (section 3), and Annex

Circular Economy Initiative Deutschland (2021): Circular Economy Roadmap for Germany. https://static1.squarespace.com/static/5b52037e4611a0606973bc79/t/61c1e696dfc16244976acee2/1640097438387/Circular+Economy+Roadmap+for+Germany_EN_Update+Dec.+2021_DOI.pdf

Eberhardt et al. (2020): Towards circular life cycle assessment for the built environment: A comparison of allocation approaches. https://iopscience.iop.org/article/10.1088/1755-1315/588/3/032026/pdf

Eucar (2020): Attributional vs. Consequential LCA, Methodology Overview, Review and Recommendations with focus on Well-to-Tank and Well-to-Wheel Assessments. https://www.eucar.be/wp-content/uploads/2020/08/20200820-EUCAR-Attributional-vs-Consequential-updated-2.pdf

European Commission (2019): Webinar - Circular Footprint Formula. https://ec.europa.eu/environment/eussd/pdf/Webinar%20CFF%20Circular%20Footprint%20Formula_final-shown_8Oct2019.pdf

European Commission (2020): European Platform on Life Cycle Assessment: Developer Environmental Footprint Annex C. https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

European Commission (2021): Annex 1 to 2 - Recommendation on the use of Environmental Footprint methods. https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

European Commission (2023): European Platform on LCA | EPLCA. https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html

European Commission (2023): Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_5469_2023_INIT&from=EN

Finnveden et al. (2009): Recent developments in Life Cycle Assessment. https://doi.org/10.1016/j.jenvman.2009.06.018

Global Battery Alliance (GBA) (2023): Greenhouse Gas Rulebook: Generic Rules - Version 1.5. https://www.globalbattery.org/media/publications/gba-rulebook-v1.5.pdf

GHG Protocol (2011). Product Life Cycle Accounting and Reporting Standard. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

International Standards Organisation (ISO) (2006): ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines. https://www.iso.org/standard/38498.html

International Standards Organisation (ISO) (2006): ISO 18604:2013 Packaging and the environment – Material recycling. https://www.iso.org/obp/ui/#iso:std:iso:18604:ed-1:v1:en

Joint Research Centre (2023): Rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries (CFB-EV)(CFB-EV). https://eplca.jrc.ec.europa.eu/permalink/battery/GRB-CBF_CarbonFootprintRules-EV_June_2023.pdf

Mohr et al. (2020): Toward a cell-chemistry specific life cycle assessment of lithium-ion battery recycling processes. https://doi.org/10.1111/jiec.13021

Rajaeifar et al. (2021): Life cycle assessment of lithium-ion battery recycling using pyrometallurgical technologies. https://doi.org/10.1111/jiec.13157

RE:SOURCE (2020): Modeling recycling in life cycle assessment. https://www.lifecyclecenter.se/wp-content/uploads/2020_05_Modeling-recyling-in-life-cycle-assessment-1.pdf

Recharge (2018): PEFCR - Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications. https://wayback.archive-it.org/org-1495/20221006222329mp_/https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Batteries_Feb%202020-2.pdf

Rinne et al. (2021): Simulation-based life cycle assessment for hydrometallurgical recycling of mixed LIB and NiMH waste. https://doi.org/10.1016/j.resconrec.2021.105586

Sphera et al. (2020): The Circular Footprint Formula (CFF) and its practical application. https://ec.europa.eu/environment/eussd/smgp/pdf/TrainingCFF%20Circular%20Footprint%20Formula10Nov2020_final_corr.pdf

Together for Sustainability (TfS) (2022): The Product Carbon Footprint Guideline for the Chemical Industry – Specifications for suppliers' product carbon footprint calculation. https://www.tfs-initiative.com/app/uploads/2022/09/TfS_PCF_Guideline_2022_pages.pdf

WBCSD (2021): Pathfinder Framework – Guidance for the Accounting and Exchange of Product Life Cycle Emissions. https://www.wbcsd.org/contentwbc/download/13299/194600/1

Distribution rules (section 4)

European Commission (2021): Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021H2279

Global Battery Alliance (GBA) (2023): Greenhouse Gas Rulebook: Generic Rules - Version 1.5. https://www.globalbattery.org/media/publications/gba-rulebook-v1.5.pdf

Intergovernmental Panel on Climate Change (IPCC) (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 – Mobile Combustion, https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

Recharge (2018): PEFCR – Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications, https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Batteries.pdf

EOL and recycling rules (section 5)

Brückner, Lisa, Julia Frank, and Tobias Elwert (2020): Industrial Recycling of Lithium-Ion Batteries—A Critical Review of Metallurgical Process Routes. https://doi.org/10.3390/met10081107

Circular Economy Initiative Deutschland (CEID) (2020): Resource-Efficient Battery Life Cycles-Driving Electric Mobility with the Circular Economy. https://static1.squarespace.com/static/5b52037e4611a0606973bc79/t/61c1e856a32b9841b83e0034/1640097893046/TB_Gesamtbericht+EN_DOI.pdf

Doose, Stefan, Julian Mayer, Peter Michalowski and Arno Kwade (2021): Challenges in Ecofriendly Battery Recycling and Closed Material Cycles: A Perspective on Future Lithium Battery Generations. https://doi.org/10.3390/met11020291

European Commission (EC) (2021): Recommendation on the use of Environmental Footprint methods – Annex 1 to 2. https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

Global Battery Alliance (GBA) (2023): Greenhouse Gas Rulebook: Generic Rules - Version 1.5. https://www.globalbattery.org/media/publications/gba-rulebook-v1.5.pdf

GHG Protocol (2011): Product Life Cycle Accounting and Reporting Standard. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

IPCC (2021): The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf

Liu, Fupeng, Chao Peng, Antti Porvali, Zulin Wang, Benjamin P. Wilson, and Mari Lundström (2019): Synergistic Recovery of Valuable Metals from Spent Nickel–Metal Hydride Batteries and Lithium-Ion Batteries. https://doi.org/10.1021/acssuschemeng.9b02863

Makuza, Brian, Qinghua Tian, Yueyi Guo, Kinnor Chattopadhyay, and Dawei Yu (2021): Pyrometallurgical options for recycling spent lithium-ion batteries: A comprehensive review. https://doi.org/10.1016/j.jpowsour.2021.229622

Mohr, Marit, Jens F. Peters, Manuel Baumann, and Marcel Weil (2020): Toward a cell-chemistry specific life cycle assessment of lithium-ion battery recycling processes. https://doi.org/10.1111/jiec.13021

Partnership for Carbon Transparency (PACT) (2023): Pathfinder Framework Guidance for the Accounting and Exchange of Product Life Cycle Emissions – Version 2.0. https://www.carbon-transparency.com/media/b13h4b25/pathfinder-framework_report_final.pdf

PE International (2014): Harmonization of LCA Methodologies for Metals – A whitepaper providing guidance for conducting LCAs for metals and metal products. https://www.euromines.org/files/publications/harmonization-lca-methodologies-metals.pdf

Rinne, Marja, Heini Elomaa, Antti Porvali, and Mari Lundström (2021): Simulation-based life cycle assessment for hydrometallurgical recycling of mixed LIB and NiMH waste. https://doi.org/10.1016/j.resconrec.2021.105586

Recharge (forthcoming): 2023 Update of “PEFCR – Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications”

Santero, Nicholas, Josh Hendry (2016): Harmonization of LCA methodologies for the metal and mining industry. The international journal of life cycle assessment. https://doi.org/10.1007/s11367-015-1022-4

Together for Sustainability (TfS) Initiative (2022): The Product Carbon Footprint Guideline for the Chemical Industry – Specifications for suppliers’ product carbon footprint calculation. https://www.tfs-initiative.com/app/uploads/2022/09/TfS_PCF_Guideline_2022_pages.pdf

Wagner-Wenz, Ronja, Katrin Berberich, Anke Weidenkaff et al. (2022): Recycling routes of lithium-ion batteries: A critical review of the development status, the process performance, and life-cycle environmental impacts. https://link.springer.com/content/pdf/10.1557/s43581-022-00053-9.pdf

Circular Footprint Formula extension (section 6)

European Commission (2019). Circular Footprint Formula. Retrieved from Webinar; Environmental Footprint (EF) transition phase. https://ec.europa.eu/environment/eussd/pdf/Webinar%20CFF%20Circular%20Footprint%20Formula_final-shown_8Oct2019.pdf

European Commission (2021). Annex 1 to 2 – Recommendation on the use of Environmental Footprint methods. https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

European Commission (2023). Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_5469_2023_INIT&from=EN

Joint Research Centre (2023). Harmonised rules for the calculation of the Carbon Footprint of Electric Vehicle batteries (CFB-EV). https://eplca.jrc.ec.europa.eu/GRB-CBF_CarbonFootprintRules-EV.pdf

Battery Pass

Have a look at our Website EXPLORE

Follow us on LinkedIn FOLLOW

Subscribe to our Newsletter REGISTER

Drop a line for more information CONTACT US

CONSORTIUM LEAD

SYSTEMIQ

CONSORTIUM PARTNERS

acatech, Audi, BASF We create chemistry, BMW GROUP, Circulor, FIWARE FOUNDATION, Fraunhofer IPK, TWAICE, umicore, VDE RENEWABLES

* under subcontract

This project receives funding from the German Federal Ministry for Economic Affairs and Climate Action by resolution of the German Bundestag under grant agreement No 16BZF335.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag