Battery Pass

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

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The Battery Pass consortium

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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.

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List of abbreviations

Abbreviation	Definition
CF	Carbon Footprint (for batteries)
CFF	Circular Footprint Formula
CO2	Carbon Dioxide
e-mobility / EV	Electric mobility / electric vehicle
EF	Environmental Footprint (relating to PEF)
EOL	End-of-life
GBA	Global Battery Alliance
GHG	Greenhouse Gas
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
Li-ion	Lithium-ion
NMC	Nickel Manganese Cobalt
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules

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Executive Summary

Under the Battery Regulation, economic operators have to declare the carbon footprint for batteries (CF) before placement on the market. The CF calculation includes the life cycle stage 'End-of-life and recycling'. Three main approaches exist to allocate the emissions occurring in this stage: the Cut-off approach, the Substitution approach and the Circular Footprint Formula (CFF). The Battery Regulation requires the CFF per reference to the Product Environment Footprint (PEF) methodology and the PEF Category Rules (PEFCR).

The Battery Pass consortium assessed these three approaches and concludes that the Cut-off approach is the most transparent and reliable. In contrast, the CFF yields sub-optimal results as it is based on hypothetical modelling of EOL scenarios which requires a significant number of assumptions, default values and secondary data. The Battery Pass consortium acknowledges the ambition of the CFF to include considerations of the battery's EOL handling. It is, however, questionable whether it achieves its implicit goal to incentivise the supply of secondary materials. The CFF – as specified at the time of writing this document – risks overestimating credits received for the supply of recycled materials at EOL which, in the case of electric vehicle (EV) batteries, is 10–15 years after placement on the market. While the Cut-off approach focuses on the usage of secondary materials only and not the supply, the Battery Pass consortium argues that the demand for recycled content and requirements for EOL management introduced by the Battery Regulation (material recovery and recycling efficiency targets) provide sufficient incentives to ramp up supply. Additionally, the factual burdens and benefits of EOL treatment of the battery cannot be estimated at the time of placing the battery on the market. A hypothetical EOL modelling based on assumptions of the battery's fate risks achieving the opposite: overestimation of credits received for the future supply of secondary materials. This confounds accuracy and comparability of declared battery carbon footprints, which are the basis for subsequent CF instruments (performance classes and maximum threshold).

The Battery Pass carbon footprint working group recommends to the relevant EU institutions to incorporate the Cut-off approach in the delegated act development. If this is not possible due to political decisions taken, the CFF parameters should be specified in way that the CFF reflects or approximates the Cut-off approach. This would be the case if the A factor is set close or equal to one. As the PEF methodology prescribes the A factor to be in between 0.2 and 0.8, the Battery Pass recommends specifying the A factor at 0.8 for all battery materials. Furthermore, R_2 should be specified taking into consideration the recyclability of batteries, a discounted collection for recycling rate (excluding EOL vehicles with unknown whereabouts) as well as the recycling yields at the output of the recycling plant for specific materials. Further recommendations to improve the practicality of the CFF are presented in section 7.

1 Introduction

The proposal for a regulation concerning batteries and waste batteries ("Battery Regulation") demands economic operators to report the carbon footprint of the battery (CF) in the form of a carbon footprint declaration (1). Therefore, the entire life cycle of the batteries needs to be considered, including the "End-of-life (EOL) and recycling" life cycle stage. The GHG GBA Rulebook (2) defines the rules for primary data collection and accounting of the upstream production process, while the Battery Pass consortium is extending these for the "EOL and recycling" life cycle stage.

To account for EOL and recycling emissions, three main allocation approaches exist, all yielding different results: the Cut-off approach, the Substitution approach, and the Circular Footprint Formula (CFF). This analysis compares these approaches, by giving an overview of the regulatory background, existing standards for modelling EOL and recycling as well as qualitatively assessing the approaches and quantitatively comparing them using a reference battery life cycle. This serves as the basis to back the decision of the Battery Pass consortium to recommend and apply the Cut-off approach as the most transparent and reliable approach. The comparative assessment and recommendations shall be viewed in the specific context of the EU Battery Regulation and corresponding carbon footprint requirements.

The methodological choice of the EOL allocation impacts the overall carbon footprints declared. To fulfil the ambition of the Battery Regulation – reliable and comparable carbon footprints declared, enabling real-world decarbonisation in the battery supply chain – it is important to understand the effects of the EOL allocation method on the calculation of the carbon footprint for batteries. This document aims to provide insights to life cycle assessment (LCA) practitioners from industry and academia as well as experts and policymakers developing and deciding on the methodology that will be translated into a delegated act for the calculation of the carbon footprint.

This analysis proceeds as follows: it first presents an overview on the CF requirements as per the Battery Regulation, including a focus on EOL management (chapter 2). Then, existing standards for modelling EOL and recycling are discussed (chapter 3). Based on this, the three main accounting approaches (Cut-off approach, Substitution approach and CFF) are explained and evaluated (chapter 4). Each of those approaches are compared with respect to their advantages and disadvantages, deriving the Battery Pass conclusion to follow the Cut-off approach (chapter 5). This is further illustrated by a quantification of the approaches using an exemplary battery inventory (chapter 6). Hence, the analysis presents a qualitative and quantitative rationale for the approach of the Battery Pass consortium to prioritise the Cut-off approach. Finally, as the Battery Regulation introduces the CFF as the required accounting method, an approach to incorporate the Cut-off approach into the CFF is discussed, as is a recommendation to specify CFF parameters that reduces the risk of overestimating secondary supply credits (chapter 7).

The descriptive and qualitative analysis is based on public documents as well as on discussions within the Battery Pass carbon footprint working group and additional expert interviews. For the quantification, public datasets and the life cycle assessment tool openLCA were used (see chapter 6.1 for more information).

2 Regulatory background

2.1 The carbon footprint in the Battery Regulation

The regulatory requirements for the battery carbon footprint (CF) follow from the EU Battery Regulation. The Battery Pass project aims at providing a regulation-compliant approach to battery passports and takes these requirements as a starting point. While the regulation sets out the essential elements and requirements for the CF, room for interpretation remains in translating these into specific approaches and methodologies for the carbon footprint calculation. Therefore, Battery Pass provides detailed guidance to collect and aggregate process- and company-specific activity data for the EOL and recycling life cycle stage to complement the work done by the GBA the GBA for cradle-to-gate processes.

Annex XIII of the Battery Regulation specifies the information to be included in the battery passport and requires economic operators to make publicly accessible the “(f) Carbon footprint referred to in Articles 7(1) and 7(2)”. The carbon footprint is regulated in Article 7 requiring EV batteries, light means of transport and rechargeable industrial batteries with a capacity above 2 kWh to draw up a carbon footprint declaration with a technical documentation that includes, for each battery model per manufacturing plant, a carbon footprint.

The declaration needs to contain, among others:

d. 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;
e. the carbon footprint of the battery differentiated per life cycle stage as described in point 4 of Annex II.

A delegated act (second sub-paragraph) regulating the methodology for the CF calculation will be published 6 months after entry into force of the regulation for EV batteries, 18 months for industrial batteries except those with exclusively external storage, 42 months for LMT batteries, and 66 months for industrial batteries with external storage. As basis for the EV delegated act, the EU Joint Research Centre (JRC) recently published “harmonised rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries” (3). In this, CFF requirements are presented.

The calculation of the CF shall build on the essential elements in Annex II and must be in compliance with the latest version of the Commission Product Environmental Footprint (PEF) (4) method and relevant Product Environmental Footprint Category Rules (PEFCRs) (5) and reflect the international agreements and technical/scientific progress in the area of life cycle assessment.

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 units, safety units) and the cathode materials have to be accurately identified, as they may become the main contributor for 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 (i.e., no default activity data shall be used). The battery-specific activity data shall be used in combination with the relevant Product Environmental Footprint-compliant secondary datasets.[1] The carbon footprint must be calculated and reported per life cycle stage (see chapter 2.2).

2.2 Carbon footprint lifecycle stage 'End-of-life' and recycling

The carbon footprint (d. and e. above) must be calculated per life cycle stage in accordance with the essential elements set out in Annex II of the Battery Regulation. As per Annex II (4), the Battery Regulation requires four life cycle stages to be calculated and hence sets the system boundaries:

- Stage 1: Raw material acquisition and pre-processing
- Stage 2: Main product production
- Stage 3: Distribution
- Stage 4: EOL and recycling

Stage 4: EOL and recycling – the focus of this document – requires the following processes as per the regulation: Collection, dismantling and recycling. Manufacturing of equipment for batteries recycling shall be excluded as impacts have been calculated as negligible in the PEFCRs for high specific energy rechargeable batteries for mobile applications (1). The regulation's requirements for EOL and recycling are not further defined.

2.3 Recycled content and recycling: target ambitions of the Battery Regulation

To align the ambitions of the Battery Regulation with the approach to model EOL and recycling, this chapter discusses targets concerning EOL and recycling. 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. These political goals are relevant for assessing the carbon footprint accounting approach to EOL and recycling modelling – which incentivises certain aspects per the approach taken to account for recycling.

The increased use of recovered materials aims at supporting the development of a circular economy for batteries and allowing a more resource-efficient use of materials, while reducing Union dependency on materials from third countries (see *Recital 20*) (1). The Battery Regulation proposal holds that, for batteries, this is particularly relevant for cobalt, lead, lithium and nickel. Therefore, it intends to promote the recovery of such materials from waste, establishing a requirement on the level of recycled content in batteries using cobalt, lead, lithium and nickel in active materials. This Regulation sets mandatory recycled content targets for cobalt, lead, lithium and nickel in industrial batteries, EV batteries (and SLI batteries) (see *Article 8* of the Battery Regulation and Annex A1 of this document). A delegated act will be adopted to establish the methodology for the calculation and verification of the share of recycled content.

At the same time, the regulation – in compliance with the EU's Circular Economy Action Plan of 2020 – incorporates measures to improve the collection and recycling rates of all batteries. Hence, improving the recycling process and outcome is a target of the regulation as well.

[1] For EF compliant dataset information, please refer to respective website of the European Commission: https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html and https://eplca.jrc.ec.europa.eu/EF-node/

Requirements concerning the EOL stage aim at addressing the environmental implications of the batteries and, in particular, to support the creation of recycling markets for batteries and markets for secondary raw materials from batteries. This requires provisions ensuring the batteries' removability and replaceability in appliances to enable proper separate collection, treatment and high quality recycling once they have become waste. Besides harmonised rules for waste management, the regulation intends to maximise separate collection of waste batteries and ensure collection and recycling by setting common minimum recycling efficiency targets. Additionally, an Extended Producer Responsibility (EPR) scheme regulates that economic operators finance the costs of collection, treatment and recycling.

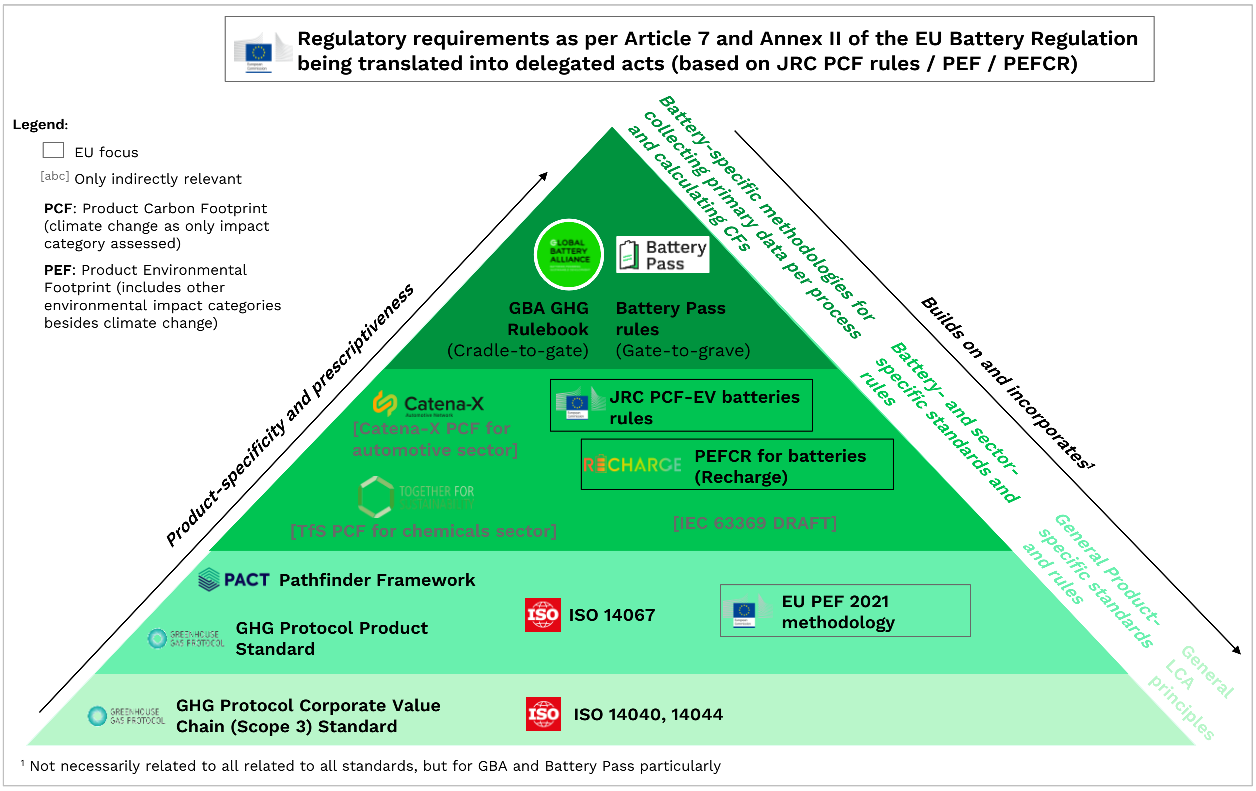
The regulation's *Article 56* holds that collected waste batteries shall not be disposed of or be the subject of an energy recovery operation, effectively requiring the recycling of each battery that enters waste status within the EU. *Article 57* stipulates the requirements for recycling efficiencies and material recovery targets, stating that recyclers shall ensure the targets in compliance with *Annex XII Parts B* and *C* (see Annex A1 of this document). Since recyclability, design-for-disassembly and design-for-recycling are not included and regulated under the responsibility of the economic operator placing the battery on the market, the recycler bears the responsibility for such targets.

3 Standards for modelling end-of-life and recycling

Figure 1 provides an overview on standards and methodologies that are applicable for the calculation of the CF. A distinction can be made between life cycle assessment and environmental footprint methodologies that generally include more than one environmental impact category and carbon footprint methodologies, that concentrate on the environmental impact of climate change indicated by global warming potential measured in CO2 equivalent. The illustrated standards and methodologies build on each other with the basis being created by the general life cycles assessment principles. Product-specificity and prescriptiveness is increased with the product-specific standards and rules followed by the battery- and sector-specific standards and rules as well as the battery-specific methodologies for collecting primary data per process and calculating CFs.

The standards and methodologies directly relevant for batteries are described below with regard to their EOL accounting approach.

Figure 1: Relevant standards and methodologies for the battery carbon footprint calculation and reporting



3.1 ISO 14040/ 14044 / (14049)/ 14067

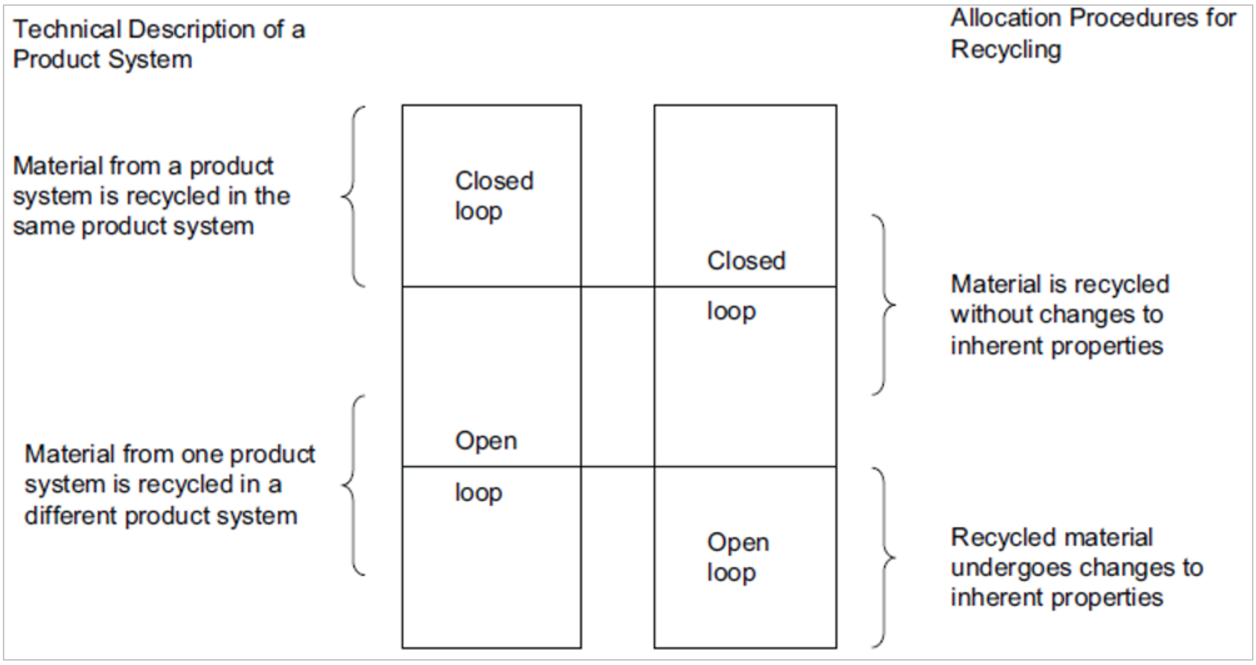
The International Organization for Standardization (ISO) is the worldwide federation of national standards bodies (6). ISO standards do not prescribe a specific method for modelling the EOL phase, but there are several standards that address topics relevant for modelling EOL and recycling:

ISO 14040:2006 describes the basic principles and framework for life cycle assessment (LCA) (7). This standard is applicable for all types of products, remains flexible and provides general guidelines (8). In this standard, the hierarchical allocation order provided for solving multifunctionality is relevant for modelling recycling emissions based on company-specific data:

1) dividing the process into sub-processes and “cutting off” the sub-processes providing the secondary function
2) “system expansion” where all functions of the product system are integrated into the system boundary through avoidance of impacts
3) if allocation cannot be avoided, an allocation approach based on inherent properties shall be applied

ISO 14044:2006 specifies requirements and provides guidelines for LCA (9). The standard defines three different EOL allocation procedures applicable for recycling (see Figure 2)

Figure 2: EOL allocation procedures for recycling (9)



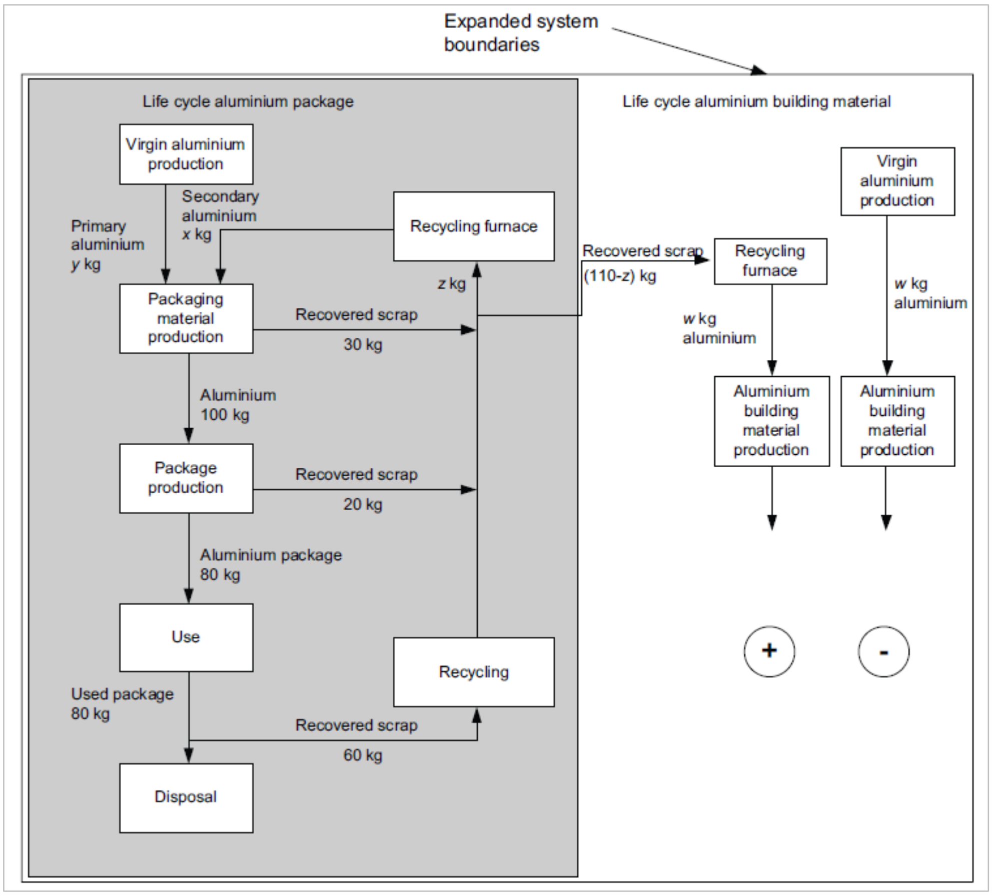
The Closed-loop allocation procedure is applicable in cases, where the need for allocation is avoided since the use of secondary material displaces the use of virgin materials. Thereby, the material is recycled without changes to its inherent properties.

An Open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and undergoes a change to its inherent properties.

A third possibility refers to an open-loop case with closed-loop procedure. This occurs when a material from one product system is recycled in a different product system but is recycled without changes to inherent properties. Hereby, an allocation problem emerges concerning the recycling benefit of export or imports to other product pools.

ISO 14049:2012 lays out examples to further explain the three procedures (10). Taking aluminium as an example for the open-loop case with closed-loop procedure: when only a fixed percentage of secondary aluminium is used, and the amount of recovered scrap aluminium is therefore higher than input capacity of the system, the net scrap output of aluminium into an open-loop product pool could be considered as a by-product. Hereby, expansion of the system boundary to avoid allocation is applied (10). This is illustrated in an example in Figure 3, where aluminium from packaging is reused as a building material.

Figure 3: Example for open-loop allocation with closed-loop procedure (10)



The above-mentioned ISO standards can be used as the basic principles and guidelines for the carbon footprint accounting as they are the basis for other standards. For example, the EOL allocation as per GHG protocol generally follows the requirements of ISO 14044, section 4.3.4.3. It concerns how to assign impacts from virgin production processes to material being recycled and used in future product systems.

Some materials in the battery value chain might follow the closed-loop and some the open-loop allocation: E.g., for metal (salts) such as Co, Ni, Li in the battery that can be recycled and then reused in a new battery, the closed-loop procedure applies. For other materials, that are possibly used in another product system but do not undergo changes to inherent properties such as Al, Cu or steel, the case of an open-loop with closed-loop procedure would apply. For this procedure, the other system would need to be known. Thereby, e.g., customer contracts could serve as proof that the recycled material is reused in a system where it replaces primary materials as well as indicate the quality of primary material substituted.

ISO 14067:2018, in comparison to the above-described standards, specifies principles, requirements and guidelines for the carbon footprint for products (CFP) (11). ISO 14067 recommends an open-loop approach in the case of materials undergoing a change in inherent properties when being recycled into other products. Hereby, the virgin material production should be partitioned between the product where the virgin material is used and the product where the material is lost (12). Therefore, this standard provides the possibility to incorporate the number of subsequent uses of a recycled material into an allocation factor of virgin material production (13). ISO 14067 defines this factor as the ratio between the global market value of scrap material or recycled material to the global market value of virgin material.

3.2 GHG Protocol – Product Life Cycle Accounting and Reporting standard

The Greenhouse Gas (GHG) Protocol is a multi-stakeholder partnership of businesses, NGOs, governments, and others initiated by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (14). The GHG Protocol has developed various standards of which the Product Life Cycle Accounting and Reporting standard is particularly relevant for the carbon footprint of batteries.

The GHG Protocol – Product Life Cycle Accounting and Reporting standard is internationally accepted and provides standards and guidance for GHG accounting and reporting of companies and other organisations. In comparison to the ISO 14064, the GHG Protocol explains and indicates best practice for GHG inventory, while for compliance with these best practices, ISO 14064 sets minimum standards. They differ slightly but are complementary documents with ISO pointing out “what to do” and the GHG Protocol explaining “how to do it” (15).

The standard provides two specific methods for allocating emissions and removals between product life cycles due to recycling and specifies when to apply them:

1) Closed-loop approximation, in this analysis referred to as Substitution approach, considers the impact of recycling on procurement of virgin materials by system expansion. This approach is recommended by the GHG Protocol, when the amount of recycled content in the products is unknown, because recycled and virgin material cannot be distinguished on the market and the demand for recycled material exceeds supply of recyclable materials, or the product service life is short and/or well known (12).
2) Recycled content method, in this analysis referred to as Cut-off approach, allocates recycling process emissions to the life cycle that uses the recycled materials. The GHG Protocol recommends this method, when the product contains recycled input but there is no or unknown amount of recycling after use, as well as when the supply of recyclable material exceeds the demand for recycled material or the company doing the LCA has control over the amount of recycled materials used (12).

Where the decision on the allocation method is not obvious, the GHG Protocol requests companies to perform a scenario uncertainty assessment by applying both methods and reporting the results (14).

3.3 EU standards: PEF 2021 recommendation and Recharge PEFCR for batteries

The Product Environmental Footprint (PEF) is a life-cycle-based methodology published by the European Commission for modelling and assessing environmental impacts of products and services (16). It aims to standardise existing LCA-methods to achieve better reproducibility, comparability, and consistency. Thereby it is built on the principles established in ISO 14040 and ISO 14044 (17). The goal is to reliably measure and make substantiated claims on the environmental performance of products (and organisations under the Organisational Environmental Footprint) and thus enable companies to compare products to improve decision-making.

The European Commission published the “Recommendation on the use of the Environmental Footprint methods” to promote use of the environmental footprint methods in relevant policies (4). The use of PEF is foreseen in the context of EU policies and legislations such as the Taxonomy Regulation and the Sustainable Products Initiative (4). PEF includes 16 impact categories, but in current legislations such as the Battery Regulation, the method is proposed with only climate change as indicator for calculating the product carbon footprint (PCF).

The Product Environmental Footprint Category Rules (PEFCRs) were developed for the application of PEF and to provide guidance for specific product types. These PEFCRs are aiming to make LCA more accessible and easier to do, to achieve higher quality and credibility of results (18). Hence, PEFCRs are a ruleset describing how to calculate the environmental footprint of a specific product type translating the PEF method into product-specific instructions. In so-called pilots, the PEFCRs are applied to further specify the application of PEFCRs for these products. For batteries, Recharge is hosting the PEFCR Technical Secretariat to further develop battery-specific PEFCRs (19). Their 2018 PEFCR pilot applies the PEFCR guidance version 6.3 document and the PEF recommendation to batteries.

Regarding the modelling of EOL, recycling and recycled content, PEF / PEFCR / Recharge propose a common procedure and allocation method, the Circular Footprint Formula (CFF):

The CFF aims to include recycled content as well as EOL recycling, energy recovery and disposal and therefore combines production burdens, burdens/benefits related to recycled content, burdens/benefits related to secondary materials output (all “material” part of the formula, see Figure 6), energy recovery and disposal.

In detail, it accounts for the share of recycled material, the ratio of material recycling, the quality of recycled material entering and leaving the life cycle and the balance between supply and demand for individual recycled materials. Hence, the formula is relatively complex and, therefore, a simplified version of the CFF is currently under development.

Please refer to chapter 4.3 for a detailed discussion of the CFF.

3.4 GBA GHG Rulebook version 1.4 and Battery Pass rules

The Global Battery Alliance (GBA) GHG Rulebook version 1.4 provides guidance to enable the calculation of comparable GHG footprints of lithium-ion batteries (LIB) for electric vehicles (EV) by users of the GBA Battery Passport (2). The scope of this version includes the GHG footprint of the manufacturing stage (cradle-to-gate) of raw materials, active and passive materials, or the battery itself. Thereby the Rulebook provides guidance for company-specific data collection in line with the GBA vision of primary data collection and aggregation along the supply chain.

The Rulebook does not define rules for EOL and recycling but clarifies EOL allocation and explains the Substitution approach as well as Cut-off approach, whereby the Cut-off approach is recommended. It distinguishes scrap in three categories: Process scrap, EOL scrap, and Scrap from unknown origin, whereof “run around scrap” within one plant is not supposed to be considered in the calculation of the recycled content and only scrap that is purchased from outside the plant.

The Battery Pass performed a standard mapping, comparing the GBA Rulebook to PEF/PEFCR/Recharge to ensure PEF-compliance. The result shows that the GBA Rulebook only contains some minor, non-significant deviations and thus is compliant with PEF/PEFCR/Recharge PEFCR. The only exception is the EOL allocation as PEF/PEFCR/Recharge PEFCR require the CFF.

The Battery Pass *“Rules for calculating the Carbon Footprint of the ‘Distribution’ and ‘End-of-life and recycling’ life cycle stages”* complement the *GBA Greenhouse Gas Rulebook* with the Distribution as well as EOL and recycling life cycle stages and therefore the gate-to-grave part as required by the Battery Regulation. The GBA and Battery Pass envision a process of primary data collection and aggregation along the supply chain and therefore recommend the Cut-off approach. However, the data collection under a Cut-off approach could be extended to fulfil the requirements and perform the calculation for the CFF, in case this is required by the delegated act specifying the methodology for calculating the CF for batteries.

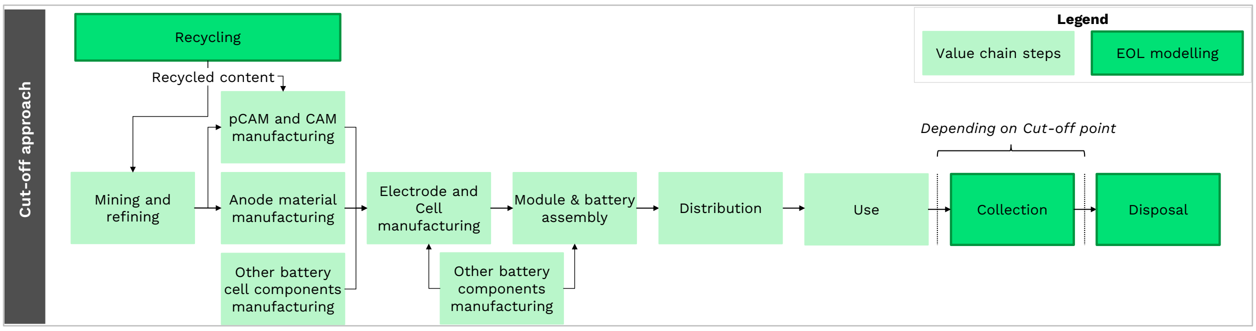
4 Three approaches to account for end-of-life and recycling

4.1 The Cut-off approach

The Cut-off approach is also known as 100:0 or recycled content approach (12). The burdens associated with the product's recycling at EOL are "Cut-off" and shifted to the life cycle that uses the recycled materials (2). 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 EOL (2). Hence, after the recycling process, the secondary materials have embedded emissions equalling the recycling process emissions which are allocated to recycled content.

For applying the method, a so-called "Cut-off point" needs to be defined. There are two possible Cut-off points illustrated in Figure 4: directly after the use, or after the collection of the batteries for recycling. The Circular Economy Initiative Deutschland defines the recycling process begins with the removed battery (20). Therefore, the Cut-off point should be set accordingly, after the use and before the collection of the battery.

Figure 4: Flow diagram of Cut-off approach



It has been found that this method is the easiest (12) and most transparent approach (2) for allocation of EOL and recycling. This is due to the possibility of using primary data for recycling processes and not including hypothetical future scenarios, e.g., regarding the EOL treatment. The approach incentivises the use of recycled material as long as the recycling process has less environmental impact than virgin material (12).

Furthermore, the Cut-off approach is compliant with the described ISO standards, the GHG Protocol and the GBA GHG Rulebook, but not compliant with PEF and PEFCR.

4.2 The Substitution approach

The Substitution approach is also known as 0:100, recyclability Substitution, avoided burden or EOL approach (12). The method uses system expansion to evaluate the impact of recycling on the net virgin acquisition of a material (14). It includes all attributable processes due to EOL and a virgin replacement factor: recycling rate of material (recycled output/virgin material input).

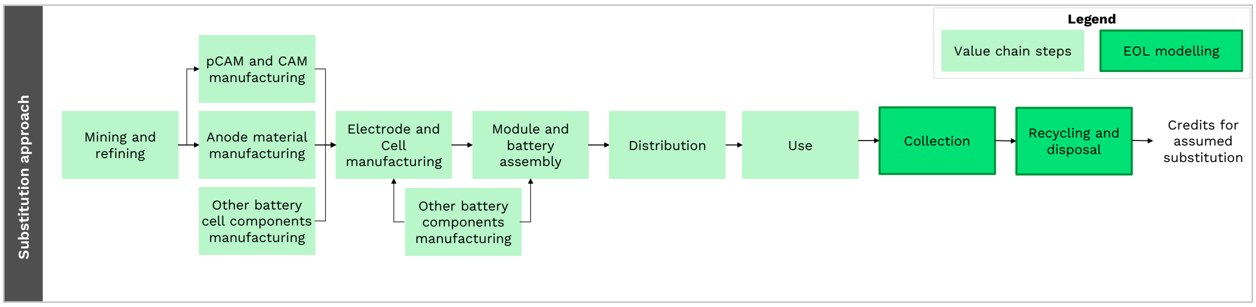
This approach is only applicable for closed-loop systems, as it assumes that recycled material substitutes for an equivalent amount of virgin material with the same inherent properties (14). As credits are given to account for the assumed material Substitution (see Figure 5), burdens equivalent to this credit should be assigned to scrap used as an input to the production process (2). Following this allocation method, impacts of recycling stay within the same product system and are not allocated to another product system.

The Substitution approach incentivises recyclability but does not take into account whether the materials are actually recycled. When examining upstream emissions, the impact of recycled materials is the same as that of virgin materials. Therefore, this approach does not incentivise the use of recycled materials.

When modelling the recycling process at the point of placing the battery on the market, this method would rely on hypothetical scenarios, assumptions, and therefore secondary data.

Similar to the Cut-off approach, this method is compliant with ISO, GHG Protocol and GBA Rulebook, but not compliant with PEF/PEFCR.

Figure 5: Flow diagram of Substitution approach



4.3 The Circular Footprint Formula

The Circular Footprint Formula (CFF) proposed by the European Product Environmental Footprint method accounts usage of recycled materials as well as benefits and burdens associated with recycling, energy recovery and disposal at the EOL (21).

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 recovery 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. Due to multiple parameters included, that refer to different life cycle stages as well as the technical requirement to calculate the formula for each material, the CFF is complex to incorporate (12).

It consists of three parts – material, energy and disposal – and is composed as follows with the parameters described below (5):

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

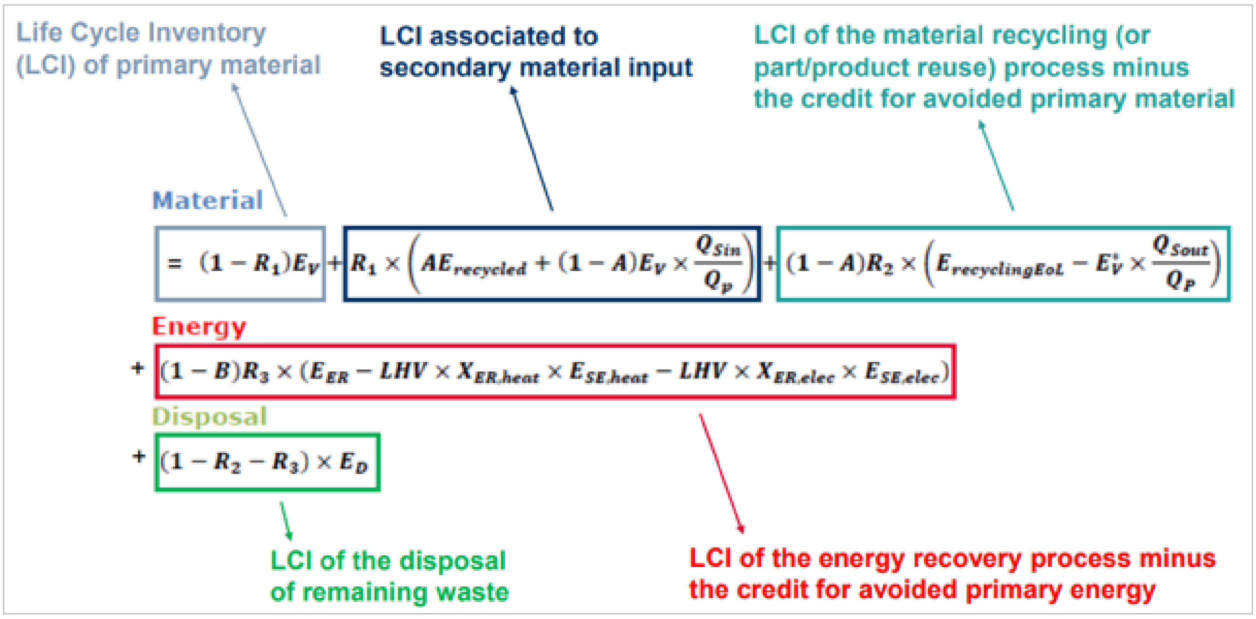
Energy $(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) +$

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

- **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, ...).
- **$E_{SE,heat}$ 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

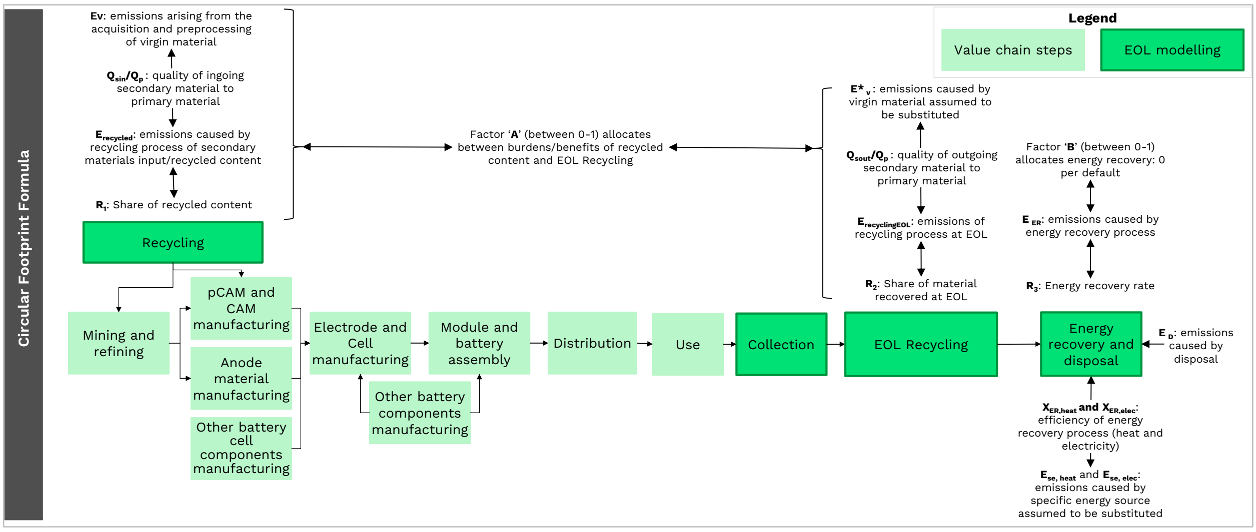
Hereby, the formula for materials consists of the life cycle inventory (LCI) of primary material, followed by the LCI of secondary material and the LCI of the material recycling. The LCI for the energy recovery process minus the credit for avoided primary energy comprises the energy related part of the CFF, while the LCI of the disposal of remaining waste is covered by the last part of the formula (see Figure 6 (21)).

Figure 6: The elements of the Circular Footprint Formula



Therefore, the different parts of the formula refer to different life cycle stages. Figure 7 illustrates which step of the value chain is influenced by the respective parameters.

Figure 7: Flow diagram of Circular Footprint Formula



In Annex C, PEFCR provides default values for the parameters A, R_1, R_2 and R_3 (22). However, these values are not all directly applicable for batteries. For example, R_3 is only provided for Municipal Solid Waste or packaging applications. An overview of the meaning of relevant CFF parameters is given in Figure 8.

Figure 8: CFF parameters, their range and meaning

Parameter	0	1
A: allocation factor of burdens and credits between supplier and user of recycled materials	Benefits to recycling output	Benefits to recycled content
B: allocation of energy recovery	100% credited to producer (default)	100% credited to user
R_1: proportion of secondary material (recycled content)	100% primary material	100% secondary material
R_2: share of material recovered at end-of-life	0% recycled at EOL	100% recycled at EOL
R_3: energy recovery rate	0% to energy recovery	100% to energy recovery
Q_{sin}/Q_p: quality of ingoing secondary material to primary material	0% same quality	100% same quality
Q_{sout}/Q_p: quality of outgoing secondary material to primary material	0% same quality	100% same quality
$X_{ER,heat}$ and $X_{ER,elec}$: efficiency of the energy recovery process for both heat and electricity	0% efficiency	100% efficiency

The definition of parameter "A" significantly influences the results (23). A allocates between burdens/benefits of recycled content and EOL recycling. The specification can therefore reflect one of the other allocation procedures depending on the material and the market situation of the material (8). 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 and JRC study define an A value of 0.2 for high quality secondary materials. The implicit assumption is that demand exceeds supply of these secondary materials. Thereby, the indicator is that their market price is close to or the same as 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 provided as default. Where the market situation is more balanced or unknown the A value should be set to 0.5, which is done for plastics as per JRC. Neither values between those mentioned, nor rules to calculate situation-specific values are indicated by PEF. Note that there is continued discussion regarding the A factor in the PEFCR Technical Secretariat working on the update of the 2018 PEFCR for batteries.

"B" is equal to 0 per default, which indicates that 100% of generated and externally used energy is credited at the producer and debited at 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 from 0 could not be found.

For all other parameters, default values are to be defined by the specific PEFCR or are part of the EF-compliant dataset tendered by the European Commission (22).

As elaborated in chapter 3.3, PEF, PEFCR as well as the application of PEFCR on lithium-ion batteries done by Recharge require the application of the CFF.

5 Qualitative assessment: Battery Pass rationale for recommending the Cut-off approach

The Battery Pass carbon footprint working group assessed the Cut-off approach to be the most suitable allocation method for modelling the EOL of batteries. The rationale for this decision is explained in the following. It has been derived from extensive working group discussions as well as expert interviews and is complemented by the reasoning in this document.

In the context of the Battery Regulation and the increasing move to company-specific carbon footprint values as a policy and management tool, the three EOL allocation approaches are compared using the subsequently explained criteria. The qualitative argumentation is summarised in Table 1. Furthermore, the advantages and disadvantages of each approach considering the defined criteria and beyond are compared (see Table 2 to Table 4).

- **Primary data availability:** With primary data, i.e. company-specific data, the carbon footprint can be calculated most transparently, differentiable and accurately. The goal of the regulatory carbon footprint instruments is to improve life cycle emissions of batteries (excluding the use phase). Only primary data can enable real-world optimisation of carbon emissions in production processes and along value chains. When primary data is not available for a process, the calculation must rely on secondary data such as sector or geographical averages and the results are therefore not as differentiating. In the specific case of reporting the carbon footprint of batteries, it needs to be declared when placing them on the market. Only processes that took place up to that time could be accounted for using primary data without the need for making assumptions. For the EOL, which takes place up to 10–20 years after placement on the market, primary data from existing processes could be used but assumptions, e.g., that the EOL recycling process equals the process that has produced the recycled content, are required.
- **Control of the economic operator placing the battery on the market:** The Battery Regulation defines the economic operator placing the battery on the market or putting it into service to be responsible for declaring the carbon footprint of the battery (1). Therefore, it is important that the life cycle stages, which are substantial in contributing to the carbon footprint, are in the control of the economic operator, i.e. company-specific data access exists. Control entails that access to the supply chain information is available. The economic operator can thus collect and report carbon footprint data transparently to make informed decisions and take actions that potentially reduce the environmental footprint, e.g., by increasing the amount of recycled content. The use phase of products generally entails that this control over information is lost, considering that information gaps are currently not yet filled with digital solutions such as battery passports. The responsible economic operator has better control in the supply chain until the placement on the market, e.g., via the choice of suppliers. In the respective supply chain, the control of the economic operator is strong, particularly with respect to immediate suppliers where technical specifications and commercial arrangements regulate the product or component requirements. This control can be continued to a limited extent after the market placement by setting up a take-back system.

Nevertheless, within and after the use phase, only operations and maintenance are indirectly controlled by economic operators, but ultimately the decision of the battery owner determines the fate of the battery (e.g., exports).

- **Adherence to key methodological principles (standardised, practical, accurate, and comparable):** The overarching goal of the carbon footprint regulatory requirements is the decarbonisation of the battery value chain by 2050 (1). This shall be achieved by introducing carbon footprint performance classes and maximum thresholds based on the carbon footprints declared in the EU, hence steering decarbonisation efforts by regulatory instruments. To design these measures effectively, methods for calculating and managing emissions should allow economic operators and political decision-makers to collect and efficiently use information and data on batteries placed on the market in order to make informed decisions. This requires that methodological choices adhere to principles that enable accurate and comparable carbon footprints being calculated in a standardised and practical manner. To be able to design effective carbon footprint measures (performance classes and maximum threshold), the Battery Pass concludes that these principles are most important for the carbon footprint declaration. <u>Standardised:</u> the method follows approaches that are consistently applied and yields consistent results. <u>Practical:</u> the method is easily understood and applicable in practice. <u>Accurate:</u> the results applying the method represent an accurate picture of the impact of the product in scope and do not rest on hypothetical assumptions but verifiable data. <u>Comparable:</u> the results can be compared across manufacturers, with differentiation of respective company-specific data.
- **Recycled content consideration:** The Battery Regulation aims for more sustainable batteries throughout their life cycle that promote more efficient use of resources and have the lowest possible environmental impact (24). Therefore, targets for the use of recycled content were defined (see Annex A.1). The primary goal of recycled content mandates is to drive demand for material recycling, irrespective of the price of primary material. Additionally, secondary battery metals likely have favourable environmental impacts compared to primary materials and their uptake can increase resource resilience. Therefore, the increased usage of recycled content in batteries is a key goal, and to achieve the lowest possible environmental impact, it is important to incentivise resource efficient and carbon reducing measures beyond the regulation requirements (i.e. recycled content target).
- **Recyclability consideration:** Similarly, to the recycled content, EOL recycling efficiency and material recovery targets are introduced by the Battery Regulation (see Annex A.1). These aim to increase the supply of secondary (battery) material and apply for the recycling companies, which do not represent the economic operator placing a battery on the market. Thereby, collection efficiency, separation efficiency and recycling process yield should be optimised. Through the carbon footprint, incentives can be provided to manufacturers, either directly or indirectly through considering recyclability in the design of batteries (e.g., through carbon footprint linked to recyclability of battery) or engaging in take-back schemes and partnerships with recycling service providers.

Based on the above elaborated criteria, Battery Pass concludes that the Cut-off approach is the most suitable method for calculating and allocating EOL emissions of batteries when placing the battery on the market as required by the EU Battery Regulation. It is the most practical, transparent and accurate approach to allocating EOL emissions in terms of attributing emissions as accumulated at the time of placement on the market, outweighing the shortcomings of the approach and the benefits of the other two methods. It is followed by the Circular Footprint Formula, while the Substitution approach presents the least appropriate accounting approach to model the EOL and recycling of batteries (see Table 1). With particular focus on the implications of the respective EOL approach on the carbon footprint of batteries, relevant advantages, and disadvantages for each of the three approaches are pointed out subsequently (see Table 2 to Table 4).

Under the emerging systems of carbon accounting, where primary data are collected and aggregated along the value chain to effectuate “real-world” optimisation, and the in the context of the carbon footprint declaration as per the Battery Regulation, the Cut-off is the most effective approach yielding comparable and accurate carbon footprints to enable emission reduction. Both the Substitution approach as well as CFF fundamentally require assumptions on future collection efficiencies and technologies that could, in total, decrease carbon footprints by overestimating credits for the (assumed) supply of secondary materials. This means that the Substitution approach and CFF estimate the EOL contribution of the footprint with scenarios based on (secondary and default) data which are not verifiable at the point of placing a battery on the market and may not accurately reflect the factual contributions, e.g., due to non-compliance with collection and recycling efficiencies. This could lead to the unintended consequence that the usage of secondary and default data is used to bias the carbon footprint, as current specifications of default values (e.g. in the batteries PEFCR (25) and the JRC draft (3)) disincentivise the use of primary data. This contradicts the intention of the carbon footprint declaration: providing an accurate and comparable basis for subsequent carbon footprint measures, for which primary data should be the basis.

It has been argued in the past that the Cut-off approach is an ineffective incentivisation method that might lead to market distortions as recycled feedstock is directed “towards designated products and away from production where recycling is most economical” (26) (27). Yet, in the context of the carbon footprint declaration for batteries as complex products containing a variety of metals and other materials as well as the EU Battery Regulation’s legislative requirements to implement minimum shares of recycled content and increase the EOL secondary battery materials supply, the argumentation that the carbon footprint should incentivise certain practices does no longer hold, particularly if company-specific data are not available. If the incentivisation argument is followed anyways, the EOL recovery of secondary materials is not being incentivised if it is credited regardless of whether it occurs. This is because economic operators placing the battery on the market receive the CFF (or Substitution) credits. In the Cut-off approach, the recycler supplying the recycled content directly gets incentivised as long as the emissions for recycled content are lower than primary production.

The findings of the comparison are summarised as follows:

1) The Cut-off approach is the most transparent approach, as it can be calculated based on primary data but shifts the EOL emissions associated with the respective battery to a different system boundary (Table 2)
2) The Substitution approach vastly relies on secondary data and assumptions and is therefore not accurate in the case of the carbon footprint declaration at the point of placing the battery on the market (Table 3)
3) The CFF tries to accommodate the weaknesses of both approaches, but effectively requires default values and assumptions that might lead to overestimation of credits for secondary material recovery as well as secondary data being used instead of primary data, confounding the primary goals of the EU Battery Regulation (Table 4)

Table 1: Summarizing comparison of relevant criteria assessed in the context of the EU CF declaration at placement on the market

At the point of placing the battery on the market	**Primary data availability**	**Control of the economic operator placing the battery on the market**	**Adherence to key methodological principles** (standardised, practical, accurate, comparable)	**Recycled content consideration**	**Recyclability consideration**
Cut-off	Primary data available, no assumptions required	Upstream value chain under the control of responsible economic operator	Practical and standardised (e.g. Catena-X, WBCSD, GBA) method yielding accurate and comparable results	Recycling process emissions allocated to product using recycled content	Does not take into account the EOL recycling of the product for which CF is declared
Substitution	Assumptions required, e.g. that primary data are the same in future	Downstream value chain can only be controlled to a limited extent	Practical method yielding comparable results, but not accurate due to assumptions required	No differentiation between recycled content and virgin material input	EOL recycling modelled based on recyclability of the product
CFF	Primary data available for recycled content, assumptions required for EOL recycling	Upstream value chain under control, downstream value chain only to limited extent	Not accurate, as default values and secondary data required; not practical as additional calculations on material level required, etc.	Recycled content accounted for in combination with allocation factor A	EOL recycling accounted for in combination with allocation factor A

1) The Cut-off approach is the most transparent approach, as it can be calculated based on primary data but shifts the EOL emissions associated with the respective battery to a different system boundary

Table 2: Pros and cons of Cut-off approach

Cut-off approach	
Pros • Transparent as primary data can be collected at the point in time of CF calculation (i.e. when placing battery on the market) • Measuring the factual emissions of recycling via recycled content based on actual and meaningful primary data (i.e. no assumptions of processes taking place in 10–15 years) • The carbon footprint for recycling is accounted in direct control of economic operator's supply chain and upstream system boundary (i.e. recycler becomes supplier), which allows steering interventions into company-specific sources of emissions • The uptake of recycled content in batteries is a clear policy goal, and indirectly incentivises the uptake of recycling of batteries • Only approach feasible for primary data collection and aggregation along the supply chain as envisioned by GBA and WBCSD	Cons • Emissions associated with the EOL treatment of the individual battery are shifted to other product systems and, therefore, the Cut-off approach does not reflect the total emissions produced by the respective product system for which the CF is declared • A supply shortage for secondary materials in the coming years is to be expected due to the lifetime of batteries and initial reliance on pre-consumer scrap, which is why it is difficult for economic operators to raise the amount of recycled content and, in turn, to lower the carbon footprint (28) • Cut-off approach does not directly incentivise EOL recovery of secondary materials

2) The Substitution approach vastly relies on secondary data and assumptions and is therefore not accurate in the case of the carbon footprint declaration at the point of placing the battery on the market

Table 3: Pros and cons of Substitution approach

Substitution approach	
Pros • Emissions associated with the EOL treatment of the individual battery are included in the product system boundary and therefore the aim is to reflect the emissions produced by the respective product system for which the CF is declared • Addresses the recyclability of materials and products as inherent properties, as the substitution is based on evaluating the recyclability of the product or material e.g., via a recyclability statement assuming a certain recyclability for future processes • Take-back systems and integrated recycling operations at the economic operators' control can inform valid assumptions on EOL recovery processes	Cons • Not accurate as EOL modelling relies on assumptions about future processes that only in special cases can be verified when placing the battery on the market limiting the applicability of valid assumptions (as batteries are long lasting products, processes can change significantly during the lifetime) • Blurs the insights for the economic operators placing the battery on the market to make informed decisions on reducing CF as they have typically no or limited control (in case of integrated operations and take-back systems) over the EOL of the batteries • Recycled materials are accounted for equally to primary material, therefore increasing usage of recycled content is not incentivised and not reflected in the CF calculation

3) The CFF tries to accommodate the weaknesses of both approaches, but effectively resorts to unverifiable EOL assumptions

Table 4: Pros and cons of Circular Footprint Formular

Circular Footprint Formula	
Pros • The CFF is likely required for legal compliance with the Battery Regulation delegated act for the CF declaration since the current draft exclusively refers to PEF and PEFCRs with reference to incentivising both demand and supply of secondary materials • As the CFF allocates recycled content emissions and EOL recycling emissions via the allocation factor A, it effectively incentivises EOL and recycled content as both are to some extent reflected in the CF calculation • Some parameters could be accounted using primary data (i.e. parameters R_1, E_v, E_{rec}, Q_{Sin}/Q_p)	Cons • Not accurate as EOL modelling relies on assumptions about future processes, that cannot be verified when placing the battery on the market (e.g. the collection for recycling rate of batteries) • 'Political' choice of parameters reduces comparability and, thus, effective steering of emission reduction • The CFF relies on default values and secondary data for emissions factors with primary data use being limited to strict conditions, potentially providing unintended incentives to use secondary instead of primary data • The CFF is a complex calculation which would be required for all materials embedded in a product, and as such, it is neither easily reproducible for all economic operators nor easily comparable • The allocation factor A gives a preference to either allocating towards recycled content or EOL recycling depending on the market situation, whereas the default values for typical battery materials tend towards EOL, i.e. Substitution approach, which Battery Pass evaluates as the least suitable method at the time of placing the battery on the market • Allocation factors introduce consequential aspects in an otherwise attributional LCA approach to pursue political goals • The CFF is a European approach being only applied within the PEF framework and not in other geographical regions – as battery value chains are global, this decreases comparability • The CFF incentivises energy recovery, which is the least preferred option from a circular economy point of view

6 Exemplary quantitative assessments

An **exemplary quantification** of the three approaches for batteries provides insights to substantiate the implications of the respective approaches. The aim of the quantification is to quantitatively compare the application of the three discussed EOL approaches for batteries to analyse their interrelationships and support the decision of choosing one of the approaches.

In summary, the quantification underlines that the Cut-off approach is more conservative, while CFF and Substitution approach are likely to yield lower carbon footprint results. However, these lower carbon footprint values are based on hypothetical modelling of EOL scenarios and rely on assumptions. Therefore, the Cut-off approach is not only more transparent but also a more cautious approach to not underestimate actual carbon emissions.

If the amount of recycled content equals the recycling output at EOL and the recycling process at EOL is the same as the process producing the recycled content, the Cut-off approach and Substitution approach have the same effect (see Figure 12). However, this is not realistic at this point in time, as the amount of recycled content is significantly lower than the materials that are assumed to be recycled in the future. Therefore, applying the Cut-off approach results in higher carbon footprint values than those calculated with the Substitution approach or CFF (see Figure 13).

The calculation of the Substitution approach shows the lowest carbon footprint due to credits given for future EOL recycling. This is largely due to favourable assumptions for recycling efficiencies and EOL collection rates. This means, that the carbon footprint calculated using the Substitution approach would be subject to sensitive assumption on future EOL treatments, potentially decreasing the real EOL burdens and the resulting carbon footprint.

The CFF accommodates between both, but as well requires sensitive assumptions such as the allocation factor ‘A’. As it is likely that the recycled content remains low in the coming years with production scrap dominating as source for recycled feed at least until 2030 (28), the CFF tends towards the Substitution approach in assuming high EOL recycling and collection rates and crediting these. This yields a carbon footprint in between the Cut-off and Substitution approach.

6.1 Scope and methodology of exemplary quantification

For the comparison, only the lifecycle stages “Raw material acquisition” and “EOL (Recycling, Disposal)” are considered. Hence, the quantification compares the production and recycling of materials included in the battery. All other life cycle stages are out of scope for this example as they are not decisive in comparing the EOL approaches (see Figure 9). This means that all processes related to mining and refining are included, while all product production processes such as CAM manufacturing are not included. Within these life cycle stages, the transport is excluded for simplicity, as it was found to be insignificant (25).

The data represent a battery that weighs 225 kg and provides 8,000 kWh over its service life (25). The functional unit of the battery carbon footprint typically is denominated per energy provided over the service life. However, since this exemplary comparison represents only a part or intermediate step of the CF calculation, it was carried out per kg of the total battery.

Recharge's PEFCR defines the default recycled content, i.e., R_1 to equal zero (25). However, in this analysis, three scenarios based on the output of the recycling process inventory given in the PEFCR as well as the recycled content targets of the Regulation Proposal (see Annex A.1) were considered in the Cut-off model:

- "Recycled content = recycling output": 69% cobalt (Co), 59% nickel (Ni) (based on the recycling output per raw material input as per Recharge inventory (25))
- "Recycling content target 1": 12% Co, 4% Ni[2]
- "Recycling content target 2": 20% Co, 12% Ni[2]

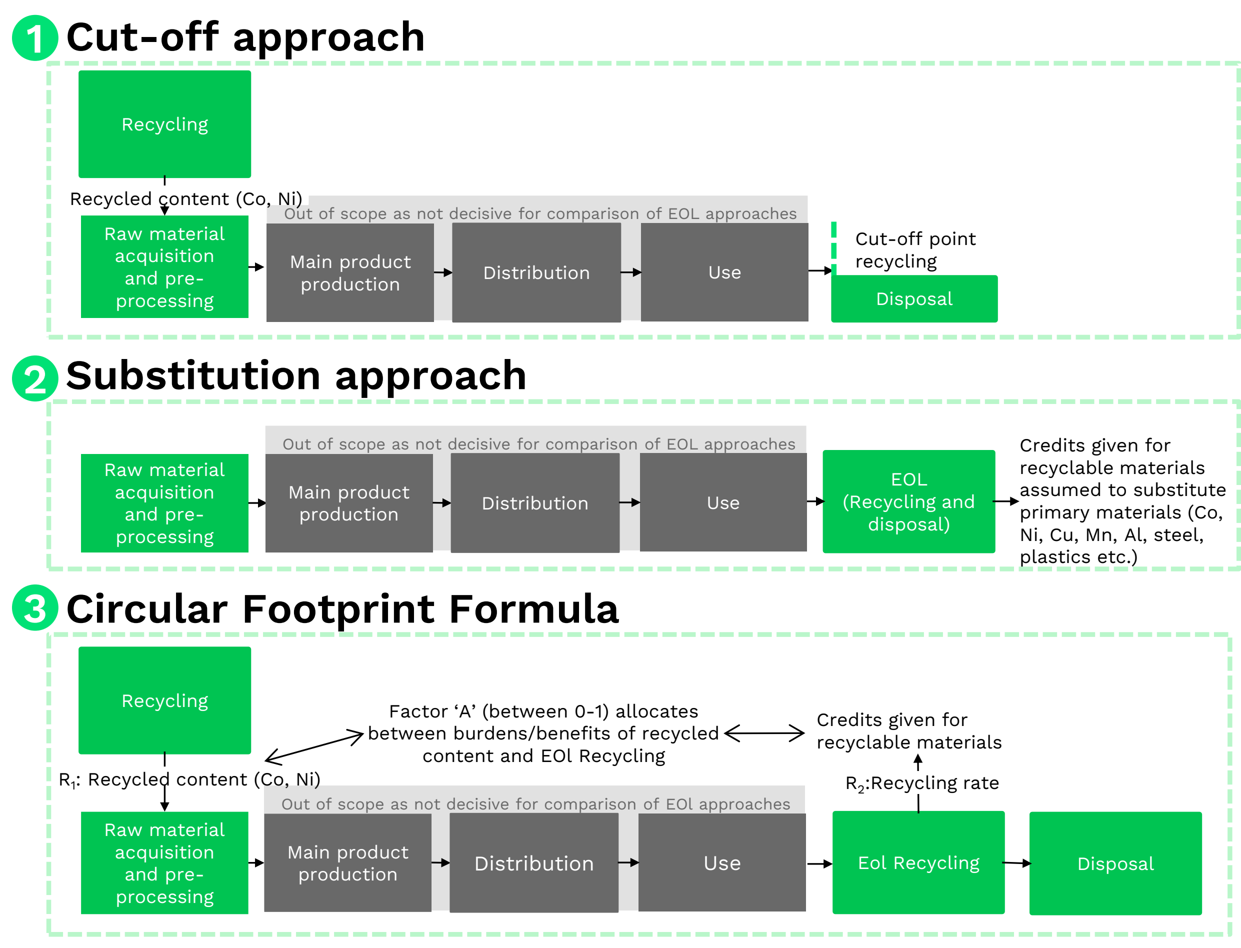
Thereby only cobalt and nickel were modelled as recycled content, as these are part of the recycled content targets by the Battery Regulation. Please note, that the inventory provided by the Recharge PEFCR does not include lithium as a recycling output. Therefore, it could not be included as recycled content in this analysis, although it is required by the Battery Regulation's recycled content targets.

In the PEFCR for batteries, the assumed recycling output rate corresponds to the collection for recycling with 95%. In this analysis however, the proportion of the recycling output in the "EOL and recycling" stage to the raw material input in the "Raw material acquisition" stage of the inventory was adopted (see Table 5 and

[2] The targets for the share of recycled content reflects the European Commission's draft proposal (32), but has in the meantime been updated to 16% Co, 6% Ni (96 months after entry into force of the Regulation) and 26% Co, 15% Ni (156 months after entry into force of the Regulation) (1)

Table 6 in Annex A.2). This was considered more realistic, since no output can be assumed for a process which is not represented in the inventory of the respective process. As per the Recharge inventory, the materials in the recycling process output, i.e. the recyclable materials comprise cobalt, nickel, manganese and copper in the active materials, as well as aluminium, steel and plastics in the passive components and OEM system.

Figure 9: System boundary for the Cut-off, Substitution and CFF model



Please note that only cobalt and nickel accounted for recycled content, as End-of-Life inventory of Recharge 2018 did not include lithium as output.

The analysis proceeds in two parts, first modelling the Cut-off and Substitution approach with openLCA, then the CFF in Excel format (using the emissions values calculated in openLCA). The inventory was adopted from the PEFCR Recharge default values for e-mobility, Li-ion (large EV) (25). In case no specific amount was given for a material, but only one value for a combination of materials, either mass balance was adopted from literature, or the values were drawn from the PEFCR Excel model. This is especially relevant for the active materials and documented in the inventory (see Annex A.2).

Part I: Cut-off and Substitution approach

Modelling and calculations for the Cut-off and Substitution approach were carried out using the software openLCA v.1.11.0 in combination with the PEF-compliant dataset EF secondary data version of February 2022 (version 2.0).

The Cut-off and Substitution approach were modelled for all the battery materials. Yet this was not possible for the CFF. The model results from openLCA can be found in Annex A.3 and are further discussed in chapter 6.2. Three comparisons are made to showcase the effects of the Cut-off and Substitution approach specifications:

- **Comparison a):** Three Cut-off scenarios with differing share of recycled content
- **Comparison b):** Cut-off and Substitution approach when recycled content equals recycling output
- **Comparison c):** Cut-off recycled content share (target 1) versus Substitution approach, which remains unchanged as it does not consider recycled content

Part II: The Circular Footprint Formula

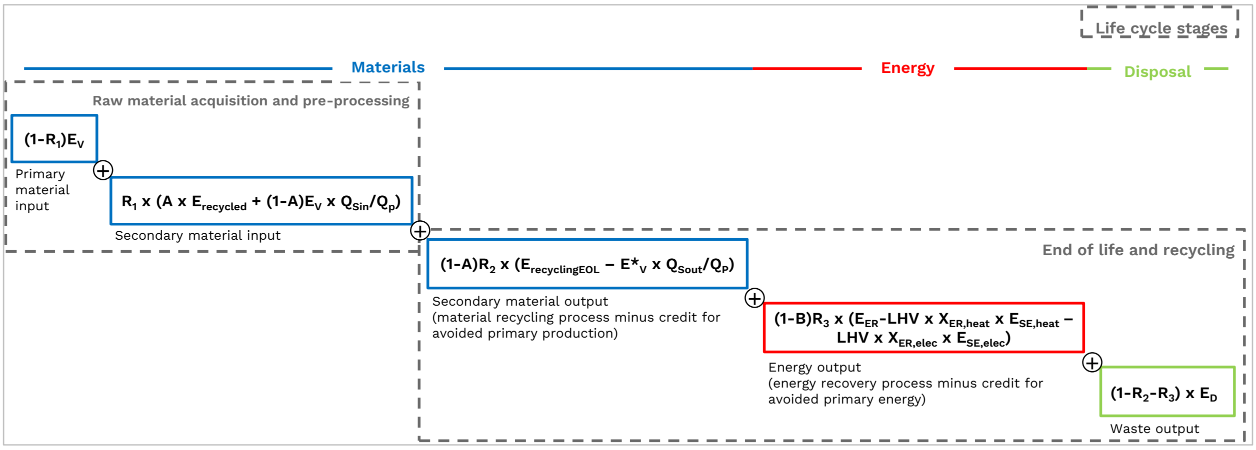
The CFF was **only calculated for the active cell components**, which includes cathode, anode, electrolyte and separator (see Annex A.4). This is due to the raw material acquisition inventory not being available on a material basis for the OEM system and passive components. I.e., the inventory included already manufactured products such as “populated printed wiring board” where the exact material composition was not known and therefore, the CFF for these components couldn’t be calculated. Thus, they could only be compared to the result of the active components in the other two approaches. It also needs to be noted, that energy recovery could not be included, as data on e.g., the LHV was missing, and it was assumed that the share of energy recovery is not substantial with regards to the active materials that comprise mostly of metal salts. The following parameters were used:

- A: Either 0.2 for metals or 0.5 for plastics (based on PEFCR Annex C (22))
- B: 0 (as defined by PEFCR (25))
- R_1: Recycled content equals recycled content target 1 (12% Co, 4% Ni)[3]
- R_2: Proportion of material that will be recycled = recycled output (69% Co, 59% Ni, 30% Manganese (Mn), 41% Copper (Cu))
- R_3: 0 (as energy recovery not included)

In order to assess the emissions calculated with the CFF on the basis of lifecycle stages, the modular formula was used. Thereby, the primary material input as well as secondary material input present the “Raw material acquisition” life cycle stage, while the secondary material output, energy output and waste output comprise the EOL and recycling stage (see Figure 10).

[3] The targets for the share of recycled content reflects the European Commission’s draft proposal (32), but has in the meantime been updated to 16% Co, 6% Ni (96 months after entry into force of the Regulation) and 26% Co, 15% Ni (156 months after entry into force of the Regulation) (1)

Figure 10: Circular Footprint Formula differentiated per life cycle stage



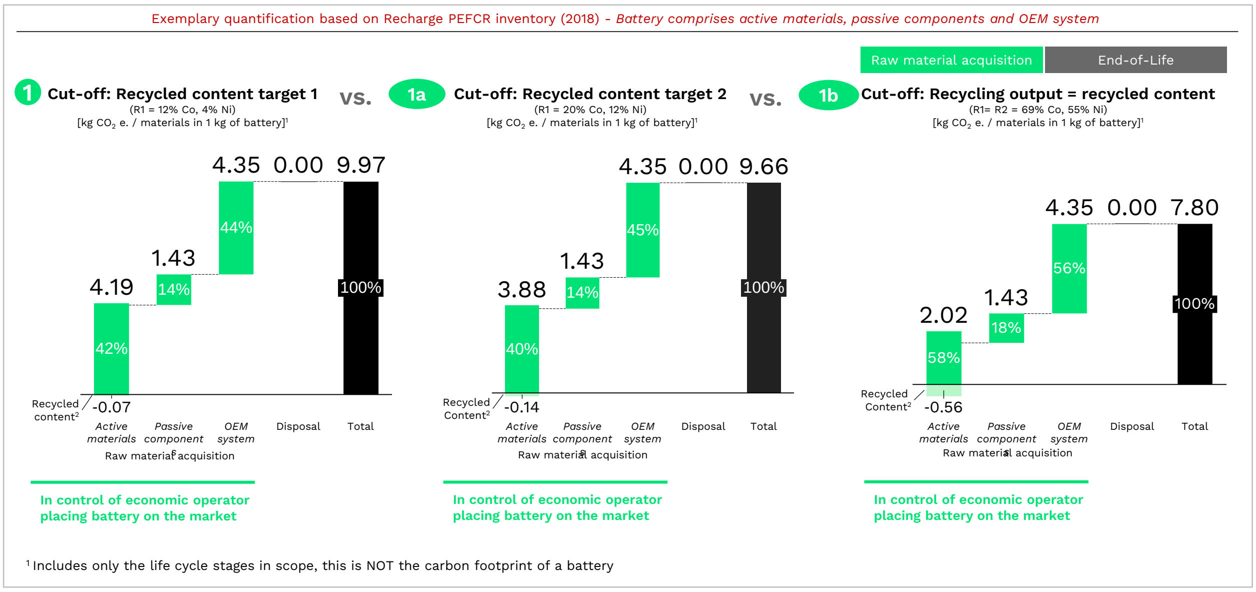
6.2 Comparison Cut-off to Substitution – all battery materials

In the Cut-off approach, recycling burdens and benefits are allocated via the recycled content, for which primary data can be obtained by the economic operator placing the battery on the market. The Substitution approach on the other hand allocates credits for recycling at the EOL. The model graphs and results for these two approaches, including the three Cut-off scenarios can be found in Annex A.3. The EOL fate of the battery is hypothetical at the point of placing the battery on the market and must rely on modelling future scenarios and secondary data.

Comparison a): First, three Cut-off scenarios are compared. Figure 11 demonstrates that relevant life cycle stage (Raw material acquisition) is in control of the economic operator placing the battery on the market. Furthermore, the recycled content lowers the emissions caused by primary materials: the higher the share of recycled content, the lower the total emissions.

By increasing the recycled content of cobalt from 12% to 20% and of nickel from 4% to 12% (scenario 1a in Figure 11), the emissions caused by the active materials could be reduced by 8%. When raising the recycled content as much as 69% for cobalt and 55% for nickel (scenario 1b), the emissions of the active materials could be reduced by 52% and the total emissions of the battery by 22% compared to the recycled content target 1 scenario.

Figure 11: Exemplary comparison of raw materials acquisition and EOL of the materials in 1 kg of battery for three recycled content scenarios using the Cut-off approach[4]

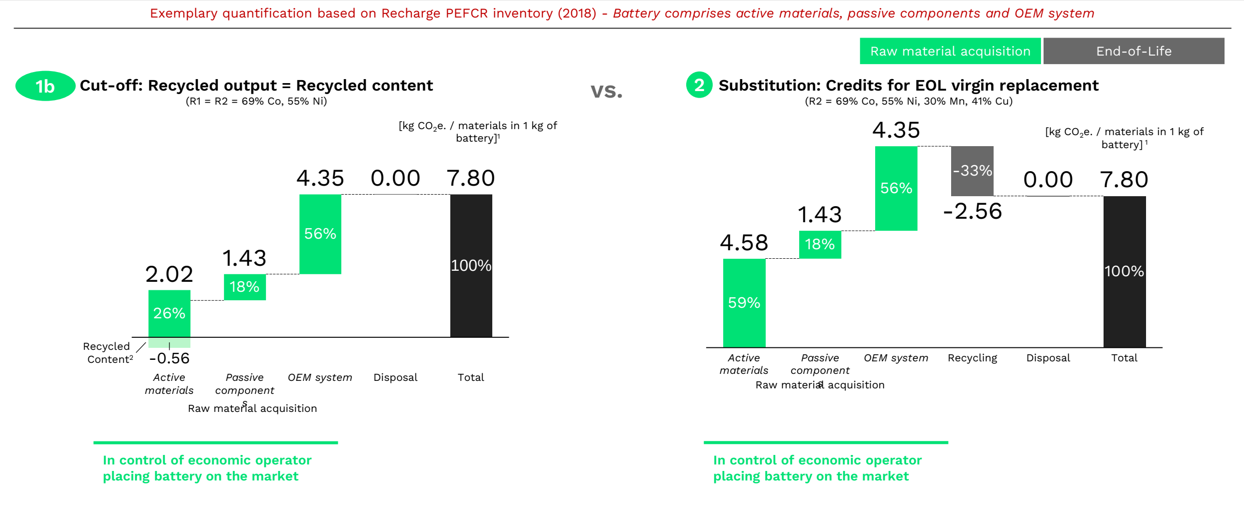


Comparison b): Figure 12 demonstrates that the overall results of the two methods are the same if the recycling process at EOL equals the recycling process producing the recycled content, i.e., % recycled content in Cut-off approach equals % recycling output in Substitution model and credits are given for by-products (via system expansion).

It is important to note, that the CO_2e footprint of recycled content in this model is negative due to the credits given for recycling by-products. If no credits for by-products would be counted, the emissions of recycled content would only comprise the allocated recycling emissions. Therefore, they would have a net burden and could only lower the impact of raw material acquisition, when the emissions of recycling are lower than of virgin material replacement.

[4] Please note that the values displayed only include the raw materials acquisition and EOL stage and therefore represent only an intermediate step of the CF calculation and NOT the battery carbon footprint.

Figure 12: Exemplary comparison of raw materials acquisition and EOL of the materials in 1 kg of battery for the hypothetical case of recycled content equals recycling output using the Cut-off and Substitution approach[5]



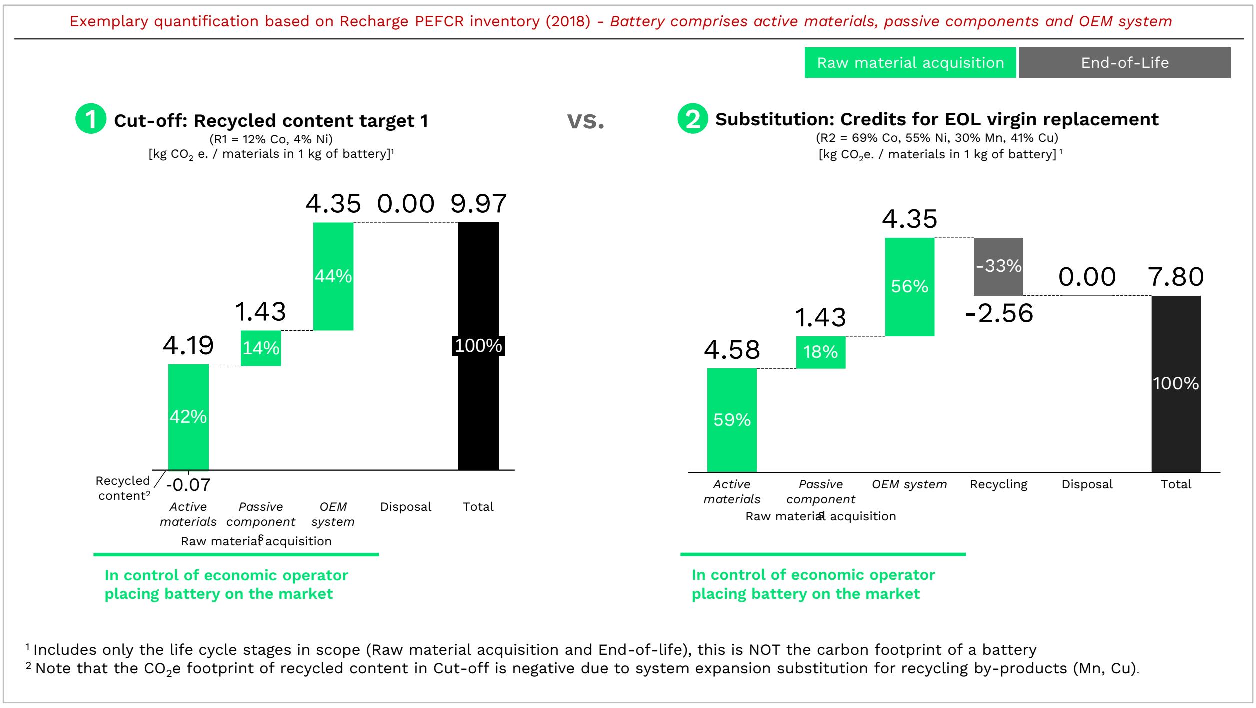
[1] Includes only the life cycle stages in scope (Raw material acquisition and End-of-life), this is NOT the carbon footprint of a battery
[2] Note that the CO_2e footprint of recycled content in Cut-off is negative due to system expansion substitution for recycling by-products (Mn, Cu).

Comparison c): Figure 13 presents a more realistic scenario with the recycled content target 1 under the Cut-off approach and the Substitution approach (that does not consider recycled content and therefore remains unchanged).

This demonstrates that when the recycled content is lower than the recyclable materials, as the recycled content targets in the Battery Regulation, the carbon footprint calculated with the Cut-off approach yields more conservative results than with the Substitution approach. This will most likely be the case in the near future, due to low availability of recycled materials. However, as the economic operator has only limited control on the recycling process at the EOL of the battery, the benefit of 33% calculated with the Substitution approach for the EOL is hypothetical, must rely on secondary data and cannot be proven at the point of placing the battery on the market.

[5] Please note that the values displayed only include the raw materials acquisition and EOL stage and therefore represent only an intermediate step of the CF calculation and NOT the battery carbon footprint.

Figure 13: Exemplary comparison of raw materials acquisition and EOL of the materials in 1 kg of battery for the Cut-off approach (recycled content target 1) and the Substitution approach[6]

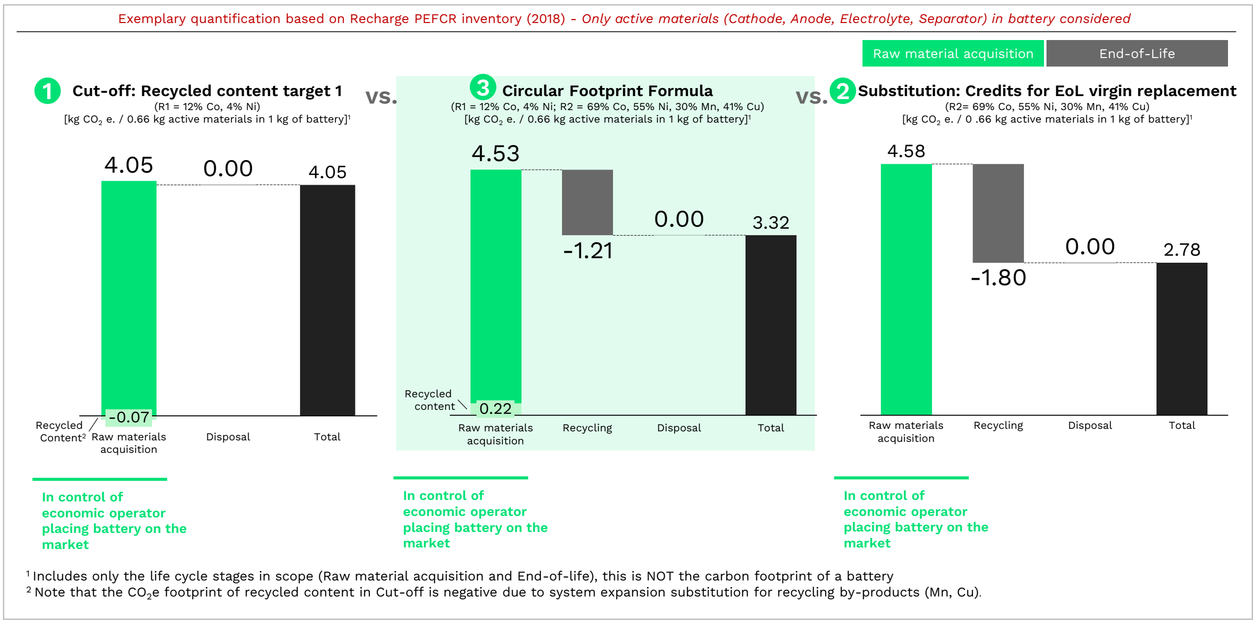


6.3 Comparison Cut-off and Substitution approach to CFF – only active materials (Cathode, Anode, Electrolyte and Separator)

As explained above, the CFF was only calculated for the active materials, i.e. cathode, anode, separator and electrolyte, which correspond to approximately 0.66 kg in 1 kg of the model battery. When comparing the results of the CFF with the active materials part of the Cut-off and Substitution model, CFF emissions range in between results calculated via the other two approaches (see Figure 14).

[6] Please note that the values displayed only include the raw materials acquisition and EOL and therefore represent only an intermediate step of the CF calculation and NOT the battery carbon footprint.

Figure 14: Exemplary comparison of raw materials acquisition and EOL of the active materials (Cathode, Anode, Separator, Electrolyte) in 1 kg of battery for using the Cut-off approach (recycled content target 1), Circular Footprint Formula and Substitution approach[7]



The results indicate the emissions of the "Raw material acquisition" and "EOL and recycling" stage for the active material share in 1 kg of a Li-Ion battery for e-mobility. The results of the Cut-off approach are 22% higher than for the CFF, while the value calculated with the Substitution approach are 19% lower. This difference, however, will decrease when further life cycle stages, such as the production phase, are included in the calculation to determine the total battery carbon footprint.

Similar to the Substitution approach, when applying the CFF to calculate the carbon footprint in the context of the EU Battery Regulation at the time of placing the battery on the market, not all relevant life cycle stages are in direct control of the economic operator and mostly rely on secondary data and hypothetical future scenarios (i.e. battery collection rate).

The results show that the CFF provides a credit for recovered materials at the EOL. The magnitude of the credit depends on the specification of the A factor and R_2 parameter. The lower A and the higher R_2, the higher the credit received by the economic operator. Current proposals by the JRC and PEFCR specify A for metals at 0.2 (note that 0.1 is also under discussion for battery materials) while the share of recovered materials (R_2) is set at 0.95. This effectively assumes that 95% of batteries are recycled at EOL with recycling yields being included in the emissions factors. The resulting credit gets weighted with 0.8 compared to the burdens associated with recycled content with 0.2. The value of the emissions credit for EOL recovery is calculated by deducting the emissions from the EOL recycling process from the emissions of primary material assumed to be substituted.

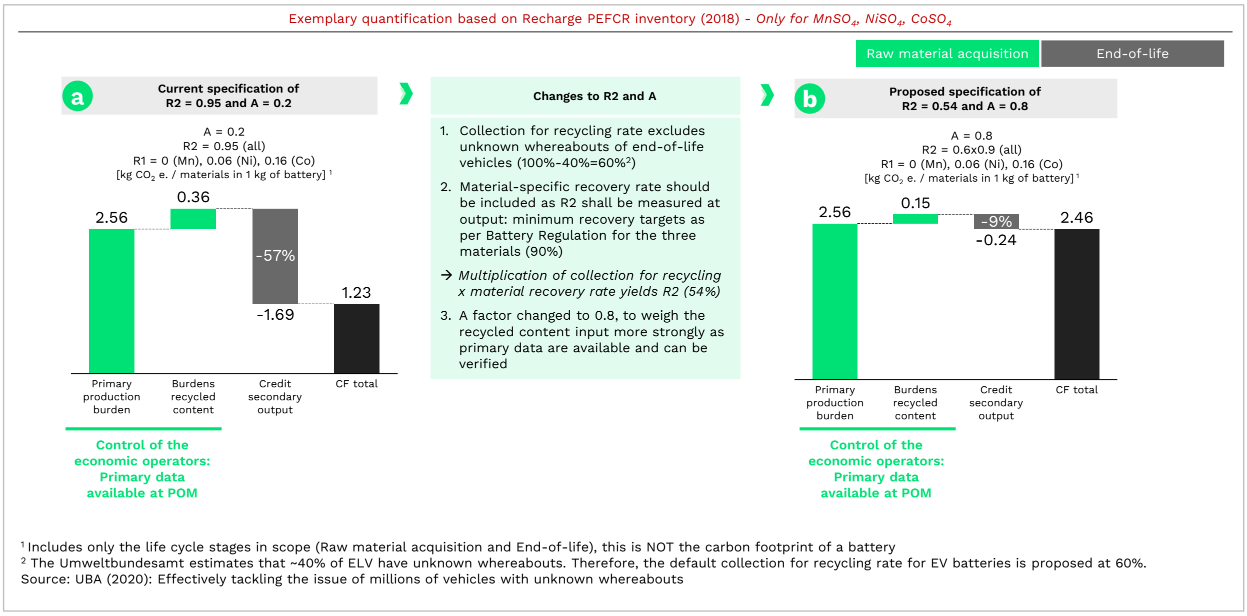
As this credit is given to the economic operator placing the battery on the market, there is only an indirect incentive for improving supply of secondary materials. There are two options to improve the carbon footprint for EOL recovery: (1) the economic operator could improve the removability of batteries (i.e. design-for-recycling). However, as recyclers typically process a variety of battery models and the data collection period is annual, the individual contribution

[7] Please note that the values displayed only include the raw materials acquisition and EOL stage for the and therefore represent only an intermediate step of the CF calculation and NOT the battery carbon footprint.

of improved design-for-recycling on recycling process emissions is marginal, particularly if R_2 is specified in the current form. (2) The economic operator could engage in partnerships with recyclers having low emissions processes to create controlled reverse battery flows. However, this is likely only possible to a minor extent as the fate of waste batteries depends on the behaviour of the owner of the battery (e.g. re-sale, exports, etc.). Additionally, take-back schemes of EOL waste batteries are not practised at scale; rather, battery manufacturers will cooperate with a multitude of recycling providers competing for the lowest price and highest quality of the recycled materials.

The current specifications of R_2 and A – as proposed by the JRC (3) and the PEFCR for batteries – risk overestimating credits given for the secondary material supplied at the EOL. These EOL credits bear risks because economic operators cannot proof that the battery model placed on the market is effectively recycled at the EOL, yielding unverifiable carbon credits. As a result, the material-specific carbon footprint is reduced. An exemplary calculation based on the Recharge 2018 inventory shows that the impact per material can be significant. To highlight the effects of the current specifications of R_2 and A, the emissions of three materials in the 'Raw material acquisition and pre-processing' stage and the corresponding EOL emissions are calculated as per the CFF (excluding energy recovery and disposal): Manganese sulfate ($MnSO_4$), Nickel sulfate ($NiSO_4$) and Cobalt sulfate ($CoSO_4$). Subsequently, results are compared in two scenarios (see Figure 15). The first scenario reflects the current specifications as proposed by JRC and the PEFCR for batteries (R_2 equals 0.95, A equals 0.2). The second scenario adjusts R_2 and A factors based on the Battery Pass recommendations (see section 7). R_2 excludes the share of unknown whereabouts for end-of-life vehicles (~40% as per (29)) and includes material recovery yields measured at the output of the recycling plant (minimum material recovery targets as per Battery Regulation). A is set to 0.8 to give more weight to the ingoing material, i.e., where primary data are available (please refer to section 7 for justification of this change). In sum, these adjustments yield that the EOL credits are reduced by ~85%, which in turn increases the material-specific carbon footprint as per the CFF.

Figure 15: The impact of CFF parameters on the overall material-specific carbon footprint for the examples of $MnSO_4$, $NiSO_4$ and $CoSO_4$[8]



[8] Please note that the values displayed only include the raw materials acquisition and EOL stage and therefore represent only an intermediate step of the CF calculation and NOT the battery carbon footprint.

7 Synthesis: Battery Pass recommendations to integrate the Cut-off approach into the CFF

In line with the ambition to use as many company-specific data as possible and given that the carbon footprint must be declared when placing the battery on the market, i.e., no reliable emissions data on steps further down the value chain is possible, the **Battery Pass consortium recommends the Cut-off approach in the context of the CF declaration as required by the EU Battery Regulation**. Note that the Regulation provides potential leeway for different approaches "Article 7 shall (…) and reflect the international agreements and technical/scientific progress in the area of life cycle assessment" (1).

Therefore, the Battery Pass consortium developed rules for calculating and reporting primary data for the EOL and recycling life cycle stage based on the Cut-off approach. With these rules, recycling providers can calculate the emissions occurring in the recycling processes while the economic operator (battery manufacturer placing the battery on the market) allocates these emissions via the recycled content. While the Cut-off approach retains the fundamental principle of accounting based on actually measured and differentiating data, the two other methods, the Substitution approach and CFF, allow arbitrary assumptions blurring accuracy and do not contribute to steering operational measures to reduce the carbon footprint of batteries.

In the likely case the regulatory framework in the European context, i.e. the delegated act specifying the methodology for calculating the battery carbon footprint, will require the application of the CFF, the data collection and carbon footprint calculation as specified by the Battery Pass consortium needs to be extended to comply with the CFF. The Battery Pass *"Rules for calculating the Carbon Footprint of the 'Distribution' and 'End-of-life and recycling' life cycle stages"* therefore include a CFF extension chapter, that should be followed when declaring a carbon footprint of batteries in the EU and in the battery passport as required by the EU Battery Regulation. In the CFF chapter addition, guidance on the specification of relevant CFF parameters and emissions values is given such that economic operators can calculate the EOL and recycling emissions via the CFF.

Since the final specification of the CFF is not known to date, the current approach is based on the CFF as per the PEF recommendation (2021). This version of the formula is to be expected under the EU Battery Regulation secondary legislation. Furthermore, default values as well as EF-compliant datasets required for the calculation still need to be published by the European Commission. Therefore, the Battery Pass consortium presents a proposal for the data collection and guidance on the calculation of the CFF under the premise that the CFF and specified parameters might change as the discussions are ongoing.

If the CFF is required by the delegated act specifying the CF methodology, the Battery Pass consortium recommends the following adjustments to the relevant EU institutions:

1) The allocation factor A should be specified in a way that the CFF approximates the Cut-off approach. This would be the case if the A factor is set close or equal to one. As the PEF methodology prescribes the A factor to be in between 0.2 and 0.8, the Battery Pass recommends specifying the A factor at 0.8 for all battery metals.

2) The specification of R_2 should take into consideration the recyclability of batteries, a collection for recycling rate that excludes the share of end-of-life vehicles with unknown whereabouts as well as the recycling yields (measured at the output of the recycling plant) for specific materials.
3) A recyclability statement should be mandatory, regardless of whether R_2 default values are used. Recyclability is a pre-condition for recycling at EOL.
4) Recycling default scenarios and default values to calculate recycling-related emissions should be defined conservatively to incentivise primary data usage. Additionally, the usage of secondary datasets should be linked to a mechanism (to be developed) to incentivise primary data usage as much as possible.
5) The conditions under which primary data are allowed for calculating EOL emissions (as proposed by JRC and PEFCR for batteries) should be reviewed, with traceability of EOL recovery becoming a requirement.
6) Suitable default data for R_3 should be provided for battery and waste materials.
7) Guidance on using EF-compliant datasets for recycling, incineration, and landfilling per material and material group should be provided.
8) It should be specified that the economic operator placing the battery on the market or putting it into service is responsible for performing the CFF EOL allocation to avoid the risk of supply chain requests for "CFF-compliant" data.

The particular recommendations to reduce the risk of unverifiable EOL credits via a change in the specification of A and R_2 follow the reasoning as described below:

- The CFF credits for the EOL recovery rest on assumptions of the battery's EOL fate – since the CF declaration needs to be prepared for a specific battery model at the time of placement on the market, it cannot be verified if and how the respective battery will be recycled. Therefore, these assumptions could overestimate the credits given for EOL recovery. This could effectively decrease the carbon footprints declared which poses reputational risks. Specifying the A factor and R_2 parameter based on approximation to actual data reduces this risk.
- As per the PEF CFF methodology, which is based on consensus achieved in its development period, the A factor "aims to reflect market realities". However as it is currently specified, the A factor focuses on incentivisation instead of reflection of a market reality. The market reality for battery metals is that demand for recycled content exceeds supply. Specifying the A factor such that more weight is given to the EOL recovery is an attempt to incentivise the supply of secondary materials, not a reflection of market realities. In contrast, reflecting market realities would entail that the dynamics are represented empirically and based on factual data, which is only possible in the Cut-off approach or where controlled reverse material flows can be proven.
- The incentivisation of EOL supply is given by the EU Battery Regulation's "no landfill and incineration" policy as well as the targets for recycling efficiencies and material recovery. Ultimately, regulatory and economic considerations are the most effective levers. Following the theoretical incentivisation argumentation, low emissive recycling is incentivised via the Cut-off approach as long as recycled materials bear lower emissions values than primary materials. As the recycler and user of recycled materials can engage in a direct relationship based on the recycled content footprint declared, this incentivisation is stronger than the mechanism under the CFF where the credit for EOL recovery is received by the economic operator not performing the recycling operations.
- Including the goal to incentivise certain parts of the battery life cycle in the methodology to calculate the carbon footprint risks confounding the most important goal of the carbon footprint declaration: providing comparable and accurate carbon footprints that

build the foundation for steering operational measures to reduce the carbon footprint of batteries. Only actual, company-specific data enable such operational optimisation along the value chain in combination with the regulatory carbon footprint instruments of performance classes and maximum thresholds.

- The CFF in its current specification of key parameters and secondary default values and datasets inherently disincentivises the usage of company-specific data. If carbon footprints declared strongly rely on secondary data that represent average values and, in parts, underestimate real process contributions, the basis for making informed decisions by industry to reduce factual CF is prone to error. As such, the current CFF specification risks that the Battery Regulation’s ambition to decarbonise the battery value chain is missed.

ANNEX

A.1 Recycled content, recycling efficiencies and material recovery targets (1)

Recycled content targets (Article 8): 96 months after entry into force of the regulation, 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.

Until 156 months after entry into force of the regulation, 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.

A.2 Inventory (25)

Table 5: Inventory for Raw material acquisition of Li-ion battery for e-mobility

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	Specific amount[9]	Source[10]	EF compliant dataset used	EF Geographical reference	Proxy (yes/ no)	UUID
Active components per cell										
Anode										
Copper foil	CN	Copper Foil (11 µm) for 1 m2	kg/kg battery	0.074			Copper sheet	EU-28+EFTA	yes	cb8a2255-c375-4d5d-9402-d62ca38787d7
Graphite powder	CN	Graphite powder (estimate)	kg/kg battery	0.126			Carbon black, general purposes production	RER	yes	fde4abff-7cd7-4535-b472-481321d7d936
Plastic compound	DE	Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	0.002			Polyvinylidene fluoride (PVDF)	GLO	no	8fd31112-01c1-46d3-8c8d-29e2bdfa6e38
	DE	Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	0.002			Styrene-butadiene rubber (SBR)	GLO	no	5312a57a-4dc4-4ee7-9c77-72afdd38f1ea
Cathode										
Cathode material (sulphates)	DE	Manganese sulphate (estimation)	kg/kg battery	0.237	0.067	Mass relation NMC battery (30)	Manganese sulphate production	GLO	no	b848a196-e27e-4e8e-953e-7de7cbc54c57
	DE	Nickel Sulfate from electrolytnickel	kg/kg battery		0.072		Nickel sulphate production	RER	no	3b369ae8-1f45-47ed-8dcf-af5f71593067
	GLO	Lithium Carbonate mix	kg/kg battery		0.026		lithium carbonate production	GLO	no	e57086c5-1bde-4f28-ac57-ac7d72db18bc
	GLO	Cobalt sulfate	kg/kg battery		0.072		Cobalt	GLO	yes	c76002c7-dfef-4d17-a100-fecd7910cfad
Plastic compound	DE	Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	0.001			Polyvinylidene fluoride (PVDF)	GLO	no	8fd31112-01c1-46d3-8c8d-29e2bdfa6e38
	DE	Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	0.001			Styrene-butadiene rubber (SBR)	GLO	no	8fd31112-01c1-46d3-8c8d-29e2bdfa6e38

[9] When not given in Recharge PEFCR inventory (25)
[10] If different than Recharge PEFCR inventory (25)

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	Specific amount[9]	Source[10]	EF compliant dataset used	EF Geographical reference	Proxy (yes/ no)	UUID
Carbon black	DE	Carbon black (furnace black; general purpose)	kg/kg battery	0.012			Carbon black, general purposes production	RER	no	fde4abff-7cd7-4535-b472-481321d7d936
Aluminium foil	EU-27	Aluminium foil	kg/kg battery	0.045			Aluminium foil	EU-28+EFTA	no	49a32f83-b59d-4f7b-b0f6-2efe9f9997aa
Electrolyte										
Carbonates mix	DE	Dimethyl carbonate (DMC)	kg/kg battery	0.086	0.0215	PEFCR excel model (31)	dimethyl carbonate production	RER	no	663a2d9b-f7ab-4941-8a27-80e96413c1d1
	DE	Ethylene carbonate	kg/kg battery		0.0215		ethylene carbonate production	RER	no	57d3c404-37e1-4077-9c55-93c51f590997
	DE	Propylene carbonate	kg/kg battery		0.0215		Polycarbonate (PC) granulate	GLO	yes	e7202044-f727-4aa7-bfc4-a8cfd1ed5812
	DE	Dimethyl carbonate (DMC) (for EMC)	kg/kg battery		0.0215		dimethyl carbonate production	RER	no	663a2d9b-f7ab-4941-8a27-80e96413c1d1
Lithium Hexafluro-phosphate	JP	Lithium Hexaflurophosphate (LiPF6)	kg/kg battery	0.015			lithium hydroxide production	GLO	yes	d08bdd01-a59f-4f80-87e8-5ad30c6934d3
Separator										
Polypropylene film	EU-27	Polypropylene Film (PP) without additives	kg/kg battery	0.045			Plastic Film, PP	EU-28+EFTA	no	3f9f3fb2-1aad-4cdf-a419-928c9818d62d
Polyethylene foil	EU-27	Polyethylene foil (PE-HD) without additives	kg/kg battery	0.015			Plastic Film, PE	EU-28+EFTA	yes	cc8ee5f1-84b3-4e04-bae3-6a531aafb606
Passive parts										
Cell casing										
Aluminium sheet	DE	Aluminium sheet mix	kg/kg battery	0.06			Aluminium sheet rolling	EU-28+EFTA	no	1dd6e422-65eb-4bdb-ba1c-ee0aff723580
Aluminium foil	EU-27	Aluminium foil	kg/kg battery	0.007			Aluminium foil	EU-28+EFTA	no	3f9f3fb2-1aad-4cdf-a419-928c9818d62d
Copper	GLO	Copper mix (99.999% from electrolysis)	kg/kg battery	0.011			Copper cathode	EU-28+EFTA	no	0b292f4d-c283-4df9-9bee-f194096ba0e1
Battery casing										
Polybutylene Terephthalate Granulate	DE	Polybutylene Terephthalate Granulate (PBT) Mix	kg/kg battery	0.002			Polybutylene Terephthalate (PBT) Granulate	GLO	no	51bb1958-c494-4490-a080-c453e90d4d7d

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	Specific amount[9]	Source[10]	EF compliant dataset used	EF Geographical reference	Proxy (yes/ no)	UUID
Polyethylene Film	EU-27	Polyethylene Film (PE-HD) without additives	kg/kg battery	0.005			Plastic Film, PE	EU-28+EFTA	no	cc8ee5f1-84b3-4e04-bae3-6a531aafb606
Polypropylene Film	EU-27	Polypropylene Film (PP) without additives	kg/kg battery	0.126			Plastic Film, PP	EU-28+EFTA	no	3f9f3fb2-1aad-4cdf-a419-928c9818d62d
Steel sheet	EU-27	Steel sheet part	kg/kg battery	0.052			Steel cold rolled coil / Steel cast part alloyed	EU-28+EFTA	no	3e5ff637-ffc2-4920-9051-11055b1d2d18
OEM System										
Battery control unit (E-MOBILITY)										
Switch PCB	EU-27	Switch PCB (EPTA)	m^2/kg battery	0.0027 [kg/kg battery]	0.000888	PEFCR excel model (31)	Populated Printed wiring board (PWB) (2-layer)	GLO	yes	91064ae4-3cf1-4b09-a430-9e01488ad11b
Polyethylene Film	EU-27	Polyethylene foil (PE-HD) (without additives)	kg/kg battery		0.000222		Plastic Film, PE	EU-28+EFTA	yes	cc8ee5f1-84b3-4e04-bae3-6a531aafb606
Polypropylene Film	EU-27	Polypropylene Granulate (PP)	kg/kg battery		0.000222		PP granulates	EU-28+EFTA	no	eb6c15a5-abcd-4d1a-ab7ffb1cc364a130
Battery management unit (E-MOBILITY)										
Switch PCB	EU-27	Switch PCB (EPTA)	m^2/kg battery	0.0042 [kg/kg battery]	0.000140	PEFCR excel model (31)	Populated Printed wiring board (PWB) (2-layer)	GLO	yes	91064ae4-3cf1-4b09-a430-9e01488ad11b
Polyethylene Film	EU-27	Polyethylene foil (PE-HD) (without additives)	kg/kg battery		0.000222		Plastic Film, PE	EU-28+EFTA	yes	cc8ee5f1-84b3-4e04-bae3-6a531aafb606
Polypropylene Film	EU-27	Polypropylene Granulate (PP)	kg/kg battery		0.000222		PP granulates	EU-28+EFTA	no	eb6c15a5-abcd-4d1a-ab7ffb1cc364a130
Connector	DE	Connector (small, w/o Au, PBTGF30 Basis - Automotive)	kg/kg battery		0.000222		Connector for printed wiring board (PWB)	GLO	yes	79ad97bb-fd4e-41d5-8e61-8ef9c2406ba6
Passive cooling system										
Aluminium sheet	DE	Aluminium sheet mix	kg/kg battery	0.018	0.018	PEFCR excel model (31)	Aluminium sheet rolling	EU-28+EFTA	no	1dd6e422-65eb-4bdb-ba1cee0aff723580
Safety management unit										

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	Specific amount[9]	Source[10]	EF compliant dataset used	EF Geographical reference	Proxy (yes/ no)	UUID
Switch PCB	EU-27	Switch PCB (EPTA)	m^2/kg battery	0.057 [kg/kg battery]	0.022800	PEFCR excel model (31)	Populated Printed wiring board (PWB) (2-layer)	GLO	yes	91064ae4-3cf1-4b09-a430-9e01488ad11b
Thermal management unit (E-MOBILITY)										
Aluminium extrusion profile	EU-27	Aluminium extrusion profile <t-agg>	kg/kg battery	0.2195	0.0244	PEFCR excel model (31)	Aluminium extrusion	EU-28+EFTA	no	f6af2ce4-e899-46d3-8806-9bb34e3b32e4
Polypropylene Granulate	EU-27	Polypropylene Granulate (PP)	kg/kg battery		0.0488	PEFCR excel model (31)	PP granulates	EU-28+EFTA	no	eb6c15a5-abcd-4d1a-ab7ffb1cc364a130
Steel sheet part	EU-27	Steel sheet part	kg/kg battery		0.146	PEFCR excel model (31)	Steel cold rolled coil / Steel cast part alloyed	EU-28+EFTA	no	366a0afd-88e4-45dc-999°-8acc20fd0ead

Table 6: Inventory EOL and recycling for Li-ion battery for e-mobility

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	EF compliant dataset used	EF Geographical reference	Proxy (yes/no)	UUID
Active materials recycling	EU-27	Electricity grid mix	MJ/kg battery	0.69	Electricity grid mix	EU-28+EFTA	no	34960d4d-af62-43a0-aa76-adc5fcf57246
	EU-27	Thermal energy from natural gas	MJ/kg battery	2.07	Thermal energy from natural gas	EU-28+EFTA	no	81675341-f1af-44b0-81d3-d108caef5c28
	EU-27	Process steam from natural gas 90%	MJ/kg battery	6.48	Process steam from natural gas	EU-28+EFTA	no	2e8bee44-f13b-4622-9af3-74954af8acea
	EU-27	Tap water	kg/kg battery	7.63	Tap water	EU-28+EFTA	no	212b8494-a769-4c2e-8d82-9a6ef61baad7
	DE	Lime (CaO; quicklime lumpy)	kg/kg battery	0.04	Lime production	RER	yes	64e2bd59-5f61-4eb3-bfd7-d19c3aec60b5
	EU-27	Hard coal mix	kg/kg battery	0.03	Hard coal mix	EU-27	no	932ce7a6-5bc6-41be-ad62-8daad6c5355c
	EU-27	Sodium hydroxide (caustic soda) mix	kg/kg battery	0.19	Sodium hydroxide production	RER	no	2ba49ead-4683-4671-bded-d52b80215e9e
	EU-27	Sulphuric acid (96%)	kg/kg battery	0.66	Sulphuric acid production (100%)	RER	no	eb6abe54-7e5d-4ee4-b3f1-08c1e220ef94
	EU-27	Landfill for inert matter (Steel)	kg/kg battery	0.09	Landfill of inert (steel)	EU-28+EFTA	no	33d6d221-f91d-4a33-9b00-9fb1ea8cd3ca
	EU-27	Municipal waste water treatment (sludge incineration)	kg/kg battery	8.27	Treatment of residential wastewater, large plant	EU-28+EFTA	no	f5ec4a19-70da-406d-be31-a7eeef2f8372
Active materials credits (depending on cell composition)	EU-27	Process steam from natural gas 90%	kg/kg battery	1.46	Process steam from natural gas	EU-28+EFTA	no	2e8bee44-f13b-4622-9af3-74954af8acea
	DE	Manganese sulphate (estimation)	kg/kg battery	0.02	Manganese	GLO	no	38085a7e-98a3-4b5d-9381-8cefce00cc27
	DE	Nickel Sulfate from electrolytnickel	kg/kg battery	0.04	Nickel (updated)	GLO	yes	3b369ae8-1f45-47ed-8dcf-af5f71593067
	GLO	Cobalt sulfate	kg/kg battery	0.05	Cobalt	GLO	yes	c76002c7-dfef-4d17-a100-fecd7910cfad

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	EF compliant dataset used	EF Geographical reference	Proxy (yes/no)	UUID
	GLO	Copper mix (99.999% from electrolysis)	kg/kg battery	0.03	Copper cathode	EU-28+EFTA	no	0b292f4d-c283-4df9-9bee-f194096ba0e1
Passive parts recycling	DE	EAF Steel billet / Slab / Bloom	kg/kg battery	0.47	Recycling of steel into steel scrap: Steel billet (St)	EU-28+EFTA	no	dadc8eb8-3ebe-4114-afc4-90d45a0b74b4
	EU-27	Landfill for inert matter (Steel)	kg/kg battery	n.a.	Landfill of inert (steel)	EU-28+EFTA	no	33d6d221-f91d-4a33-9b00-9fb1ea8cd3ca}
	EU-27	Aluminium recycling (2010)	kg/kg battery	0.07	Recycling of aluminium into aluminium scrap – from post-consumer	EU-28+EFTA	no	c4f3bfde-c15f-4f7f-8d35-bed6241704db
	EU-27	Landfill for inert matter	kg/kg battery	n.a.	Landfill of inert material (other materials)	EU-28+EFTA	no	448ab0f1-4dd6-4d85-b654-35736bb772f4
	EU-27	Recycling of copper from electronic scrap	kg/kg battery	0.01	Recycling of copper from electronic and electric waste	EU-28+EFTA	no	1827dd93-8b53-4b5c-8430-01d10d51e86c
	DE	Plastic granulate secondary	kg/kg battery	0.10	Plastic granulate secondary (low metal contamination)	EU-28	yes	dad7268b-41ef-46e0-9641-48e431bbf937
Passive parts credits	EU-27	Aluminium ingot mix	kg/kg battery	0.06	Aluminium ingot mix (high purity)	EU-28+EFTA	no	e3f12a3b-6cb9-49ab-b437-f6f7df83ec62
	GLO	Copper mix (99.999% from electrolysis)	kg/kg battery	0.009	Copper cathode	EU-28+EFTA	no	0b292f4d-c283-4df9-9bee-f194096ba0e1
	DE	Polyethylene Low Density Granulate (LDPE/PE-LD)	kg/kg battery	0.06	LDPE granulates	EU-28+EFTA	no	d327f4a5-93a1-4ead-856c-aeb8b2f25080
	EU-27	Steel sheet part	kg/kg battery	0.05	Steel cast part alloyed	EU-28+EFTA	no	366a0afd-88e4-45dc-999a-8acc20fd0ead
Recycling of OEM parts	EU-27	Aluminium recycling (2010)	kg/kg battery	0.04	Recycling of aluminium into aluminium scrap – from post-consumer	EU-28+EFTA	no	c4f3bfde-c15f-4f7f-8d35-bed6241704db
	DE	EAF Steel billet / Slab / Bloom	kg/kg battery	0.0988	Recycling of steel into steel scrap: Steel billet (St)	EU-28+EFTA	no	dadc8eb8-3ebe-4114-afc4-90d45a0b74b4
	DE	Plastic granulate secondary	kg/kg battery	0.053	Plastic granulate secondary (low metal contamination)	EU-28	yes	dad7268b-41ef-46e0-9641-48e431bbf937
	EU-27	Recycling of copper from electronic scrap	kg/kg battery	1.05E-09	Recycling of copper from electronic and electric waste	EU-28+EFTA	no	1827dd93-8b53-4b5c-8430-01d10d51e86c

Material/ Process	PEFCR Geographical reference	PEFCR Dataset name	Unit (output)	Amount	EF compliant dataset used	EF Geographical reference	Proxy (yes/no)	UUID
Recycling of OEM electronic parts	EU-27	Recycling of gold from electronic scrap	kg/kg battery	2.47E-16	Recycling of gold from electronic and electric scrap	EU-28+EFTA	no	27f18feb-4aa7-4c49-a495-6849945890bf
	EU-27	Recycling of palladium from electronic scrap	kg/kg battery	1.12E-16	Recycling of palladium, from electronic and electric scrap	EU-28+EFTA	no	012626e4-62d9-4ac9-b1dd-9d9a42a611c5
	EU-27	Recycling of silver from electronic scrap	kg/kg battery	1.50E-13	Recycling of silver, from electronic and electric scrap	EU-28+EFTA	no	502a8a4f-c7bc-4d3c-87ce-44c3aad3e332
OEM parts credits	EU-27	Aluminium ingot mix	kg/kg battery	0.03	Aluminium ingot mix (high purity)	EU-28+EFTA	no	e3f12a3b-6cb9-49ab-b437-f6f7df83ec62
	EU-27	Steel sheet part	kg/kg battery	0.09	Steel cold rolled coil / Steel cast part alloyed	EU-28+EFTA	no	366a0afd-88e4-45dc-999a-8acc20fd0ead
	DE	Polyethylene Low Density Granulate (LDPE/PE-LD)	kg/kg battery	0.03	LDPE granulates	EU-28+EFTA	no	d327f4a5-93a1-4ead-856c-aeb8b2f25080
OEM electronic parts credits	GLO	Copper mix (99.999% from electrolysis)	kg/kg battery	9.52E-10	Copper cathode	EU-28+EFTA	no	0b292f4d-c283-4df9-9bee-f194096ba0e1
	GLO	Gold mix	kg/kg battery	2.42E-16	Gold (primary route)	GLO	no	e8e47de2-87ef-41cf-b202-51d15a9e77cc
	GLO	Palladium mix	kg/kg battery	1.09E-16	Palladium	GLO	no	93eeb7db-08d5-4695-bfb4-a3d4280381d8
	GLO	Silver mix	kg/kg battery	1.47E-13	Silver	GLO	no	a28acad1-3e38-45fd-b071-eca95457b624
	EU-27	Waste incineration of glass/inert material	kg/kg battery	0.00528	Waste incineration of inert material	EU-28+EFTA	no	55cd3dde-21f9-47f8-8f15-bc319c732107
	EU-27	Landfill for inert matter	kg/kg battery	0.00528	Landfill of inert material (other materials)	EU-28+EFTA	no	448ab0f1-4dd6-4d85-b654-35736bb772f4
Treatment of unsorted battery fraction	EU-27	Landfill for inert matter	kg/kg battery	0.0634	Landfill of inert material (other materials)	EU-28+EFTA	no	448ab0f1-4dd6-4d85-b654-35736bb772f4

A.3 Model results: Cut-off and Substitution approach

Figure 16: Model graphs: Cut-off approach (left) Substitution approach (right)

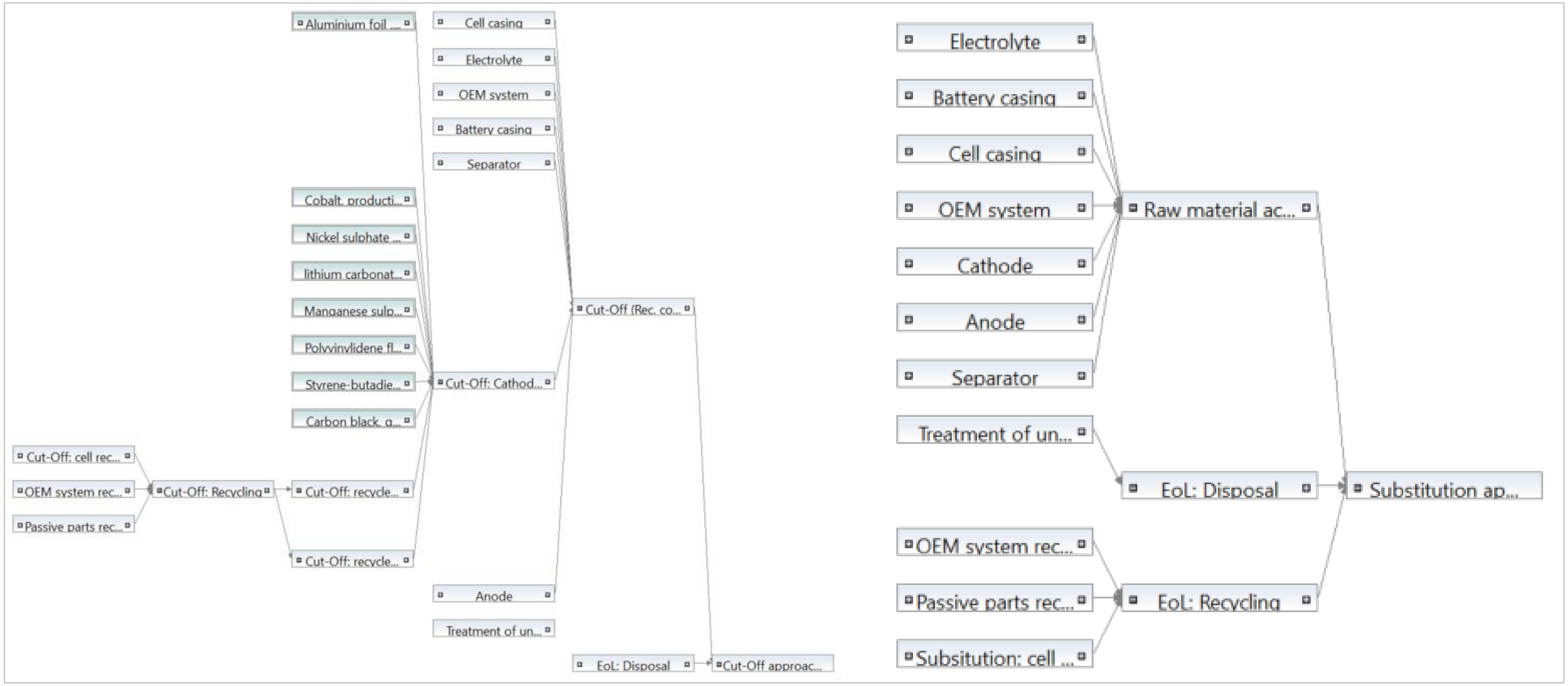


Figure 17: Contribution tree of Substitution approach for entire battery

Contribution	Process	Amount	Unit
100.00%	P Cut-Off approach (Rec. output = rec. content): Lifecycle	7.80626	kg CO2 eq
99.98%	P Cut-Off: (Rec. output = rec. content) Raw material acquisition and pre-processing	7.80459	kg CO2 eq
55.71%	P OEM system	4.34914	kg CO2 eq
14.67%	P Cut-Off: Cathode (inkl. 0.05 kg recycled cobalt, 0.04 kg recycled nickel	1.14523	kg CO2 eq
10.16%	Cobalt, production mix, at plant, hydro- and pyrometallurgical processes, >99% Co - GLO	0.79317	kg CO2 eq
07.83%	Aluminium foil , single route, at plant, primary production, 2.7 g/cm3 - EU-28+EFTA	0.61135	kg CO2 eq
01.93%	Nickel sulphate production, production mix, at plant, technology mix, 100% active substance - RER	0.15093	kg CO2 eq
00.75%	Manganese sulphate production, production mix, at plant, technology mix, 100% active substance - GLO	0.05885	kg CO2 eq
00.69%	lithium carbonate production, production mix, at plant, technology mix, 100% active substance - GLO	0.05382	kg CO2 eq
00.41%	Carbon black, general purposes production, production mix, at plant, technology mix, 100% active substanc...	0.03185	kg CO2 eq
00.11%	Polyvinylidene fluoride (PVDF), production mix, at plant, polymerisation of vinyl fluoride, 1.76 g/cm3 - World	0.00854	kg CO2 eq
00.05%	Styrene-butadiene rubber (SBR) fiber, production mix, at plant, Emulsion polymerization of styrene and buta...	0.00359	kg CO2 eq
-03.27%	P Cut-Off: recycled nickel sulfate	-0.25509	kg CO2 eq
-03.27%	P Cut-Off: Recycling	-0.25509	kg CO2 eq
01.13%	P Cut-Off: cell recycling	0.08836	kg CO2 eq
-01.55%	P Passive parts recycling	-0.12116	kg CO2 eq
-02.85%	P OEM system recycling	-0.22230	kg CO2 eq
-03.99%	P Cut-Off: recycled cobalt	-0.31178	kg CO2 eq
-03.99%	P Cut-Off: Recycling	-0.31178	kg CO2 eq
01.38%	P Cut-Off: cell recycling	0.10799	kg CO2 eq
-01.90%	P Passive parts recycling	-0.14808	kg CO2 eq
-03.48%	P OEM system recycling	-0.27170	kg CO2 eq
12.84%	P Cell casing	1.00246	kg CO2 eq
05.50%	P Battery casing	0.42960	kg CO2 eq
05.48%	P Anode	0.42813	kg CO2 eq
04.09%	P Electrolyte	0.31948	kg CO2 eq
01.67%	P Separator	0.13055	kg CO2 eq
00.02%	P EoL: Disposal	0.00168	kg CO2 eq

Figure 18: Contribution tree for Cut-off approach, recycled content equals recycled output scenario, for entire battery

Contribution	Process	Amount	Unit
100.00%	Substitution approach: Lifecycle	7.80626	kg CO2 eq
132.75%	Raw material acquisition and preprocessing	10.36279	kg CO2 eq
55.71%	OEM system	4.34914	kg CO2 eq
47.44%	Cathode	3.70343	kg CO2 eq
12.84%	Cell casing	1.00246	kg CO2 eq
05.50%	Battery casing	0.42960	kg CO2 eq
05.48%	Anode	0.42813	kg CO2 eq
04.09%	Electrolyte	0.31948	kg CO2 eq
01.67%	Separator	0.13055	kg CO2 eq
00.02%	EoL: Disposal	0.00168	kg CO2 eq
00.02%	Treatment of unsorted battery fraction	0.00168	kg CO2 eq
-32.77%	EoL: Recycling	-2.55820	kg CO2 eq
-03.45%	Passive parts recycling	-0.26923	kg CO2 eq
-06.33%	OEM system recycling	-0.49399	kg CO2 eq
-22.99%	Subsitution: cell recycling	-1.79498	kg CO2 eq
05.03%	Process steam from natural gas, production mix, at heat plant, technology mix regarding firing and flue gas cleaning, MJ, 90% efficiency - EU-28+3	0.39237	kg CO2 eq
01.89%	Sodium hydroxide production, production mix, at plant, technology mix, 100% active substance - RER	0.14728	kg CO2 eq
01.87%	Thermal energy from natural gas, production mix, at heat plant, technology mix regarding firing and flue gas cleaning, MJ, 100% efficiency - EU-28+3	0.14563	kg CO2 eq
01.78%	Sulphuric acid production, production mix, at plant, technology mix, 100% active substance - RER	0.13930	kg CO2 eq
01.14%	Electricity mix for plastic processing - EU-28+EFTA	0.08860	kg CO2 eq
00.60%	Lime production, production mix, at plant, technology mix, 100% active substance - RER	0.04709	kg CO2 eq
00.14%	Hard coal mix, consumption mix, to consumer, technology mix - EU-27	0.01108	kg CO2 eq
00.14%	Tap water, at user, technology mix, per kg water - EU-28+3	0.01104	kg CO2 eq
00.03%	Landfill of inert (steel), production mix (region specific sites), at landfill site, landfill including leachate treatment and with transport without collection and p...	0.00247	kg CO2 eq
00.00%	Wastewater input dummy - GLO	0.00000	kg CO2 eq
-02.42%	Nickel sulphate production, production mix, at plant, technology mix, 100% active substance - RER	-0.18866	kg CO2 eq
-03.19%	Manganese, production mix, at plant, mining, separation, calcination, electrolysis, 7.21 g/cm3 - GLO	-0.24913	kg CO2 eq
-06.91%	Copper cathode, at plant, production mix, per kg - EU-28+3	-0.53936	kg CO2 eq
-23.09%	Cobalt, production mix, at plant, hydro- and pyrometallurgical processes, >99% Co - GLO	-1.80267	kg CO2 eq

Figure 19: Contribution tree for Cut-off approach, recycled content target 1 (left) and target 2 (right)

Contribution	Process	Amount	Unit
100.00%	Cut-Off approach (Rec. content target 1): Lifecycle	9.96714	kg CO2 eq
99.98%	Cut-Off (Rec. content target 1): Raw material acquisit...	9.96546	kg CO2 eq
43.63%	OEM system	4.34914	kg CO2 eq
33.17%	Cut-Off: Cathode: Rec. content target 1 (12% Co, 4%...	3.30610	kg CO2 eq
22.92%	Cobalt, production mix, at plant, hydro- and pyrom...	2.28434	kg CO2 eq
06.13%	Aluminium foil , single route, at plant, primary prod...	0.61135	kg CO2 eq
03.27%	Nickel sulphate production, production mix, at plant,...	0.32601	kg CO2 eq
00.59%	Manganese sulphate production, production mix, at ...	0.05885	kg CO2 eq
00.54%	lithium carbonate production, production mix, at pla...	0.05382	kg CO2 eq
00.32%	Carbon black, general purposes production, product...	0.03185	kg CO2 eq
00.09%	Polyvinylidene fluoride (PVDF), production mix, at pl...	0.00854	kg CO2 eq
00.04%	Styrene-butadiene rubber (SBR) fiber, production mi...	0.00359	kg CO2 eq
-00.18%	Cut-Off: recycled nickel sulfate	-0.01837	kg CO2 eq
-00.18%	Cut-Off: Recycling	-0.01837	kg CO2 eq
00.06%	Cut-Off: cell recycling	0.00636	kg CO2 eq
-00.09%	Passive parts recycling	-0.00872	kg CO2 eq
-00.16%	OEM system recycling	-0.01601	kg CO2 eq
-00.54%	Cut-Off: recycled cobalt	-0.05388	kg CO2 eq
-00.54%	Cut-Off: Recycling	-0.05388	kg CO2 eq
00.19%	Cut-Off: cell recycling	0.01866	kg CO2 eq
-00.26%	Passive parts recycling	-0.02559	kg CO2 eq
-00.47%	OEM system recycling	-0.04695	kg CO2 eq
10.06%	Cell casing	1.00246	kg CO2 eq
04.31%	Battery casing	0.42960	kg CO2 eq
04.30%	Anode	0.42813	kg CO2 eq
03.21%	Electrolyte	0.31948	kg CO2 eq
01.31%	Separator	0.13055	kg CO2 eq
00.02%	EoL: Disposal	0.00168	kg CO2 eq

Contribution	Process	Amount	Unit
100.00%	Cut-Off approach (Rec. content target 2): Lifecycle	9.65965	kg CO2 eq
99.98%	Cut-Off (Rec. content target 2): Raw material acquisition ...	9.65798	kg CO2 eq
45.02%	OEM system	4.34914	kg CO2 eq
31.04%	Cut-Off: Cathode: Rec. content target 2 (20% cobalt, 12...	2.99862	kg CO2 eq
21.50%	Cobalt, production mix, at plant, hydro- and pyrometall...	2.07667	kg CO2 eq
06.33%	Aluminium foil , single route, at plant, primary producti...	0.61135	kg CO2 eq
03.09%	Nickel sulphate production, production mix, at plant, tec...	0.29884	kg CO2 eq
00.61%	Manganese sulphate production, production mix, at pla...	0.05885	kg CO2 eq
00.56%	lithium carbonate production, production mix, at plant, ...	0.05382	kg CO2 eq
00.33%	Carbon black, general purposes production, production...	0.03185	kg CO2 eq
00.09%	Polyvinylidene fluoride (PVDF), production mix, at plant, ...	0.00854	kg CO2 eq
00.04%	Styrene-butadiene rubber (SBR) fiber, production mix, at...	0.00359	kg CO2 eq
-00.57%	Cut-Off: recycled nickel sulfate	-0.05510	kg CO2 eq
-00.57%	Cut-Off: Recycling	-0.05510	kg CO2 eq
00.20%	Cut-Off: cell recycling	0.01909	kg CO2 eq
-00.27%	Passive parts recycling	-0.02617	kg CO2 eq
-00.50%	OEM system recycling	-0.04802	kg CO2 eq
-00.93%	Cut-Off: recycled cobalt	-0.08979	kg CO2 eq
-00.93%	Cut-Off: Recycling	-0.08979	kg CO2 eq
00.32%	Cut-Off: cell recycling	0.03110	kg CO2 eq
-00.44%	Passive parts recycling	-0.04265	kg CO2 eq
-00.81%	OEM system recycling	-0.07825	kg CO2 eq
10.38%	Cell casing	1.00246	kg CO2 eq
04.45%	Battery casing	0.42960	kg CO2 eq
04.43%	Anode	0.42813	kg CO2 eq
03.31%	Electrolyte	0.31948	kg CO2 eq
01.35%	Separator	0.13055	kg CO2 eq
00.02%	EoL: Disposal	0.00168	kg CO2 eq

Figure 20: Contribution tree for Cut-off, recycled content target 1 (left) and Substitution (right) for active materials

Contribution	Process	Amount	Unit
100.00%	Cut-Off Rec. content target 1): Cell (Raw material acquisition and EoL)	4.18537	kg CO2 eq
78.99%	Cut-Off: Cathode: Rec. content target 1 (12% Co, 4% Ni)	3.30610	kg CO2 eq
54.58%	Cobalt, production mix, at plant, hydro- and pyrometallurgical proces...	2.28434	kg CO2 eq
14.61%	Aluminium foil , single route, at plant, primary production, 2.7 g/cm3 ...	0.61135	kg CO2 eq
07.79%	Nickel sulphate production, production mix, at plant, technology mix, ...	0.32601	kg CO2 eq
01.41%	Manganese sulphate production, production mix, at plant, technology...	0.05885	kg CO2 eq
01.29%	lithium carbonate production, production mix, at plant, technology mi...	0.05382	kg CO2 eq
00.76%	Carbon black, general purposes production, production mix, at plant, ...	0.03185	kg CO2 eq
00.20%	Polyvinylidene fluoride (PVDF), production mix, at plant, polymerisatio...	0.00854	kg CO2 eq
00.09%	Styrene-butadiene rubber (SBR) fiber, production mix, at plant, Emulsi...	0.00359	kg CO2 eq
-00.44%	Cut-Off: recycled nickel sulfate	-0.01837	kg CO2 eq
-00.44%	Cut-Off: Recycling	-0.01837	kg CO2 eq
00.1!	Cut-Off: cell recycling	0.00636	kg CO2 eq
-00.2	Passive parts recycling	-0.00872	kg CO2 eq
-00.3	OEM system recycling	-0.01601	kg CO2 eq
-01.29%	Cut-Off: recycled cobalt	-0.05388	kg CO2 eq
-01.29%	Cut-Off: Recycling	-0.05388	kg CO2 eq
00.4!	Cut-Off: cell recycling	0.01866	kg CO2 eq
-00.6	Passive parts recycling	-0.02559	kg CO2 eq
-01.1	OEM system recycling	-0.04695	kg CO2 eq
10.23%	Anode	0.42813	kg CO2 eq
07.63%	Electrolyte	0.31948	kg CO2 eq
03.12%	Separator	0.13055	kg CO2 eq
00.03%	EoL: Disposal	0.00111	kg CO2 eq

Contribution	Process	Amount	Unit
100.00%	Subsitution: cell (raw material acquisition and EoL)	2.78661	kg CO2 eq
164.41%	Cell (active)	4.58159	kg CO2 eq
132.90%	Cathode	3.70343	kg CO2 eq
15.36%	Anode	0.42813	kg CO2 eq
11.46%	Electrolyte	0.31948	kg CO2 eq
04.68%	Separator	0.13055	kg CO2 eq
-64.41%	Subsitution: cell recycling	-1.79498	kg CO2 eq
14.08%	Process steam from natural gas, production mix, at h...	0.39237	kg CO2 eq
05.29%	Sodium hydroxide production, production mix, at pl...	0.14728	kg CO2 eq
05.23%	Thermal energy from natural gas, production mix, at ...	0.14563	kg CO2 eq
05.00%	Sulphuric acid production, production mix, at plant, t...	0.13930	kg CO2 eq
03.18%	Electricity mix for plastic processing - EU-28+EFTA	0.08860	kg CO2 eq
01.69%	Lime production, production mix, at plant, technolog...	0.04709	kg CO2 eq
00.40%	Hard coal mix, consumption mix, to consumer, techn...	0.01108	kg CO2 eq
00.40%	Tap water, at user, technology mix, per kg water - EU...	0.01104	kg CO2 eq
00.09%	Landfill of inert (steel), production mix (region specifi...	0.00247	kg CO2 eq
00.00%	Wastewater input dummy - GLO	0.00000	kg CO2 eq
-06.77%	Nickel sulphate production, production mix, at plant, ...	-0.18866	kg CO2 eq
-08.94%	Manganese, production mix, at plant, mining, separa...	-0.24913	kg CO2 eq
-19.36%	Copper cathode, at plant, production mix, per kg - E...	-0.53936	kg CO2 eq
-64.69%	Cobalt, production mix, at plant, hydro- and pyrome...	-1.80267	kg CO2 eq

A.4 Calculation of the Circular Footprint Formula

Table 7: Calculation of Circular Footprint Formula for active components of Li-ion battery for e-mobility

Material	Unit (output)	Amount	Parameters																			Result	Unit
			A	B	Q_{sin}	Q_{sout}	Q_p	R_1	R_2	R_3	$E_{recycled}$ (kg CO_2e)	$E_{recyclingEOL}$ (kg CO_2e)	E_v (kg CO_2e)	E^*_v (kg CO_2e)	E_{ER} (kg CO_2e)	$E_{SE,heat}$ (kg CO_2e)	$E_{SE,elec}$ (kg CO_2e)	E_D (kg CO_2e)	$X_{ER,heat}$	$X_{ER,elec}$	LHV		
Anode																							
Copper Foil (11 µm) for 1 m2	kg/kg battery	7.40E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	4.05E-01	0.00E+00	0.00E+00	2.11E-01	6.89E-02	6.89E-02	0.00E+00	0.00E+00	0.00E+00	1.24E-04	0.00E+00	0.00E+00	0.00E+00	1.26E-01	kg CO_2e
Graphite powder (estimate)	kg/kg battery	1.26E-01	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.34E-01	3.34E-01	0.00E+00	0.00E+00	0.00E+00	2.12E-04	0.00E+00	0.00E+00	0.00E+00	3.35E-01	kg CO_2e
Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	2.00E-03	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.71E-02	1.71E-02	0.00E+00	0.00E+00	0.00E+00	3.36E-06	0.00E+00	0.00E+00	0.00E+00	1.71E-02	kg CO_2e
Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	2.00E-03	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-03	7.70E-03	0.00E+00	0.00E+00	0.00E+00	3.36E-06	0.00E+00	0.00E+00	0.00E+00	7.70E-03	kg CO_2e
Cathode																							
Manganese sulphate (estimation)	kg/kg battery	6.70E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	2.99E-01	0.00E+00	0.00E+00	1.41E-01	5.88E-02	5.88E-02	0.00E+00	0.00E+00	0.00E+00	1.13E-04	0.00E+00	0.00E+00	0.00E+00	8.31E-02	kg CO_2e
Nickel Sulfate from electrolytnic kel	kg/kg battery	7.20E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	4.00E-02	5.56E-01	0.00E+00	2.81E-01	2.81E-01	3.40E-01	3.40E-01	0.00E+00	0.00E+00	0.00E+00	1.21E-04	0.00E+00	0.00E+00	0.00E+00	3.08E-01	kg CO_2e
Lithium Carbonate mix	kg/kg battery	2.60E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.38E-02	5.38E-02	0.00E+00	0.00E+00	0.00E+00	4.37E-05	0.00E+00	0.00E+00	0.00E+00	5.39E-02	kg CO_2e

Material	Unit (output)	Amount	Parameters																				Result	Unit
			A	B	Q_{sin}	Q_{sout}	Q_p	R_1	R_2	R_3	$E_{recycled}$ (kg CO_2e)	$E_{recyclingEOL}$ (kg CO_2e)	E_v (kg CO_2e)	E^*_v (kg CO_2e)	E_{ER} (kg CO_2e)	$E_{SE,heat}$ (kg CO_2e)	$E_{SE,elec}$ (kg CO_2e)	E_D (kg CO_2e)	$X_{ER,heat}$	$X_{ER,elec}$	LHV		
Cobalt sulfate	kg/kg battery	7.20E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.20E-01	6.94E-01	0.00E+00	3.52E-01	3.52E-01	2.60E+00	2.60E+00	0.00E+00	0.00E+00	0.00E+00	1.21E-04	0.00E+00	0.00E+00	0.00E+00	1.05E+00	kg CO_2e
Polyvinylidene fluoride (emulsion polymerization) (PVDF)	kg/kg battery	1.00E-03	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.54E-03	8.54E-03	0.00E+00	0.00E+00	0.00E+00	1.68E-06	0.00E+00	0.00E+00	0.00E+00	8.54E-03	kg CO_2e
Styrene-Butadiene Rubber (SBR) Mix	kg/kg battery	1.00E-03	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E-03	3.59E-03	0.00E+00	0.00E+00	0.00E+00	1.68E-06	0.00E+00	0.00E+00	0.00E+00	3.59E-03	kg CO2e
Carbon black (furnace black; general purpose)	kg/kg battery	1.20E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-02	3.19E-02	0.00E+00	0.00E+00	0.00E+00	2.02E-05	0.00E+00	0.00E+00	0.00E+00	3.19E-02	kg CO_2e
Aluminium foil	kg/kg battery	4.50E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-01	6.11E-01	0.00E+00	0.00E+00	0.00E+00	7.56E-05	0.00E+00	0.00E+00	0.00E+00	6.11E-01	kg CO_2e
Electrolyte																								
Dimethyl carbonate (DMC)	kg/kg battery	2.15E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.98E-02	4.98E-02	0.00E+00	0.00E+00	0.00E+00	3.61E-05	0.00E+00	0.00E+00	0.00E+00	4.98E-02	kg CO_2e
Ethylene carbonate	kg/kg battery	2.15E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.51E-02	3.51E-02	0.00E+00	0.00E+00	0.00E+00	3.61E-05	0.00E+00	0.00E+00	0.00E+00	3.51E-02	kg CO_2e
Propylene carbonate	kg/kg battery	2.15E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.87E-02	9.87E-02	0.00E+00	0.00E+00	0.00E+00	3.61E-05	0.00E+00	0.00E+00	0.00E+00	9.88E-02	kg CO_2e
Dimethyl carbonate (DMC) (for EMC)	kg/kg battery	2.15E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.98E-02	4.98E-02	0.00E+00	0.00E+00	0.00E+00	3.61E-05	0.00E+00	0.00E+00	0.00E+00	4.98E-02	kg CO_2e
Lithium Hexaflurophosphate ($LiPF_6$)	kg/kg battery	1.50E-02	1.00E-02	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.61E-02	8.61E-02	0.00E+00	0.00E+00	0.00E+00	2.52E-05	0.00E+00	0.00E+00	0.00E+00	8.61E-02	kg CO_2e

Material	Unit (output)	Amount	Parameters																			Result	Unit
			A	B	Q_{sin}	Q_{sout}	Q_p	R_1	R_2	R_3	$E_{recycled}$ (kg CO_2e)	$E_{recyclingEOL}$ (kg CO_2e)	E_v (kg CO_2e)	E^*_v (kg CO_2e)	E_{ER} (kg CO_2e)	$E_{SE,heat}$ (kg CO_2e)	$E_{SE,elec}$ (kg CO_2e)	E_D (kg CO_2e)	$X_{ER,heat}$	$X_{ER,elec}$	LHV		
Separator																							
Polypropylene Film (PP) without additives	kg/kg battery	4.50E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.44E-02	9.44E-02	0.00E+00	0.00E+00	0.00E+00	7.56E-05	0.00E+00	0.00E+00	0.00E+00	9.45E-02	kg CO_2e
Polyethylene foil (PE-HD) without additives	kg/kg battery	1.50E-02	5.00E-01	0.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.62E-02	3.62E-02	0.00E+00	0.00E+00	0.00E+00	2.52E-05	0.00E+00	0.00E+00	0.00E+00	3.62E-02	kg CO_2e
																						3.32E+00	kg CO_2e

References

1. **European Commission.** 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. [Online] 2023. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_5469_2023_INIT&from=EN.

2. **Global Battery Alliance (GBA).** Greenhouse Gas Rulebook. *Generic Rules - Version 1.4.* [Online] 2023. https://www.globalbattery.org/media/gba-rulebook-master.pdf.

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

4. **European Commission.** Recommendation on the use of Environmental Footprint methods. [Online] 2021. https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en.

5. **European Commission.** Product Environmental Footprint Category Rules Guidance. *Version 6.4.* [Online] 2018. https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf.

6. **European Commission: Joint Research Centre.** Analysis of Existing Environmental Footprting Methodologies for Products and Organizations: Recommendations, Rationale and Alignment. [Online] 2011. https://ec.europa.eu/environment/eussd/pdf/Deliverable.pdf.

7. **International Standards Organization (ISO).** ISO 14040:2006. *Environmental management - Life cycle assessment - Principles and framework.* [Online]

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

9. **International Standards Organization (ISO).** ISO 14044:2006. *Environmental management - Life cycle assessment - Requirements and guidelines.* [Online] https://www.iso.org/standard/38498.html.

10. **International Standards Organization (ISO).** ISO/TR 14049:2012. *Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis.* [Online] https://www.iso.org/standard/57110.html.

11. **International Standards Organization (ISO).** ISO 14067:2018. *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification.* [Online] https://www.iso.org/standard/71206.html.

12. **RE:SOURCE.** Modeling recycling in life cycle assessment. [Online] 2020. https://www.diva-portal.org/smash/get/diva2:1549446/FULLTEXT01.pdf.

13. *The ISO 14067 approach to open-loop recycling of paper products: Making it operational.* **Hohenthal, Catharina, et al.** 2018. https://doi.org/10.1016/j.jclepro.2019.03.179.

14. **Greenhouse Gas (GHG) Protocol.** Product Life Cycle Accounting and Reporting Standard. [Online] 2011. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf.

15. **Wintergreen, Jay and Delaney, Tod.** ISO 14064, International Standard for GHG Emissions Inventories and Verification. [Online] https://www3.epa.gov/ttnchie1/conference/ei16/session13/wintergreen.pdf.

16. **Umweltbundesamt.** Environmental Footprint. *Der Umwelt-Fußabdruck von Produkten und Dienstleistungen.* [Online] 2018. https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Forschungsdatenbank/fkz_3712_95_337_environmental_footprint_bf.pdf.

17. **Bach, Vanessa, et al.** Product Environmental Footprint (PEF) Pilot Phase - Comparability over Flexibility? [Online] https://doi.org/10.3390/su10082898.

18. **Prè.** Review of supporting studies for the PEF pilots. [Online] https://pre-sustainability.com/customer-cases/review-supporting-studies-for-environmental-footprint-rules/.

19. **European Commission.** Results and deliverables of the Environmental Footprint pilot phase. [Online] 2023. https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm.

20. **Circular Economic Initiative Deutschland (CEID).** Resource-Efficient Battery Life Cycles. *Driving Mobility with Circular Economy.* [Online] 2021. https://static1.squarespace.com/static/5b52037e4611a0606973bc79/t/61c1e856a32b9841b83e0034/1640097893046/TB_Gesamtbericht+EN_DOI.pdf.

21. **European Commission.** Circular Footprint Formula. *Webinar; Environmental Footprint transition pase.* [Online] 2019. https://ec.europa.eu/environment/eussd/pdf/Webinar%20CFF%20Circular%20Footprint%20Formula_final-shown_8Oct2019.pdf.

22. **European Commission.** European Platform on Life Cycle Assessment. *Annex C.* [Online] 2020. https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml.

23. **Rickert, J. and Ciroth, A.** Application of the Circular Footprint Formula (CFF) in Product Environmental Footprint (PEF). [Online] 2020. https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml.

24. **European Commission.** Green Deal: Sustainable batteries for a circular and climate neutral economy. [Online] 2020. https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312.

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

26. **Nickel Institute.** Declaration by the metals industry on recycling principles. [Online] 2006. https://nickelinstitute.org/media/2540/recycling-principles.pdf.

27. **PE International.** Harmonization of LCA Methodologies for Metals. [Online] 2014. https://www.euromines.org/files/publications/harmonization-lca-methodologies-metals.pdf.

28. **Benchmark Mineral Intelligence .** Battery Production Scrap to be Main Source of Recyclable Material this Decade. [Online] 2022. https://source.benchmarkminerals.com/article/battery-production-scrap-to-be-main-source-of-recyclable-material-this-decade.

29. **Umweltbundesamt.** Effectively tackling the issue of millions of vehicles with unknown whereabouts. [Online] 2020. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/sciopap_uba_elv_measures_to_combat_illegal_dismantling_2020_06_29.pdf.

30. **Ellingsen, Linda, et al.** Life Cycle Assessment of a Lithium-Ion Battery Vehicle Pack. [Online] 2013. https://doi.org/10.1111/jiec.12072.

31. **European Commission.** PEFCR Rechargeable batteries: Excel model of the RP Rechargeable batteries. [Online] 2018. https://wayback.archive-it.org/org-1495/20221004164603mp_/https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm.

32. **European Commission.** 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.* [Online] https://eur-lex.europa.eu/resource.html?uri=cellar:4b5d88a6-3ad8-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF.

33. **World Business Council for Sustainable Development (WBCSD) .** Pathfinder Framework. *Guidance for the Accounting and Exchnage of Product Life Cycle Emissions - Version 2.0.* [Online] 2023. https://www.wbcsd.org/contentwbc/download/15625/226889/1.

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