

Industry guidelines for LCA of passenger cars and parts



These Guidelines have been developed by the automotive industry to provide a common understanding and practical guidance on the topics addressed herein. They are intended to facilitate a consistent approach among industry stakeholders and to support a common understanding between industry, authorities and other relevant stakeholders. Automotive LCA is a complex assessment relying on evolving methodologies, assumptions, and data from multiple stakeholders across global supply chains. Accordingly, these guidelines reflect the current state of industry knowledge and is subject to future updates, refinements, and interpretation as experience and best practices develop.

These Guidelines are **non-binding industry guidance**. They do not constitute legislation, regulation, an official interpretation of applicable legislation, or a legally enforceable requirement. They do not create, modify or replace any legal or regulatory obligations applicable to manufacturers, authorities or other stakeholders.

October 2026

Version 1.0

Developed jointly by

CLEPA | European Association of Automotive Suppliers

OICA | International Organization of Motor Vehicle Manufacturers

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Preamble

I. Statement of technical rationale and justification

1. Introduction

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all developed and developing countries in a global partnership.

UN SDG 12 on "responsible consumption and production" and 13 on "climate action" encourage efficient use of natural resources and to limit climate warming through long-term societal goals. Sound and reasoned resource use and climate change mitigation are key preoccupation of citizens, corporations, investors, legislator and society as a whole.

The Paris Agreement has set ambitious targets to limit global warming to well below 2 degrees, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. To achieve this long-term temperature goal, stakeholders aim to reach a global peak of greenhouse gas (GHG) emissions as soon as possible and transition towards achieving a climate neutral world by mid-century.

In 2010 the transport sector was a major contributor to global GHG emissions (23% of global GHG emissions¹) and road transport had the majority of the overall transport sector emissions (72.06%¹).

In the event that stakeholders seeks to have comprehensive, comparable and consistent values for the carbon footprint over the whole life of new automotive products across the globe, from material extraction and processing, to manufacturing, use and dismantling / recycling at the end-of-life (EoL), it is desirable to define and develop an internationally unified methodology for Life Cycle Assessment (LCA) focused on GHG of passenger cars.

The ISO 14000 family of standards has been in effect since 2006 as an international standard on LCA for environmental management, and automotive manufacturers have been publishing results of LCA in accordance with these ISO standards for several types of vehicles.

However, the ISO standards state that the scope of the investigation and the preconditions for conducting LCAs should be determined by the investigator, such as the automotive manufacturer, and since each investigator conducts LCAs according to their own method, an internationally harmonised LCA methodology designed for the automotive industry with global business activity is needed. While LCA is intended to be a multi-impact tool accounting for impact trade-offs, the ISO standards allow for single impact assessments provided such a choice is acknowledged at the outset and the resulting limitations are noted. This LCA effort focuses entirely on GHG emissions and makes no claims regarding other potential impacts that may arise throughout the life cycles of the assessed technologies.

Currently it is unclear when the UNECE ITC action 32, which calls for the development of a globally harmonised methodology to determine the carbon footprint of vehicles from cradle to grave by 2025, will be completed. To avoid a long period of uncertainty without a UNECE LCA methodology that stakeholders can refer to, it was decided to put forward this reference document as guidelines for LCA for passenger cars from industry side.

1 https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf

2. Methodology background

During the 85th GRPE session in January 2022, Japan and Korea proposed to work on clarifying methodologies for assessing life cycle GHG emissions of automotive products in the context of GRPE (GRPE-85-29r1e). GRPE agreed to organise a dedicated workshop during the 86th GRPE session in June 2022. Following the successful workshop, GRPE agreed to put the Automotive LCA (A-LCA) methodology on its priority list and agreed to create a new Informal Working Group (IWG) on A-LCA under GRPE (ECE/TRANS/WP.29/GRPE/86/Rev.1). Accordingly, the first session of the IWG on A-LCA was held in October 2022 in Okinawa, Japan.

The IWG on A-LCA is an open structure that will enable the exchange of information and experiences on relevant regulations, policy measures, and standardisation efforts. It is intended that the discussions will encompass all types of road automotive products with different technologies for energy pathways.

The 1958 Agreement and the 1998 Agreement do not define methods of measuring GHG emissions from automotive life cycles. The objective of the IWG on A-LCA is to develop an internationally harmonised methodology to determine carbon footprint (CFP) for all stages of the life cycle of passenger cars, taking into consideration energy use for energy pathways and automotive types from production to use and disposal as a Resolution under the framework of WP.29. The ISO 14000 family of LCA standards and definitions serve as the foundation of the A-LCA methodology. The definition of CFP used within this methodology is based upon the 100-year global warming potentials (GWP100) – as defined by the United Nations Intergovernmental Panel on Climate Change (IPCC).

3. Existing guidelines, regulations and standards

Several countries and organisations throughout the world have already introduced guidelines and standards related to the Life Cycle Assessment of vehicles. However, these guidelines and standards differ in terms of methodology, scope of application, objectives and targeted audiences.

Examples of existing standards:

- (a) ISO 14040:2006 & 14044:2006: describing the principles and framework for general LCA.
- (b) ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification.

Examples of existing guidelines from the automotive industry:

- (a) PFA LCA guidelines ²: where the French automotive platform provided methodological guidelines on vehicle and component LCA for 7 environmental indicators.
- (b) VDA LCA guidelines ³: where the German Association of the Automotive Industry provided methodological guidelines on vehicle and component LCA for 5 environmental indicators.

² https://pfa-auto.fr/wp-content/uploads/2023/04/DT_Me%CC%81thodologie_2023_V15_ENGLISH.pdf

³ <https://webshop.vda.de/VDA/en/vda-900-100-082022>

- (c) JAMA LCA guidelines⁴: the Japanese Automobile Manufacturers Association provided a certified methodology for passenger car, truck, bus and motorcycle, focusing on GHG emissions only.
- (d) EPD PCR passenger cars⁵: providing rules for the assessment of the environmental performance of passenger cars including internal combustion engine vehicles ICEVs, battery electric vehicles BEVs, fuel cell electric vehicles FCHVs, hybrid electric vehicles HEVs ...
- (e) Catena-X Product Carbon Footprint Rulebook (version 4)⁶

4. Technical rationale and justification

The purpose of these industry guidelines is to support the global automotive sector's efforts to reduce GHG emissions throughout the supply chain. In other words, it is intended to provide a harmonized and consistent framework of conducting LCAs and contextualizing the results for the automotive industry and government authorities to assess CFPs for passenger cars.

Compiling the supply chain data for a vehicle as final product requires all data providing parties (suppliers and OEM) to follow the same reporting rules. Effective GHG reduction will require to progressively include data from the supply chain; Figure 1 shows the basic principle of CFP reporting along a supply chain from Tier 1 to Tier n.

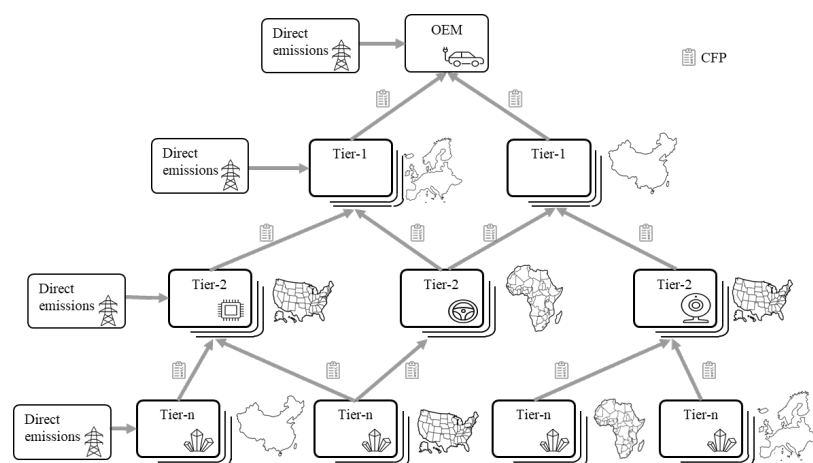


Figure 1: Reporting CFP along a supply chain

II. Text of the Industry Guidelines

1. Purpose and principles

1.1. These guidelines provide an internationally harmonised methodology to determine the CFP for passenger cars, also considering energy use for energy pathways and automotive types from production to use and disposal.

1.2. These guidelines intend to inform policy makers and can support automotive industries to reduce CFP via improved efficiencies at all stages of

4 https://www.jama.or.jp/operation/ecology/LCA/pdf/JAMA_guidelines_CFP_2024_en.pdf

5 https://www.environdec.com/pcr-library/pcr_30d0eef5-9d45-4641-6e9d-08da5dd0027d

6 (https://catenax-ev.github.io/assets/files/CX-NFR-PCF-Rulebook_v.4.0-760ee9e1d078f76317dc8e91f785d183.pdf)

the life cycle. The methodology is intended to respect the principles of transparency and consistency and shall be consistent with the ISO 14000 family of LCA international standards. It also intends to strike a balance between the accuracy and the workload to determine CFPs considering the complex supply chain of the automotive industry.

1.3. To produce reliable, reproducible, verifiable and comparable A-LCA studies, a core suite of analytical principles shall be adhered to. They shall be considered with respect to each phase, from defining the goal and the scope, through data collection, impact assessment, reporting and verification of study outcomes.

1.4. Practitioners of this methodology shall observe the following principles in conducting an A-LCA study (complete or partial as defined in ISO 14000 family of standards):

(a) Relevance

The selection of data and methods shall be appropriate to the assessment of the GHG emissions and removals arising from the system under study.

(b) Completeness

Quantification of the CFP shall include all GHG emissions and removals that provide a significant contribution to the CFP of the product system under study within the defined system boundaries. The level of significance is determined by the cut-off criteria.

(c) Consistency

Assumptions, methods and data shall be applied in the same way throughout the A-LCA study to arrive at conclusions in accordance with the goal and scope definition.

(d) Accuracy

Quantification of the CFP shall be correct, verifiable, and not misleading, and bias and uncertainties shall be minimised.

(e) Transparency

All relevant issues shall be addressed and documented in an open, comprehensive and understandable presentation of information. Any relevant assumptions shall be disclosed, and methodologies and data sources used shall be appropriately referenced. Any estimates shall be clearly explained, and bias shall be avoided so that the A-LCA study report represents what it purports to represent.

2. Scope and application

2.1 Product Category

These guidelines apply to passenger cars.

2.2 Level Concept

The Level Concept was developed in UNECE IWG A-LCA to reflect the different motivations and goals of determination of CFP for passenger cars and indicates four classes or levels which correspond to intended use cases of an automotive LCA. The importance of LCA has grown considerably in recent years and the number and type of use cases for LCA expanded as a result. The Level Concept also considers the increasing demand for primary data to inform LCA results. By addressing variations in availability and quality of data inputs, the Level Concept helps to ensure a consistent analysis across all product systems and goals. By transparently addressing these new forms of vehicle

LCAs and their input data variation, the Level Concept helps to ensure a consistent application of the vehicle LCA method and the appropriate selection of a product system model for an intended application and scope.

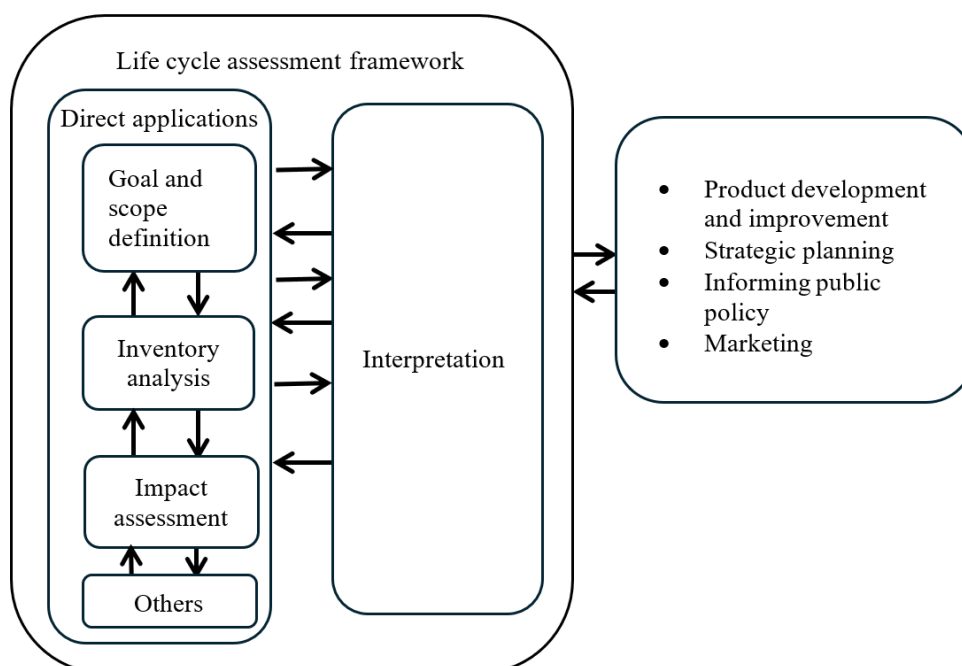


Figure 2: Life cycle assessment framework based on ISO 14040:2006

Based on the ISO 14040:2006 standard, a life cycle assessment (LCA) consists of four steps (Figure 2). Goal and scope definition is the first step of these four. In this step the study is defined in detail and central choices are made regarding its conduct.

“The goal definition shall firstly state the intended application(s) of the LCA results in a precise and unambiguous way. The decision-context is one key criterion for determining the most appropriate methods for the LCI model.”⁶

For the practitioner it is crucial to define appropriate requirements for modelling the product system according to the intended purpose and application of an LCA.

At the same time, vehicle LCAs are used by a growing number of stakeholders for an increasing range of different purposes and applications. Traditionally, vehicle LCAs were mainly used in R&D for technology comparisons and support of strategic decision making (e.g. which powertrain / material / production technology / ... is environmentally superior?) or by OEMs (Original Equipment Manufacturer) to show that their successor models were more environmentally friendly than the previous ones (continuous improvement). This is also reflected in the list of direct applications in ISO 14040:2006 (compare Figure 2, box on the right). Currently, an extension of applications towards implementation and reporting of reduction measures – especially in the context of GHG reduction and circular economy (CE) – can be observed by various stakeholders with different expectations from automotive LCAs.

Potential stakeholders are listed below, but are not limited to:

- (a) Society/ Policy makers

- (b) Green finance & ESG (Environment, Social and Governance) rating
- (c) Customer, as defined in 3.19
- (d) OEM
- (e) Suppliers

Potential motivations are listed below, but are not limited to:

- (a) Decision support of policy making
- (b) Comparison / rating
- (c) Communication /marketing
- (d) Fair competition
- (e) Incentivisation
- (f) Internal steering of decarbonisation
- (g) Proof of decarbonisation
- (h) Identification of reduction potentials

As a consequence, these guidelines on A-LCA addresses different types of use cases by using the Level Concept, and highlights where these require different scope definitions and requirements concerning approach (as defined in 3.3) and data granularity.

2.3 Use cases and application of Level Concept

The Level Concept distinguishes four different levels based on the underlying questions of the assessment. This could range from “what is the right mobility concept for a city?” to “what is the carbon footprint of a certain vehicle model?”. This leads to different requirements for the product system model especially with regard to the upstream life cycle stage in the foreground system (material production, part manufacturing, and vehicle production).

According to questions of the assessment granularity, product specificity and the scope of the foreground and background is chosen. To put it the other way round: whereas Level 1 study is representative of a broad range of products, e.g. all vehicles, Level 4 is more focused on the fine variations of individual vehicle models and the supply chain of their specific components (parts).

The choice of representativity and specificity also concerns downstream life cycle stages (Well To Wheel (WtW) / use stage, End-of-Life (EoL)) or background system processes (e.g. energy production). Also, for the use stage or EoL the data for a specific vehicle could be used. This implies however that the LCA is done retrospectively. For many use cases the analysis (declaration) point in time is the moment the product is put on the market. Consequently, the following life cycle stages can only be analysed prospectively. For predictive data, average data (e.g. for lifetime mileage) can be used. For predictive data there is no way to provide measured data.

In general, every LCA practitioner who has the necessary data (granularity) available for the respective level, may conduct an A-LCA study for this level. However, in practice mainly OEMs have access to the bills of material (BoM) and the material data system (MDS) which are required as basis of the vehicle models for Levels 2 to 4. Level 1 can be used by government officials for public policy making or by researchers for general research purposes, since it doesn't require proprietary information by OEM, such as BoM.

It is crucial to understand that emission magnitudes are only directly comparable between studies that use the same methodological approaches, underlying databases, datasets, assumptions, and modelling choices for each life cycle stage. Vehicle LCAs that differ in their combination of approaches

shall not be compared on a quantitative basis. Since Level 1 and Level 2 studies can have multiple combinations of approaches depending on the practitioners or the study purposes, comparability across the studies is typically not recommended.

Level 3 and Level 4 are based on activity data or CFP results from the supply chain that are fully or partially provided by the entity responsible for the processes within its system boundaries. The primary information focus in Level 3 is on defined hotspots of the vehicle. This requires passing the activity data or CFP information from process-step to process-step and Tier to Tier to aggregate the environmental impacts of the attributable processes. Simplified the concept is illustrated in Figure 3 for a vehicle supply chain. Each Tier (n) is quantifying activity data or GHG emissions from their own operations (gate-to-gate, see Figure 3) with a well-defined consistency and adding the upstream activities or emissions from their respective Tiers (n+1) when reporting activities or CFP to the next Tier in line (n-1).

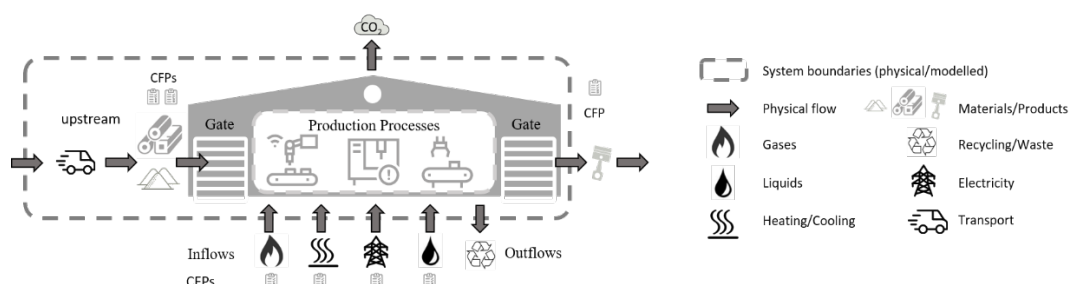


Figure 3: Gate-to-Gate reporting

Following this concept Level 3 and Level 4 CFP studies target an improved comparability between studies respecting the respective Level approach.

This does not imply any rating on the quality of studies. Level 1 LCA is not necessarily of lower quality than Level 4 study. Both serve different purposes / use cases (strategy focused or reporting focused) and therefore have different underlying “models of reality”. The following provides intended use cases and general approaches for each level.

Description of Level 1

- (a) Intended use case:
 - (i) General uses, including research and public policy making based on generic or public data sources.
 - (ii) Industry strategic planning: future projection, fleet modelling, etc.
- (b) Approach:
 - (i) Multiple approaches possible for different life cycle stages in these guidelines, depending on the purpose of the study, availability of data, etc.
 - (ii) For comparability and transparency, practitioners shall specify and maintain the discrete combination of methodologies used for their applications.

Description of Level 2

- (a) Intended use case:
 - (i) Research and public policy development based on specific data sources relevant to the use case (e.g. bill of material, material data system)
 - (ii) OEMs internal assessment and strategic planning
 - (iii) Product development and improvement

- (iv) Marketing, e.g. of technology choices
- (b) Approach:
 - (i) Multiple approaches possible for different life cycle stages in these guidelines, other than vehicle modelling, depending on the purpose of the assessment
 - (ii) For comparability and transparency, practitioners shall specify and maintain the discrete combination of approaches used for their applications.

Description of Level 3

- (a) Intended use case:
 - (i) OEMs official reporting for public information, marketing, etc.
 - (ii) Supplier's reporting on hotspots (as defined in 3.33) to OEMs official reporting for public information, marketing, etc.
 - (iii) OEMs official reporting for government programs
- (b) Approach:
 - (i) Each lifecycle stage provides one fixed set of approaches for a harmonised A-LCA.

Description of Level 4

- (a) Intended use case:
 - (i) OEMs and supplier's official reporting for public information, marketing, etc.
 - (ii) OEMs and supplier's official reporting for government programs
- (b) Approach:
 - (i) Each lifecycle stage provides one fixed set of approaches for a harmonised A-LCA.

3. Definitions

3.1 "A-LCA "

means Automotive Life Cycle Assessment of GHG emissions through whole vehicle life cycle.

3.2 "Actual mass"

means the minimum curb mass of a fully operational vehicle, excluding the driver, including all operating fluids and a fuel tank filled to at least 90% capacity, plus the mass of all series-available optional equipment.

3.3 "Allocation"

means partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems⁷

3.4 "Approach"

in the LCA context means a specific methodological choice or concept to define, model and calculate a process.

3.5 "Attributional"

means process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.⁸

3.6 "Attributable process"

means one of those processes that consist of all service, material and energy flows that become, make and carry a product throughout its life cycle.⁹

3.7 "Background System"

means in contrast (to the foreground system) processes that are operated as part of the system but are not under direct control or decisive influence of the producer of the good (or operator of the service, or user of the good).⁶

3.8 "Bill of Material(s)"

means a list of raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture the product in the scope. In some sectors it is equivalent to the bill of components.¹⁰

3.9 "Biogenic carbon"

means carbon derived from biomass.¹¹

3.10 "Biomass"

means material of biological origin, excluding material embedded in geological formations and material transformed to fossilised material.
Note 1: Biomass includes organic material (both living and dead), e.g. trees, crops, grasses, tree litter, algae, animals, manure and waste of biological origin.
Note 2: Biomass excludes peat.¹¹

3.11 "Carbon Footprint (CFP) or Product Carbon Footprint (PCF)"

means the sum of GHG emissions and GHG removals in a product system, expressed as CO₂ equivalents.¹¹

3.12 "Carbon dioxide equivalent (CO₂eq) "

means the unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide.¹¹

3.13 "Carbon offsetting"

means a mechanism for compensating for a full PCF or a partial PCF through the prevention of the release of, reduction in, or removal of an amount of GHG emissions in a process outside the product system under study.¹¹

3.14 "Characterisation factor"

means a factor derived from a characterisation model, which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator.¹²

8 [EC recommendation 2021/2279 Annex](#)

9 [WBCSD Pathfinder](#)

10 [EC recommendation 2021/2279 Annex](#) adaption

11 ISO 14067:2018

12 ISO 14050:2020

3.15 "Circular Footprint Formula (CFF)"

means a framework for evaluating the environmental impacts of a product throughout its entire life cycle, particularly based on the principles of a circular economy. This method calculates the environmental burdens and benefits obtained from recycling a product and aims to improve resource use efficiency. The Circular Footprint Formula is defined in (EU) 2021/2279⁸.

3.16 "Climate Change"

means the environmental footprint impact category considering all inputs and outputs that result in greenhouse gas (GHG) emissions. The consequences include increased average global temperatures and sudden regional climatic changes.⁸

3.17 "Co-product"

means any of two or more products coming from the same unit process or product system.¹¹

3.18 "Cradle-to-gate"

means a partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer's 'gate'. The distribution, storage, use stage and end of life stages of the supply chain are omitted.⁸

3.19 "Cradle-to-grave"

means a product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.⁸

3.20 "Customer"

means any natural or legal person using, purchasing, operating, leasing, renting, or owning a vehicle after it has been placed on the market or entered into service, including dealerships

In the context of a product value stream customer can also refer to the natural or legal person to whom a supplier delivers a product.

3.21 "Cut-off criteria"

means the specification of the amount of material or energy flow or the level of significance of GHG emissions associated with unit process or the product system, to be excluded from a CFP study.¹¹

3.22 "Curb mass"

Means mass of fully operational vehicle including all operating fluids, fuel tank filled to at least 90 %, without driver.

3.23 "Declared unit"

means the quantity of a product for use as a reference unit in the quantification of a partial CFP.¹¹

3.24 "Deterioration factor"

means the quantitative measure of the progressive, irreversible decline in performance characteristics—such as energy capacity (for batteries) or power output/voltage (for fuel cells)—compared to their initial, brand-new (factory) condition.

3.25 "Direct emissions"

means the GHG emissions from the processes that are owned or controlled by the reporting company.⁹

3.26 "Discrepancy factor"

means the ratio between vehicle real-world and certification fuel and/or energy consumption, calculated at the beginning of vehicle's life.

3.27 "Elementary flow"

means the material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.¹¹

3.28 "End-of-life"

means the point in time during the life cycle at which a product or resource is taken out of use and is disposed. ¹³

3.29 "Foreground system"

means processes of the system that are regarding their selection or mode of operation directly affected by the decisions analysed in the study. The foreground processes are hence those that are under direct control of the producer of the good or operator of the service or user of the good or where they have decisive influence.

3.30 "Functional unit"

means the quantified performance of a product system for use as a reference unit.⁷

3.31 "Gate-to-gate"

means a partial product supply chain of all the attributable processes from the manufacturer's 'inbound gate' up to the manufacturer's 'outbound-gate'.

3.32 "Global warming potential (GWP)"

means an index, based on radiative properties of GHGs, measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO₂).¹¹

3.33 "Greenhouse gases (GHGs) "

means the gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds.¹¹

3.34 "Hotspot"

refers to an input, a process or a life cycle stage that has the highest contribution to the impact category of the product system under consideration. It can also refer to a group of these inputs or processes or life cycle stages.

Note: Definitions for hotspots exist in other references such as the 2017 UNEP report or the European Union (EU) Environmental Footprint method (PEF, 2021)

13 ISO 59004:2024 adaption

3.35 "Infrastructure emission"

means the embodied emissions that arise due to the production or dismantling of infrastructure.

Note 1: infrastructure refers to any capital goods e.g. production facilities, energy provision (powerplants, transmission lines) or transport services (roads, railways, vehicles).

Note 2: emissions arising from the operation of infrastructure (operation of a power plant) is not understood as infrastructure emissions.

3.36 "Input"

means the product, material, or energy flow that enters a unit process.⁹

3.37 "Land use"

means the human use or management of land within the relevant boundary.¹¹

3.38 "Life cycle"

means the consecutive and interlinked stages related to a product, from raw material acquisition or generation from natural resources to end-of-life treatment.⁷

3.39 "Life cycle assessment (LCA)"

means the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.¹¹

3.40 "Life cycle emissions"

means the sum of GHG emissions resulting from all stages of the life cycle of a product and within the specified boundaries of the product.⁹

3.41 "Life cycle impact assessment" (LCIA)

means the phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.⁷

3.42 "Life cycle inventory analysis" (LCI)

means the phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.¹¹

3.43 "Market-mediated effects"

means the indirect impacts that arise from the market dynamics associated with a product or service throughout its life cycle. These effects can occur due to changes in supply and demand, price fluctuations, and shifts in customer behaviour that are influenced by the introduction or modification of a product.

3.44 "Material"

means physical goods that are further processed (and not consumed) in manufacturing processes.¹⁴

3.45 "Methodology"

means the defined set of approaches within these guidelines for an LCA-study to analyse a product system.

3.46 "Modular Burdens and Benefits Method (MBBM)"

Means a calculation approach for emissions related to burdens and benefits associated with secondary material input and output in material recycling and with energy recovery, as defined in the UNECE A-LCA Circular Footprint Formula (CFF). It is conceptually based on the avoided burden approach within an expanded system boundary.

3.47 "Multi output allocation "

means an operation or process with multiple outputs, such as products co-products and waste.

3.48 "Output"

means any product, material, or energy that leaves a (unit) process.⁹

3.49 "Packaging"

means any product to be used for the containment, protection, handling, delivery, storage, transport and presentation of goods, from raw materials to processed goods, from the producer to the user or consumer, including processor, assembler or other intermediary.¹⁵

3.50 "Part"

in the context of these guidelines means a product that is provided by a supplier to a customer in the supply chain. A part can also be referred to as a component.

3.51 "Partial CFP or PCF"

means the sum of GHG emissions and GHG removals of one or more selected process(es) in a product system, expressed as carbon dioxide equivalents and based on the selected stages or processes within the life cycle.¹¹

3.52 "Passenger car"

"Category 1 vehicle" means a power driven vehicle with four or more wheels designed and constructed primarily for the carriage of (a) person(s).

Means a vehicle comprising not more than nine seating positions in addition to the driver's seating position. A passenger car cannot have standing passengers.

3.53 "Primary data"

means a quantified value of a product, process, or an activity obtained from a direct measurement, or a calculation based on direct measurements.

Note 1: Primary data need not necessarily originate from the product system under study because primary data might relate to a different but comparable product system to that being studied.

Note 2: Primary data can include greenhouse gas emission factors and/or greenhouse gas activity data.

15 ISO 21067:2007

Note 3: Average data from industry associations or global averages do not qualify as primary data.¹⁶

3.54 "Primary material"

means material extracted from nature also referred to as virgin material.

3.55 "Process"

means the set of interrelated or interacting activities that transforms inputs into outputs.¹¹

3.56 "Product"

means any good or service.

Note 1: The product can be categorised as follows:

- (a) services (e.g. transport);
- (b) software (e.g. computer program, dictionary);
- (c) hardware (e.g. engine mechanical part);
- (d) processed materials (e.g. lubricant);
- (e) unprocessed material (e.g. agricultural product).

Note 2: Services have tangible and intangible elements. Provision of a service can involve, for example, the following:

- (a) an activity performed on a customer-supplied tangible product (e.g. automobile to be repaired);¹¹

Software consists of information and is generally intangible and can be in the form of approaches, transactions or procedures.

Hardware is generally tangible, and its amount is a countable characteristic. Processed materials are generally tangible, and their amount is a continuous characteristic.

3.57 "Product category"

means a group of products that can fulfil equivalent functions.¹¹

3.58 "Product category rules (PCR)"

means a set of specific rules, requirements and guidelines for developing Type III environmental declarations.¹¹

3.59 "Product system"

means the collection of unit processes with elementary flows and product flows, performing one or more defined functions, and which models the life cycle of a product.¹¹

3.60 "Raw material"

means any primary or secondary material that is used to produce a semi-finished good, product or service.⁷

3.61 "Recovered material"

means material that is recovered according to ISO14021:2026.

3.62 "Recycled Content Method (RCM)"

means a technique used to assess and quantify the contribution of recycled materials to the environmental impact of new products. RCM does not account for any benefits of process residues to the current product. Emissions from recycling processes are fully allocated to the following product cycle.¹⁷

3.63 "Reference flow"

means a measure of the inputs to or outputs from processes in a given product system required to fulfil the function expressed by the functional unit.¹¹

3.64 "Region"

means a geographical area that shares common features, such as physical traits, cultural habits, or government rules.

Macro region is a geographical subdivision that encompasses several politically defined countries e.g. European Union or MENA (Middle East and North Africa).

Micro region is geographic region of the size between community and country, e.g. Normandy in France.

3.65 "Renewable Energy"

means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.¹⁸

3.66 "Residue"

means a process output that is neither product nor co-product and that the holder intends or is required to recycle or treat as waste.

3.67 "Secondary data"

means any data which do not fulfil the requirements for primary data.¹⁴

Note 1: Secondary data can include data from databases and published literature, default emission factors from national inventories, calculated data, estimates or other representative data, validated by competent authorities.

Note 2: Secondary data can include data obtained from proxy processes or estimates.

3.68 "Secondary material"

means any material taken from a recycling flow.

3.69 "Semi-finished product"

means a product state at which a preliminary endpoint of material processing is reached by bringing the material into an initial preliminary form that allows to count or measure it as discrete elements or parts.

17 Weidema, B. P., et al. (2008). "Overview of the Recycling Credit Method." International Journal of Life Cycle Assessment.

18 Renewable Energy Directive (2018/2001)

3.70 "Starter Lightning and Ignition battery, (SLI battery)"

means a battery that is specifically designed to supply electric power for starting, lighting, or ignition and that can also be used for auxiliary or backup purposes in vehicles, other means of transport or machinery

3.71 "Sectoral guidelines"

means PCF reporting rules issued by industry associations or initiatives as guidance for their members.

3.72 "Sensitivity analysis"

means systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a CFP study.¹¹

3.73 "Supply chain"

means a network of organisations involved, through upstream and downstream linkages, in process and activities relating to the provision of products to the user.¹⁶

3.74 "Sustainability"

means a dynamic process that guarantees the persistence of natural and human systems in an equitable manner.¹⁹

3.75 "System boundary"

means a boundary based on a set of criteria representing which unit processes are a part of the system under study.⁸

3.76 "Traction battery"

means a rechargeable electrical energy storage system (REESS) installed in an electrified vehicle and used mainly for traction purposes

3.77 "Type III environmental declarations"

means declarations which present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function.²⁰

3.78 "Unit process"

means the smallest element considered in the life cycle inventory analysis for which input, and output data are quantified.¹³

3.79 "Use stage"

means that part of the life cycle of a product that occurs between the transfer of the product to the consumer and the end-of-life of the product.¹⁴

3.80 "Utility factor"

Means the share between driving in 'charge depleting' and 'charge sustaining' mode for PHEVs

3.81 "Value chain"

means all upstream and downstream activities associated with the product system.

19 IPCC SR15 Report Glossary

20 ISO 14025:2010

3.82 "Waste"

means materials or process outputs that the holder intends or is required to dispose by landfill or incineration.

4. Abbreviations

A-LCA	- Automotive Life Cycle Assessment
AC	- Air Conditioning
ACEA	- European Automobile Manufacturers' Association
ASR	- Automobile shredder residue
BEV/PEV	- Battery Electric Vehicle / Pure Electric Vehicle
BoM	- Bill of Materials
CD	- charge-depleting electric
CE	- Circular Economy
CFF	- Circular Footprint Formula
CFP	- Carbon Footprint
CLEPA	- European Association of Automotive Suppliers (Comité de Liaison des Équipements et de Pièces d'Automobiles)
CLTC	- China Light-Duty Vehicle Test Cycle
CNG	- Compressed Natural Gas
CO ₂	- Carbon Dioxide
CO ₂ eq	- Carbon Dioxide equivalent
CS	- charge-sustaining
DLUC	- Direct Land Use Change
EA	- European Aluminium
EAC	- Energy Attribute Certificate
EAER	- Equivalent All Electric Range
EF	- Emissions Factor
ELV	- End-of-Life Vehicle
EMEP	- European Monitoring and Evaluation Programme
EoL	- End-of-Life
EPD	- Environmental Product Declaration
EPDM	- Ethylene Propylene Diene Monomer
ESG	- Environment, Social and Governance
EU	- European Union
EU27	- The 27 Member States of the European Union
FC	- Fuel Cell
FCEV	- Fuel Cell Electric Vehicle
FCHV	- Fuel Cell Hybrid Vehicle
FCV	- Fuel Cell vehicle

FTP	- Federal Test Procedure
FU	- Functional Unit
GCD	- Great Circle Distance
GHG	- Greenhouse Gas
GO	- Guarantee of Origin
GREET	- The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GRPE	- (UNECE) Groupe de Rapporteurs Pollution et Energie
GWP	- Global Warming Potential
HC	- Hydrocarbon
HCFC	- Hydrochlorofluorocarbons
HDV	- Heavy-Duty Vehicle
HEV	- Hybrid Electric Vehicle
HFC	- Hydrofluorocarbons
HFET/HWFET	- Highway Fuel Economy Test
HS	- Hotspot
ICE(V)	- Internal Combustion Engine (Vehicle)
IEA	- International Energy Agency
ILCD	- International Life Cycle Data Format
ILUC	- Indirect Land Use Change
IPCC	- (United Nations) Intergovernmental Panel on Climate Change
ISO	- International Organisation for Standardisation
IT	- Information Technology
IWG	- Informal Working Group
JAMA	- Japanese Automobile Manufacturers Association
LCI	- Life Cycle Inventory
LDV	- Light-Duty vehicle
LGE	- LCA Group End-of-Life
LGP	- LCA Group Production
LGPP	- LCA Group Production Parts
MAC	- Mobile Air Conditioning
MBBM	- Modular Burdens and Benefits Method
(I)MDS	- (International) Material Data Sheet
NOVC-HEV	- Not Off-Vehicle Charging Hybrid Electric Vehicle
OBFCM	- On-Board Fuel Consumption Monitoring
OEM	- Original Equipment Manufacturer
OICA	- Organisation Internationale des Constructeurs d'Automobiles
OVC-HEV	- Off-Vehicle Charging Hybrid Electric Vehicle
PCF	- Product Carbon Footprint

PDS	- Primary Data Share
PEF	- Product Environmental Footprint
PFA	- Plateforme Française Automobile
PHEV	- Plug-in Hybrid Electric Vehicle
PPA	- Power Purchase Agreements
R&D	- Research and Development
RCM	- Recycled Content Method
REC	- Renewable Energy Certificate
RFS	- Renewable Fuel Standard
REEV	- Range-Extended Electric Vehicle
RV	- Representative Vehicle
SDG	- Sustainable Development Goals
SFD	- Shortest Feasible Distance
SLI	- Starting-Lighting-Ignition (Battery)
SOCE	- State of Certified Energy
t-km	- tonne-kilometres
TtW	- Tank to Wheel
UF	- Utility Factor
UN GTR	- United Nations Global Technical Regulation
UNECE	- United Nations Economic Commission for Europe
VDA	- German Association of the Automotive Industry
WEO	- World Energy Outlook
WLTP	- Worldwide Light-duty Test Procedure
WP.29	- (UN-ECE) Working Party 29
WtT	- Well to Tank
WtW	- Well to Wheel

5. General methodological definitions

5.1 Terminology: Shall, should, may, can

Clarification on ISO expressions²¹ used in this document:

The following definitions apply in understanding how to implement an ISO International Standard and other normative ISO deliverables:

- The term “shall” indicates what is required for a CFP to be compliant with these guidelines.
- The term “should” indicates a recommendation rather than a requirement. Any deviation from a “should” recommendation must be justified by the party conducting the study and made transparent.
- The term “may” indicates an option that is permissible.

21 ISO/IEC Directives, Part 2, section 7 („Verbal forms for the expression of provisions“)

- The term “can” is used to indicate that something is possible, for example, that an organization or individual is able to do something.

5.2 Environmental impact category and indicator

The calculation of the CFP shall include non-CO₂ GHGs.

The GHGs to be included shall be considered with reference to the latest IPCC Assessment Report (AR). The potential climate change impact of each GHG emitted and removed by the product system shall be calculated by multiplying the mass of GHG released or removed by the 100-year GWP characterisation factor given by the IPCC in units of kg CO₂eq per kg emission.

Where GWP values are amended by the IPCC, the latest values shall be used in the calculations. For example, once IPCC releases a new Assessment Report, the GWP100 values shall supersede those of the previous Assessment Report within a year. In any case, there should be a clear statement by the LCA practitioner regarding the applied AR. All life cycle stages include fuel and energy cycle. For reference, the AR6 characterisation factors for the substances that are not listed in case of AR6 in Table 7.15 of the IPCC AR6 shall be extracted from Table 7 SM6 in Section 7 Supplementary Materials (SM) of the AR6 Climate Change 2021.

5.3 Inclusion of specific GHG emissions and removals

Table 1 gives an overview on the possible GWP contributions to a CFP.

Table 1: Explanation of GWP contributions

Position	Emission	Description
A	GWP fossil	All fossil emissions, including industrial processes, stationary/mobile combustion and fugitive emissions. This position eventually includes the fossil emissions associated to land management.
B	GWP biogenic emissions other than CO ₂	Non-CO ₂ biogenic emissions related to agricultural activities. It encompasses emissions from livestock and manure; CH ₄ emissions from biomass burning and fires; CH ₄ emissions from rice production; CH ₄ emissions from transformation and degradation (e.g., combustion, digestion, composting, landfilling). It must be noted that N ₂ O from land management activities are not included in this position and are reported in position A.
C	GWP land use change (LUC, excluding iLUC)	Emissions from LUC constitute a release of GHG emissions due to a change in land use from one land use category or subcategory to another, such as primary forest to agricultural land, or peat land (type of wetland) to cropland. This position encompasses dLUC (direct land use change) emissions. If that data is not available, companies should account for LUC using statistical land-use change emissions. Indirect LUC emissions are excluded.
D	GWP aviation emissions	Aviation emissions that occurred in transport activities.
E	GWP Land Management CO ₂ Emissions	Carbon stock losses occurring within the same land use category or subcategory due to agricultural practices such as tillage, field preparations, pruning and harvest. Land Management CO ₂ emissions measures biogenic CO ₂ emissions from a net loss in carbon stock within one land use category or subcategory. This includes impact on

		the land-carbon pools, including above- and below-ground biomass, dead organic matter, and soil carbon pools.
F	GWP Land Management CO ₂ Removals	Land management removals are net CO ₂ removals resulting from net increases to carbon stored in land-based carbon pools (biomass, dead organic matter and soil carbon pools; negative contributions) due to ongoing land management practices. This extra net carbon stock is gained over the crop rotation or crop cultivation cycle (e.g., multiple years for perennial crops and multiple years in a rotation that includes annual crops).
G	Net biogenic CO ₂ -uptake (biogenic CO ₂ contained in the product)	Net emission contribution due to any biogenic CO ₂ emissions that may have occurred during production processes reduced by any CO ₂ which was absorbed from the atmosphere during the growth period of the biomass and of which the C is now bound in the product as biogenic carbon content. In cradle-to-gate studies, this position is negative as it shows the biogenic CO ₂ contained in the product.

All relevant unit processes of the life cycle of biomass-based products shall be included in the system under study, including, but not limited to, cultivation, production and harvesting of biomass.

Currently different GHG accounting schemes, i.e., CFP including (ISO 14067) and excluding biogenic CO₂ (PEF and GHG protocol), are applied. The situation is depicted in Figure 4.

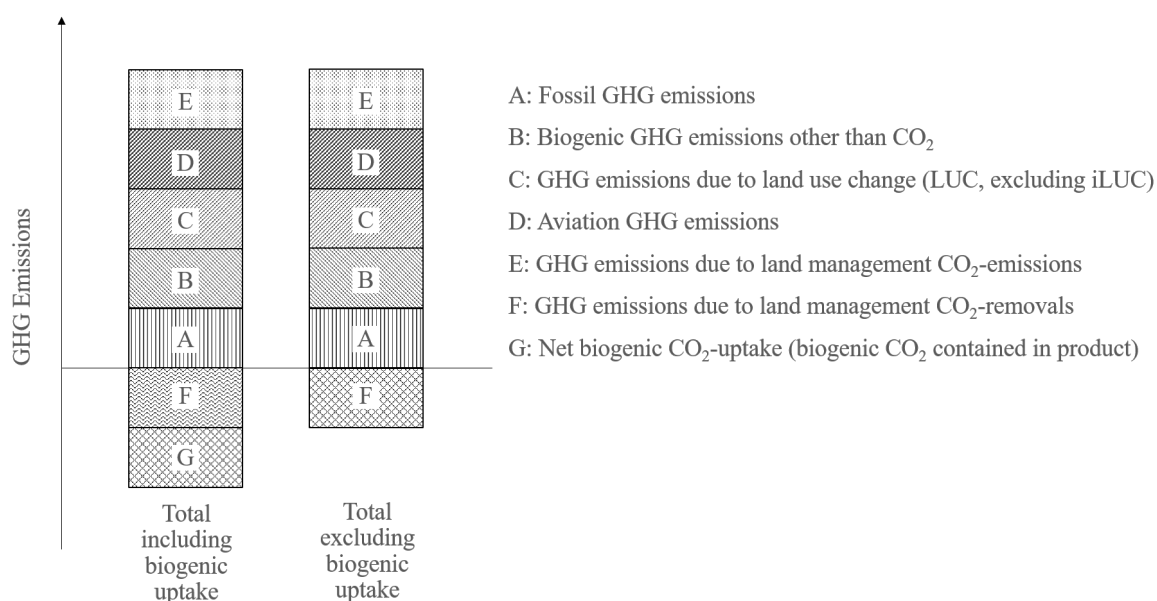


Figure 4: Overview of the specific components of the CFP including and excluding biogenic uptake

For CFP reporting, both the total GWP including biogenic CO₂ uptake (T1 in Table 2) and the total GWP excluding biogenic CO₂ uptake (T2 in Table 2) shall be provided. The total GWP including biogenic CO₂ uptake shall be used for the calculation of the primary data share or primary activity data share.

A product's biogenic carbon content shall be calculated and reported separately. If mass balanced materials (see 5.10.5) are used in the supply, the attributed biogenic carbon content shall additionally be reported to accurately account for emissions from combustion of these materials.

Table 2: CFP contributions to be reported

Emission	Description
GWP total incl. biogenic CO ₂ Uptake	Position T1 $T1 = A+B+C+D+G$ (negative contribution). Letters refer to Table 1. This also refers to the -1/+1 Approach.
GWP total excl. biogenic CO ₂ uptake	Position T2 $T2 = A+B+C+D$ Letters refer to Table 1 This also refers to the 0/0 Approach.
Biogenic carbon	Amount of carbon from biogenic origin that is bound in the product and could be confirmed by a C14 analysis
Attributed biogenic carbon	Amount of carbon of biogenic origin allocated to the product through a certified mass-balance or chain-of-custody system, regardless of the physically measurable biogenic carbon content that could be confirmed by a C14 analysis
If separate emission values do not occur, these emission values may -without misstatement - be reported as zero instead of “not applicable”. Removals in the CFP shall not include any measures not related to the product system, usually referred to as carbon offsets.	

5.4 Land Use Change emissions

Land use change (LUC) occurs when the demand for a specific land use results in a change in carbon stocks of that land. LUC is differentiated in direct land use change and indirect land use change. Direct land use change (DLUC) is generally defined as a localized process where cropland expansion results in land competition between croplands and natural lands. Indirect land use change (ILUC), which is generally defined as including broader, market-mediated effects, interactions and trade among regions describe a global phenomenon that goes beyond the regions expanding biofuels production.

Both DLUC and ILUC are already taken into account within life-cycle emission factor provided by some national and regional governments for biofuels. For example, biofuels life-cycle emission intensity from the RFS^{22 23 24} Program in the United States serves as the official source of life-cycle emission intensity for biofuels use by light-duty vehicles and engines used in heavy-duty on-road applications and incorporates DLUC and ILUC.

Similarly, the EU Renewable Energy Directive (RED) includes criteria for determining biofuel impacts due to DLUC and addresses ILUC by caps on the counting of food and feed-crop-based biofuels.

22 U.S. Title 40 CFR Part 80, Subpart M. <https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-80/subpart-M>.

23 U.S. EPA (2023). Lifecycle Greenhouse Gas Results. <https://www.epa.gov/fuels-registration-reporting-and-compliance-help/lifecycle-greenhouse-gas-results>.

24 U.S. EPA (2023). Renewable Fuel Standard (RFS) Program: Standards for 2023–2025 and Other Changes - Regulatory Impact Analysis. EPA-420-R-23-015. <https://nepis.epa.gov/Exec/ZyPDF.cgi?Dockkey=P1017OW2.pdf>.

Official, government-provided life-cycle emission factor for biofuels, including treatment of DLUC and ILUC, shall be used within national and regional jurisdictions whenever available.

For circumstances under which there is no available government life-cycle emission intensity for biofuels, other approaches may be acceptable and should be reported and verified if used. The DLUC emissions should encompass the annualized emissions and sequestration resulting from carbon stock changes in biomass, dead organic matter and soil organic matters, etc. ILUC cannot be directly measured and must be projected with economic models.

The emissions due to ILUC, and the spatial/temporal impacts of the ILUC effects, are dependent on factors such as local/regional conditions and agronomical practices, regional food import demand and related projections, alternative economic uses of the same feedstock, etc. Given the variability of assumptions underlying the evaluation of indirect effects, quantitative assessment of GHG effects of ILUC is subject to additional uncertainty. ILUC results shall be subjected to a sensitivity analysis within projected economic bounds, consistent with the goal and scope of the study. ILUC should be reported separately for scenario analysis in level 3 and 4 if biomaterials or biofuels are modelled

5.5 Functional Unit and reference flow

The primary function of a passenger car is to transport passengers from one location to another. The functional unit (FU) for passenger cars is defined as the passengers transported over vehicle lifetime measured in kilometres in a defined region.

FU shall be consistent with official national regulations and/or legislation according to each jurisdiction.

In regions without fixed loading conditions that have been pre-defined by the relevant government authority, the FU shall be defined in the following manner: For vehicles carrying passengers, the default functional unit is defined as “passenger-km” (p-km).

For these guidelines the functional unit (FU) for a passenger car is defined as the transportation of one passenger per km of distance travelled over the vehicle lifetime. Passenger cars are typically designed to transport multiple people; therefore, defining an occupancy of one passenger represents a conservative approach.

Lifetime distance varies depending on macro region or country. The LCA practitioner shall use the universal generic value of 200,000 km unless a macro regional or country authority requests other lifetime distance.

The reference flow for a vehicle is defined as the measurable quantity of inputs and outputs necessary to meet the defined *functional unit* of the product over its lifecycle. The reference flow in automotive LCAs translates this functional unit into specific, quantifiable measures of resources consumed and emissions produced, covering aspects such as:

- (a) Vehicle components and materials (e.g., steel, aluminium, plastics required to manufacture the car),
- (b) Fuel and/or energy consumption over the vehicle’s lifetime,
- (c) Maintenance and replacement parts (such as tyres, fluids, SLI batteries²⁵, etc.),

25 Batteries for starting-lighting-ignition (SLI) and auxiliary applications only - does not apply to primary battery packs used for electric-drive powertrains

- (d) End-of-life treatment for disposal or recycling.

The processes listed above serve as illustrative examples and are not intended to be exhaustive. The standardised reference flow enables consistent and comparable assessments across different automotive products, focusing on the impacts associated with achieving the defined service.

5.6 System boundaries

Life cycle stages

The following life cycle stages are covered (Figure 5):

- (a) Material production stage
- (b) Parts production and vehicle assembly stage
- (c) Use stage
- (d) End-of-life stage

All life cycle stages include fuel and energy cycle.

The second life of components after the recycling of the recovered parts at EoL are excluded from the scope of these guidelines.

More details regarding system boundaries per life cycle stages are given in dedicated life cycle stage sections.

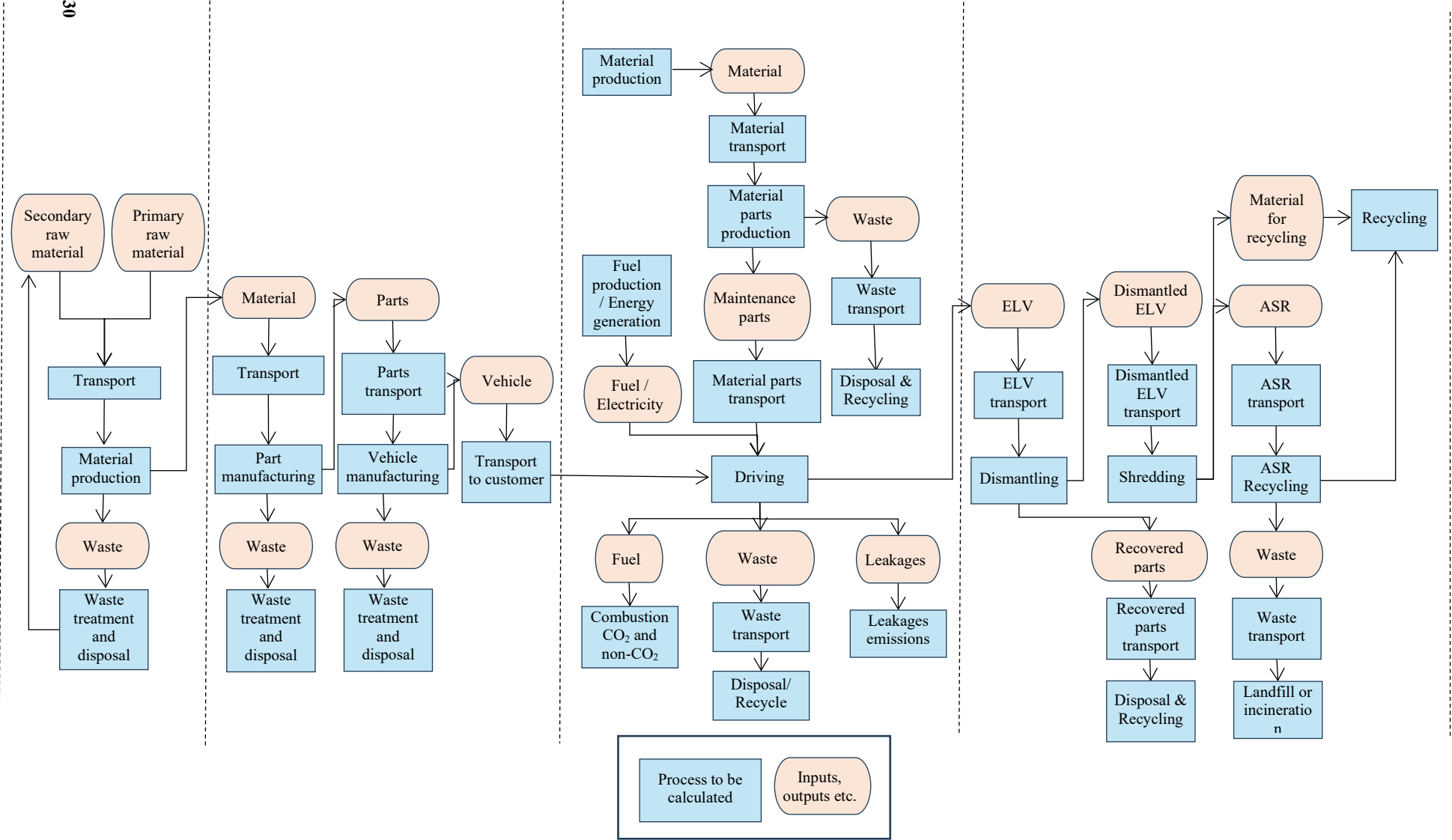


Figure 5: Example of Life cycle stages covered by these guidelines

5.7 Infrastructure and capital goods

This section provides rules for infrastructure and capital goods, such as the building in which the product or upstream materials or components are produced, machinery used in the manufacturing of the product or its materials or components, vehicles used for transportation in the product system, the equipment used in the production and supply of energy (e.g. electricity generation equipment), the construction and maintenance of roads and production of charging infrastructure (list without claiming completeness). The applicable infrastructure and capital goods are limited to those that are not consumed and retain their function for a certain period.

In general, the production and end-of-life processes of infrastructure and capital goods used in the product system shall be excluded from the system boundaries. The exceptions are those infrastructure and capital goods for the production of fuels and for generation of electricity, which should be included by default within the system boundary for the vehicle use stage (as is also the best practice adopted by UNECE publications on LCA of electricity generation²⁶, the GREET model²⁷, and other models and publications available in different global regions) unless otherwise required to ensure consistency with the selected regional energy modelling approach (e.g. RED). The general cut-off criteria apply.

Deviations from the above requirements may be possible in the following case:

Infrastructure/capital goods (i.e. also others in addition to those for/resulting from production of fuels and generation of electricity) may be included for any life cycle stage if a dataset used already includes infrastructure emissions, and it is not possible, to subtract the infrastructure emissions from this dataset.

5.8 Cut-off

In general, all processes and flows that are attributable to the analysed system shall be included. The analysed system can be the complete product to which the functional unit is associated, (e.g. a passenger car,) but also a subsystem (component, part) to the product or an individual life cycle stage that contributes additively to the life cycle GHG emissions of the final product. For practical reasons (see ISO 14067, PEF method), process modules, inputs and outputs may only be excluded if their sum represents less than 3% of the GHG emissions over the relevant life cycle stages of the analysed (sub)system (e.g. cradle-to-gate stages for parts). It is not permitted to cut-off an entire life cycle stage, even if that falls below the threshold value. GHG emission reported from upstream entities shall be regarded as correct and complete and may not be subject to any further cut-off. Evidence shall be documented that the cut-off criterion is met, and which cut-offs were applied. The documentation can be given in the form of a screening analysis.

Compliance with the cut-off threshold value can be proven on a product category or sectoral level and does not have to be executed on a product level. Product category rules or sectoral guidelines can lay down simplified rules for the evidence to be documented.

5.9 Screening Analysis

A screening analysis ensures that cut-off emissions in total do not exceed a threshold value of the GWP impact.

The screening shall allow further refinement of the LCI and the associated emission factors of the system in scope in an iterative manner. Within

26 Life Cycle Assessment of Electricity Generation Options | UNECE

27 www.greet.anl.gov for the model and reports

screening, no exemption of flows is allowed, and readily available primary or secondary data may be used. If data, such as emission factors, activity data, or measurements are unavailable or challenging to identify, it is essential to find the most appropriate proxy data or emission factors, in case of doubt a conservative choice shall be taken. Emission factors or activity data received from upstream reporting entities shall be regarded as correct and complete. The scope of the final screening iteration shall be documented to inform on the cut-offs and prove compliance with the cut-off threshold value.

5.10 Data collection requirements and data types

5.10.1 Data quality

Data selection shall follow data quality requirements outlined in ISO 14044:2006 (see sec. 4.2.3.6 of ISO 14044:2006) including:

5.10.1.1 Temporal representativity:

The data collection period shall correspond to the activity data that is most relevant to the process.

For retrospective data emissions shall by default be reported averaged over the period of one year (reporting or calendar year) to avoid seasonal fluctuations and for example, reflect typical production and operation conditions. Shorter periods may be considered if data on a full year are not yet available. Longer averaging periods may be considered but shall not exceed three years. Any averaging period deviating from the default shall be flagged and justified.

5.10.1.2 Geographical representativity:

The geographical location of data collection shall correspond to the activity data that is geographically representative to the process.

For material, parts and vehicle production emissions shall be reported as geographically specific as possible by default (e.g. on the plant level). Averaging over a region or country may be considered, but shall be flagged as such.

5.10.1.3 Technological representativity:

The data shall be collected/selected for the processes used in the activity to ensure technological representativeness.

If the practitioner cannot access such information and instead refers to data of a technically similar process from a secondary dataset or other sources, the reason shall be documented and justified.

5.10.1.4 Completeness:

The Life cycle assessment shall include all processes and flows that are attributable to the analysed system. Processes and flows being able to exclude are determined according to the cut-off threshold (see 5.8).

5.10.1.5 Consistency:

The data selection shall ensure uniform application of the approach to the various components of the analysis.

5.10.1.6 Traceability:

The source of data used in a study shall be documented.

Primary data are to be prioritised if available, otherwise secondary data shall be used.

Specific details on data quality requirements are provided for individual life cycle stages in sections 6.1- 6.4.

5.10.2 Data types

GHG emissions can either be directly measured or quantified based on a calculation that in general takes the form

$$C_{GHG} = CEF_{GHG} \times A_{GHG} \quad (1)$$

C_{GHG} means greenhouse gas emissions, [kg CO₂eq];

CEF_{GHG} means greenhouse gas emission factor, [kg CO₂eq per activity];

A_{GHG} means quantitative measure of activity that results in greenhouse gas emission or removal [unit of activity];

Activity data can be an amount of energy, fuel or electricity consumed, the amount of material, auxiliary material or number of parts required for the manufacturing of products, the amount of services provided or the area of land affected.

An emission factor expresses the quantity of greenhouse gas emissions (GHGs) associated with a defined unit of activity. Typical units include kg CO₂eq/kWh, kg CO₂eq/litre of fuel, or kg CO₂eq/kg of material. Emission factors may represent direct emissions only e.g. from combustion or include upstream and life-cycle emissions, depending on the defined system boundary e.g. cradle-to-gate. Primary data may be obtained through meter readings, purchase records, utility bills, direct monitoring, material or product balances, stoichiometry or other methods for obtaining data from specific processes in the value chain of the company carrying out the process. Note that GHG emission information passed through a supply chain in most cases represents a mix of primary and secondary data.

GHG emissions are considered as primary information if quantified by direct measurement of the emissions or they are considered primary to the extent that activity data and emission factor are primary.

Requirements regarding data collection and data types (primary or secondary) are given for each life cycle stages in dedicated sections (see 6.1 - 6.4).

5.10.3 Primary data share and primary activity data share

To create visibility on the share of primary data based emissions in CFP calculations for vehicles, a primary data share (PDS) indicator and a primary activity data share (PADS) indicator can be defined. The PDS is the proportion (percentage) of greenhouse gas emissions that is derived from primary data. The PADS is the proportion (percentage) of a greenhouse gas emissions that is derived based on primary activity data. Equation 1 shows that primary activity data are important to achieve primary emission results. It is therefore justified not only to track the share of primary emissions but also the share of emissions for which primary activity data are provided.

Reporting of a PDS/PADS is relevant in case of detailed supply chain and vehicle modelling. Therefore, the PDS/PADS shall be determined and reported for any intra-industrial reporting (i.e. business to business) during material production stage and parts production stage and may optionally be determined and communicated for vehicle production, use stage and end-of-life stage. The PDS/PADS data communicated can be zero when no primary data was collected and only secondary data is used. The PDS/PADS of each product on

the output side is reported for the total CFP (C_{total}) which is algebraic sum of the positive and negative CFP contributions on the input side and the company's own operations (C_i). To ensure that a consistent PDS/PADS can be reported no matter if reporting is done stepwise or collectively for multiple process steps C_{as} , the absolute sum of C_i is also to be calculated. Figure 6 illustrates the definition of C_{total} and C_{as} .

$$C_{total} = \sum_i C_i ; C_{as} = \sum_i |C_i| \quad (2)$$

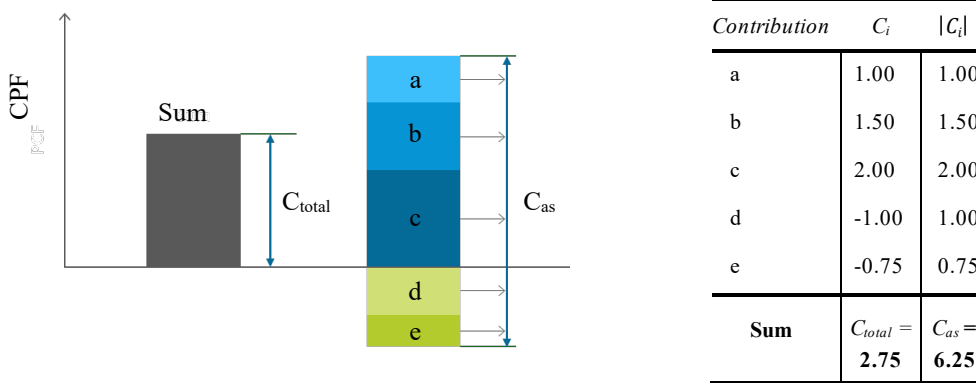


Figure 6: Definition of C_{as}

In case there are no negative CFP contributions C_{total} is equal C_{as} . Having introduced C_{as} the primary data share of each process/company on the output side is defined by:

$$PDS = \frac{\sum_i |Part\ of\ CFP\ based\ on\ primary\ data|}{C_{as}} \quad (3)$$

Similarly, the primary activity data share is defined as follows:

$$PADS = \frac{\sum_i |Part\ of\ CFP\ based\ on\ primary\ activity\ data|}{C_{as}} \quad (4)$$

The aggregated primary data share on the output side for multiple CFP contributions reported with individual PDS (i.e. PDS_i) from the input side or own operations is defined by:

$$PDS = PDS_{aggregated} = \frac{\sum_i (|C_{as,i}| \cdot PDS_i)}{\sum_i C_{as,i}} \quad (5)$$

Similarly, the aggregated primary activity data share on the output side for multiple CFP contributions reported with individual PADS (i.e. $PADS_i$) from the input side or own operations is defined by:

$$PADS = PADS_{aggregated} = \frac{\sum_i (|C_{as,i}| \cdot PADS_i)}{\sum_i C_{as,i}} \quad (6)$$

As an example, three suppliers, Company A, Company B and Company C, provide parts to Company D. Each part has a different primary data share and contribution to the total CFP value of the product of Company D (Figure 7). According to the formula above, the primary data share of Company D's part is calculated from the primary data share and contributions to the absolute value total CFP (Table 3)

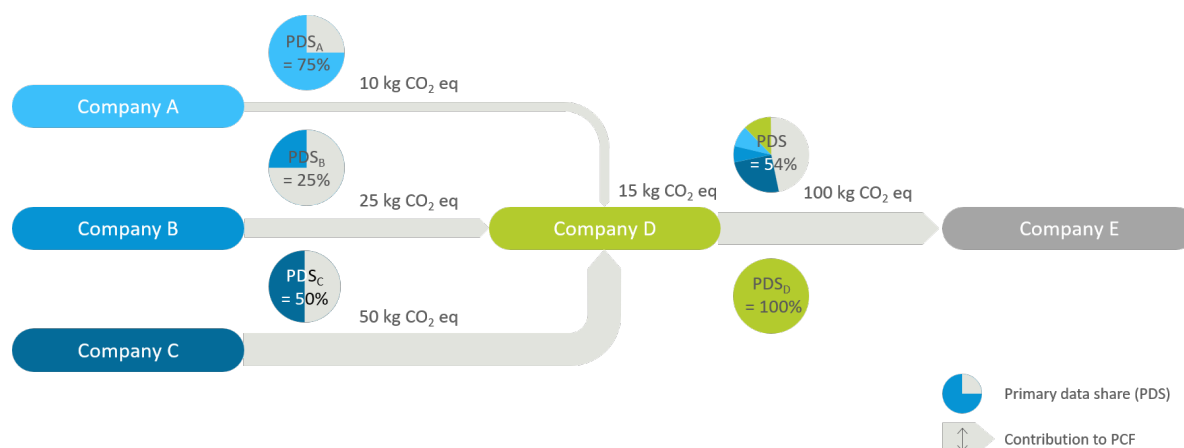


Figure 7: Cascading PDS

Table 3: Primary data share of the example as in Figure 7

	PDS_i	$C_{total,i}$	$PDS \text{ Contribution}$
Company A	75%	10 kg CO ₂ eq	$75\% * 10 \text{ kg CO}_2 \text{ eq} = 7.5 \text{ kg CO}_2 \text{ eq}$
Company B	25%	25 kg CO ₂ eq	$25\% * 25 \text{ kg CO}_2 \text{ eq} = 6.3 \text{ kg CO}_2 \text{ eq}$
Company C	50%	50 kg CO ₂ eq	$50\% * 50 \text{ kg CO}_2 \text{ eq} = 25 \text{ kg CO}_2 \text{ eq}$
Company D	100%	15 kg CO ₂ eq	$100\% * 15 \text{ kg CO}_2 \text{ eq} = 15 \text{ kg CO}_2 \text{ eq}$
Total	54%	100 kg CO₂ eq	54 kg CO₂ e, (7.5 + 6.3 + 25 + 15)kg CO₂ eq

Note: The primary data share is not directly linked to the accuracy of the total CFP. When a product with a high PDS in the supply chain (e.g., the product of Company A in Figure 8) is decarbonised through carbon reduction measures, the PDS of the final product (e.g., the product of Company D in Figure 7) may rather decrease as a result of the lowered total CFP. Therefore, while the PDS can be an indicator of the primary data usage, it shall always be considered in conjunction with the total CFP value.

5.10.4 Allocations

In case a process has more than one output, the question how to allocate the CO₂eq-burden to the outputs arises. Outputs of a process can be viewed as products, co-products or waste. Products or co-products share the CO₂eq-burden of the production/generation process, whereas residues eventually increase the CO₂eq-burden for the product. In a first step the question: ‘Is this a residue or a co-product?’ must be answered (see Figure 8).

5.10.4.1 Residue vs Co-product

Residue is any material or process output which is not deliberately produced as an integral part of a multi-output production process. No further use of the material or process output is certain. Additionally, the holder discards or intends to discard or is legally required to discard the residue based on national waste legislation.

Residues with certain further use but requiring further treatment other than normal industrial practice before use (i.e., residues recovered for recycling) shall follow the requirements on material recycling.

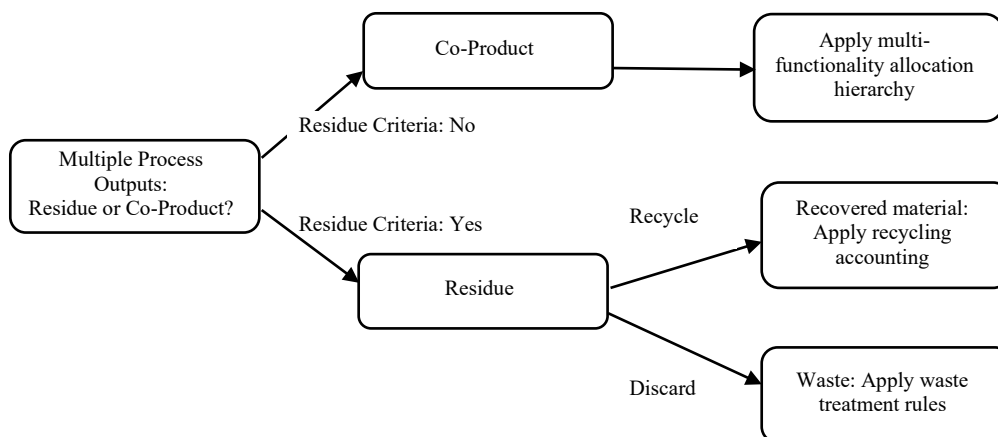


Figure 8: Co-Product or Residue

“Normal industrial practice” can include all steps which a producer would take for a product, such as the material being filtered, washed, or dried; or adding materials necessary for further use; or carrying out quality control. However, treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense. Some of such processing tasks considered as normal industrial practice can be carried out on the production site of the manufacturer, some on the site of the next user, and some by intermediaries, as long as they also meet the criterion of being ‘produced as an integral part of a production process’ (adopted from the EU’s Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste²⁸).

A co-product in contrast is produced as an integral part of a multi-output process where its further use is certain. Typically, co-products directly replace a raw material or fuel without requiring further processing other than normal industry practice. For co-product allocation, multi-output allocation applies (please refer to 5.10.4.2).

The following hierarchy shall be applied (please refer to ‘Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste’⁴⁰ for definitions of the respective criteria):

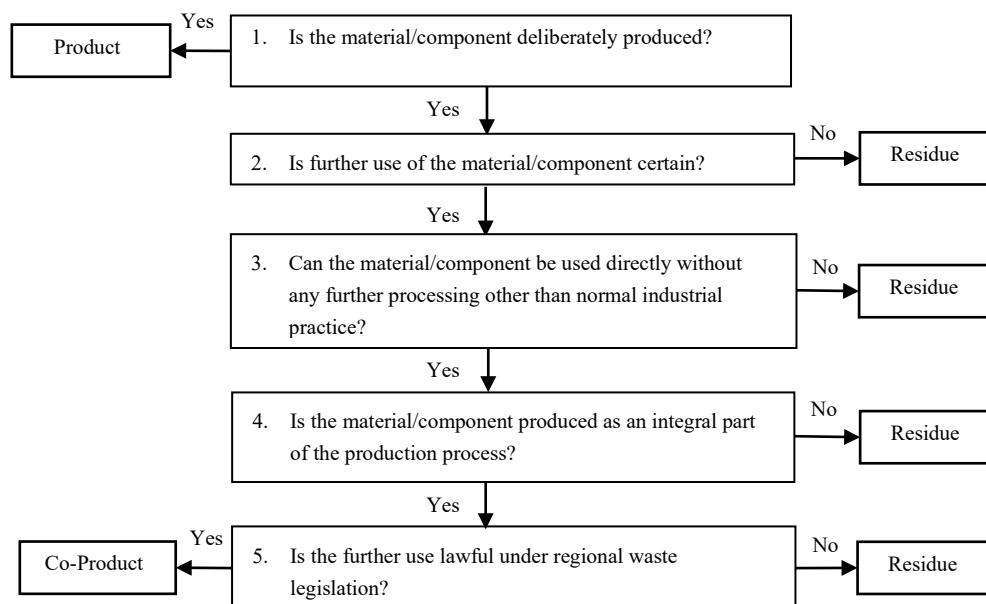


Figure 9: Residue vs. co-product classification hierarchy

Note: This is based on EU Waste Framework Directive

Output classified as residue following the hierarchy can also be transformed into recycled feedstock. However, this transformation would require further processing other than normal industry practice (see point 3 in Figure 9), such that the output would be classified as residue in the first instance.

Pre-consumer scrap that is not reintroduced into the same process (i.e., all scrap except run-around scrap) shall be defined as residue unless legal evidence (following legislation of the region where scrap is generated, e.g., legal judgement or legal report from regional waste legislation) exists that classifies the pre-consumer scrap material as co-product.

5.10.4.2 Multi-output allocation

Allocation shall be avoided whenever possible by dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or expanding the product system to include the additional functions related to the co-products.

If allocation cannot be avoided, allocation shall be carried out in accordance with the methods specified by ISO 14044:2006:

- The inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them, i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
- Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

In ISO 14044:2006, allocation may be conducted on economic value basis, when physical relationship alone cannot be established or used as the basis for allocation; however, no specific criterion is provided to determine whether to adopt economic instead of physical allocation. Therefore, economic allocation is recommended when the economic value ratio, defined as being the ratio

between the reference product to one co-product per declared unit, is equal or higher than 5. For the use of economic values, the global sales prices should be averaged.

a) over the last 10 years for metals, ores and metal compounds

b) over the last 5 years for all other commodities

c) over the last 3 years in the case that the preferred data is not available.

This approach is expected to practically cover cases such as rare metals used in the automotive industry. However, since economic value ratio may not be applied consistently with existing databases, its use should be properly reported, including the applicable economic value ratio and the rationale behind its determination.

In case of multi-output allocation is applied to fuels, allocation shall be determined in proportion to the energy content of the products, determined by lower heating value in the case of co-products other than electricity and heat.

5.10.5 Chain of custody

In the automotive supply chain, the multiple inputs (resources), outputs (products), and processes exist, and the LCA of automotive products is generally conducted within a complex system. As a method for the appropriate allocation and management of environmental attributes within such a system, Chain of Custody may be applied. ISO 22095:2020 and ISO22095-2:2026 specifies five models of Chain of Custody (Table 4, Figure 10).

Table 4: Chain of Custody Models

<i>Input/Output Relation</i>	<i>Identity preserved</i>	<i>Segregated</i>	<i>Controlled blending</i>	<i>Mass balance</i>	<i>Book and claim</i>
All input characteristics translate unchanged to output characteristics	✓	—	—	—	—
Mixing of inputs with different characteristics	—	—	✓	✓	✓
Output characteristics reflect the average of input flow characteristics	✓	—	✓	—	—
Physical connection or Physical presence**	✓	✓	✓	✓	—

** : Physical connection or presence is defined as "Chance that parts of the inputs with specific characteristics are physically present in the outputs" (source: ISO/FDIS 13662:2025) (final draft, under development, in the approval phase).

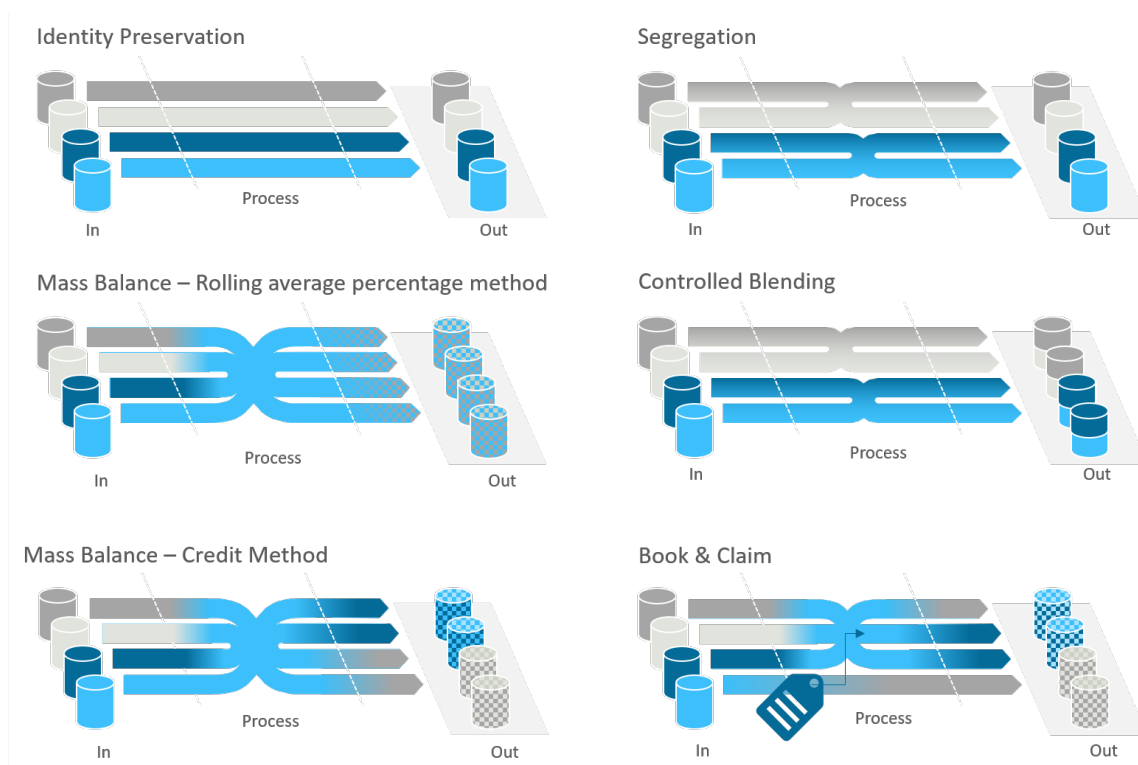


Figure 10: Overview of chain of custody models

Mass balance and Book and Claim do not ensure the physical presence of the claimed characteristics. By contrast, identity preservation, segregation and controlled blending do ensure physical presence, with controlled blending ensuring physical presence for the percentage with specific characteristics.

The Mass Balance and Book and Claim model may enable a flexible allocation of environmental attributes; however, in order to ensure transparency and credibility, its application requires prudent consideration.

Accordingly, these guidelines define minimum requirements that shall be established to prevent diverse interpretations and misuse of Mass Balance and Book and Claim.

5.10.5.1 Verification and Assurance Requirements for Mass Balance and Book and Claim

- The reliability of these models shall be ensured through verification, and an equivalent independent and transparent certification scheme shall be required.
- If these models are used, they shall be clearly explained to the verifier with sufficient information so that the verifier can judge the appropriateness and correct application of the model.
- When the environmental attributes of products using these models are claimed, clear and transparent information shall be provided to stakeholders.

5.10.5.2 Applicability and Certification Requirements for Book & Claim

In these guidelines, Book and Claim may only be applied to energy carriers such as electricity, fuels, and biomethane. It shall be noted that the Book and Claim model is intended to be applied in the electricity domain, and electricity certificates shall follow section 5.11.1.2.1 (Electricity). When a similar approach is applied to other energy carriers, the same level of reliability of contractual instrument defined in section 5.11.1.2.1 shall be demonstrated and verified.

5.10.5.3 Operational and Technical Requirements for Mass Balance

This model shall correspond to „Mass Balance” as defined in ISO 22095:2020 and ISO22095-2:2026.

- (a) This model shall only be applied in principle when a physical connection between input and output could be established. However, establishing the physical connection is not required if it would lead to additional GHG emissions due to activities such as transportation of products between multiple separate manufacturing sites within the system boundary.
- (b) This model shall be operated under the management of the same company, corporate group, or joint venture.
- (c) This model shall be operated under accounting controls so that the claimed output exactly matches the actual input, also taking into account material yield and scrap, to avoid any double counting.
- (d) Technical feasibility: This model shall only be applied within the range that is technically feasible to produce the output from the input, and the environmental attributes allocated shall not exceed that range.
- (e) Technical equivalence: When this model is applied, the environmental attributes shall only be allocated among products that have the same technical properties.
- (f) This model shall only be applied to additional CFP reduction measures relative to the residual product. The residual product is the product without reduction measures used in mass balance within the respective reporting year. When this model is applied, the allocation of the CFP reduction resulting from the measure shall reflect an actual increase in green inputs, rather than a redistribution that merely makes some products appear greener without any change in production.

5.11 Treatment of specific GHG emissions

5.11.1 Energy modelling

5.11.1.1 Fuel modelling

The definition of emission factors for fuels shall include:

- (a) Upstream processes referring to the extraction or cultivation of raw materials.
- (b) Processes related to the fuel’s processing.
- (c) Downstream processes e.g. referring to the treatment of waste from fuel processing
- (d) Transport and distribution processes at each life cycle stage.
- (e) Emissions from the fuel in use.

In case it cannot be ensured that all attributable fuel emission components (a - e) are included in the fuel emission factor, this situation must be reported and justified in the LCA-report in accordance with the reporting requirements specified in section 7. The reporting shall include a reference to the used LCI and the name of the applied database.

As regards infrastructure and capital goods, refer to section 5.7 Infrastructure and Capital Goods.

Additionally, concerning fuels originated from bio-materials referred to;

- (a) Additional emissions related to changes from soil carbon stock caused by land use change (e.g. wetlands conversion, some specific forest areas, etc.). See section 5.4 on Land Use Change Emissions.
- (b) Emission savings from soil carbon accumulation via improved agricultural management (e.g. shifting to reduced or zero-tillage, using cover crops, etc.), CO₂ capture and geological sequestration, and CO₂ capture and replacement. Refer to section 5.3 Inclusion of specific GHG emissions and removals, for reporting of such emissions.

In the case of one or more other products (co-products, e.g. sugar beet pulps, Distillers Dried Grains with Solubles), allocation shall be determined based on section 5.10.4.2.

5.11.1.2 Electricity modelling

The definition of emission factors for electricity shall include:

- (a) Upstream processes referring to the extraction or cultivation of energy carriers.
- (b) Processes related to the processing of energy carriers.
- (c) Downstream processes, e.g. referring to the treatment of waste from electricity generation
- (d) Emissions from the conversion to electricity.
- (e) Transport and distribution processes at each life cycle stage (losses during transmission and distribution).

In case it cannot be ensured that all attributable electricity emission components (a - e) are included in the electricity emission factor, this situation must be reported and justified in the LCA-report in accordance with the reporting requirements specified in section 7. The reporting shall include a reference to the used LCI and the name of the applied database.

As regards infrastructure and capital goods, refer to section 5.7 Infrastructure and capital goods.

The following approaches are to be used for modelling electricity consumption by a product system:

- (a) The location-based approach is a method of allocating electricity impacts among end-users based on geographical representativeness (economic area, country, bidding zone, etc.); this approach is currently the most commonly used by LCA practitioners, with main LCA databases offering detailed models at a relatively fine geographic scale. The same GHG intensity (g CO₂eq per kWh) is applied to all electricity consumers within a single area. The GHG Protocol defines it as follows: “A location-based method reflects the average emissions intensity of grids on which energy consumption occurs (using mostly grid-average emission factor data)”²⁹. In this approach subnational consumption grid mix (i.e. for the United States of America (USA) California grid mix) or a national consumption grid mix (i.e., country-specific), or economic integration area grid mix (i.e. European Union (EU) grid mix) or a consumption grid mix (i.e., EU grid mix, Africa grid mix, North America) can be used based on section 5.10.1.2 Geographical representativity.
- (b) The market-based approach allocates electricity impacts among end-users based on a principle of individual contractual instruments, which can be claimed by the consumer. The GHG Protocol defines it as

follows: “A market-based method reflects emissions from electricity that companies have purposefully chosen (or their lack of choice). It derives emission factors from contractual instruments, which include any type of contract between two parties for the sale and purchase of energy bundled with attributes about the energy generation, or for unbundled attribute claims.”²⁹ In this approach, every electricity consumption process is modelled using either:

- (i) Processes that reflect the electricity mix purchased via specific contractual instruments related to the considered process and including losses during transmission and distribution of the purchased electricity
- (ii) Or, if no contract on generation attributes exists for the given process, a residual consumption mix related to it, which can be derived either at a national level, a sub-national level or supra-national level, where consumption occurs.

The market-based approach entails a risk of double counting of inventories and impacts. The risk can systematically be avoided by ensuring that volumes covered by contractual instruments are consistently tracked and excluded from the residual consumption mix. The contractual instruments that are used shall comply with the specific requirements as stated in the following section 5.11.1.2.1.

- (c) In circumstances where industries lack sufficient or appropriate data—whether concerning processes required for residual mixes or the processes utilizing them and likewise in situations pertaining to Level 3 and Level 4, they may employ the following **mixed-method approach**. The mixed method approach uses available location-based electricity mixes consumption processes from the LCA databases as the default for all non-contracted consumption, while using specific processes that reflect the electricity mix purchased via specific contractual instruments from suppliers and / or the electricity mix produced on-site in the factories and including clearly documented production/consumption volumes and losses during transmission and distribution of the purchased electricity.

This approach reflects current (2026) practice due to limitations in data availability and especially as collection of primary data along a supply chain is only ramping up.

5.11.1.2.1 Electricity from the grid via a contractual instrument

Electricity data from electricity certificates for a specific generator site or supplier documented by energy certificates may be used in the calculation of emission factors for electricity supplied from the grid if it can be ensured that all the following conditions are met. The contractual arrangement should:

- (a) convey the information associated with the unit of electricity delivered;
- (b) assure with a unique claim, to avoid double counting of GHG emissions and GHG removals within the boundary of the subject;
- (c) be tracked and redeemed, retired or cancelled by, or on behalf of, the reporting entity.
- (d) be consumed within a year during which electricity was produced

Information about the electricity certificate should be clearly stated in the LCA report:

- Name and location of the generating facility;
- Method of generation;

- Amount of electricity generated and amount of electricity certificates issued;
- If available, tracking number assigned by the electricity certificate system.

In ISO 14067:2018, there are examples of certificates that can be used by contractual instruments, such as European Guarantee of Origin (GOs) and US Renewable Energy Certificates (RECs) which meet the above conditions. Electricity certificates that do not guarantee compliance with the above conditions shall not be used. PPAs, utility tariffs or comparable products are also acceptable if the underlying EACs meet the above-described conditions.

If processes within the subject are located in Small Island Developing States (SIDS), the carbon footprint may additionally be quantified using contractual instruments for such processes, irrespective of grid interconnectivity.

If the contractual instruments do not include the provision of electricity certificates the residual consumption mix shall be reported, where the electricity market is tracked and the residual consumption mix determined. In an untracked market or a market that does not issue electricity certificates the electricity emission factors shall be calculated based on the average consumption electricity grid mix, where:

(a) The consumption per country of the different electricity sources (coal, natural gas, nuclear, hydropower, wind, solar PV) Imports should be modelled as the average production mix of the country from which the electricity is imported. The consumption mix and the exported mix are the same.

(b) The emission factors per country of each primary electricity source (coal, natural gas, nuclear, hydropower, wind, solar PV), are provided by the same database.

The practitioner shall ensure that all components of the electricity emission factor (see section 5.11.1.2 (a) to (e)) are taken into account.

5.11.1.2.2 Electricity from a directly connected supplier

Site-specific electricity data may be used in the calculation of emission factors for electricity supplied directly from electricity generators via dedicated transmission lines to facilities manufacturing the respective products and consumed in the manufacture of such products, if no contractual instruments have been sold to a third party.

5.11.1.2.3 Electricity from on-site generation

On-site electricity production can only be accounted for under the following conditions:

- The production asset is owned by the same entity as the factory, or the asset has a direct connection to the factory and is not connected to the grid.
- Only the fraction of electricity that is used on-site and not sourced from the grid shall be accounted for.
- No credits can be claimed for electricity produced in excess and sent to the grid.
- For electricity that is claimed to be auto consumed, no contractual instruments have been sold to a third party

Any deviation, along with detailed explanations of the calculation methods or models used to revise emission factors, must be reported in the LCA report.

5.11.1.3 Prospective energy modelling

To model energy at use stage and EoL stage, a consistent approach between fuel and electricity modelling is required. Modelling should be temporally and spatially matched to both use stage and EOL.

A scenario for the expected future evolution of the fuel or electricity grid mix in the geographical region of interest shall be selected, according to the following order of preference.

- (a) Official, government published energy mix or emissions factors (where these are consistent with the defined scope) based on currently implemented policies for a country or geographical region of interest shall be used if available.
- (b) If option (a) is not available, a static scenario shall be used. The energy mix composition of the year of first registration of vehicle operation shall be used.
- (c) If option (b) is not available, the Stated Policies Scenario (STEPS) from the most recent International Energy Agency's World Energy Outlook (IEA WEO) report, for the geographical region of interest, shall be used. In addition, the IEA WEO Sustainable Development Scenario (SDS) shall also be used as a sensitivity case (or equivalent scenario taking into account international commitments under the UNFCCC).
- (d) Only if none of the previous options above are available for the geographical region of interest, a projected future electricity grid mix (or emissions factors for this) from either dispatch modelling or peer-reviewed published literature-based dispatch modelling may be used. Due to the inherent uncertainties involved, any such analysis shall include a sensitivity case consistent with the goals of the IEA WEO SDS (or equivalent scenario taking into account international commitments under the UNFCCC). For fuel mix a peer-reviewed published literature modelling may be used, provided that such scenarios are strictly aligned with the regulatory frameworks in force in the relevant country or region of use (for example, the RED Directive the EU or the Renewable Fuels Standard in the US). In the equivalent approach for the average fuels mix, only those scenarios from peer-reviewed data reflecting implemented policies shall be considered that are based on announced production capacities

The selected scenario should be communicated and justified. The detailed calculations of the fuel or grid mix composition and average representative fuel or grid mix composition over the full-service life of the vehicle should be communicated. For reporting details refer to section 7.

For any prospective LCA, secondary data will be needed. If such data is not available, region-specific secondary data from IEA should be used. Note that currently IEA data do not include infrastructure emissions.

5.11.1.4 Overview of electricity model application

Table 5: Overview on electricity model choices per level and life cycle stage

	Purpose	Degree of freedom	ENERGY Modeling for Mining & Material production	ENERGY Modeling for Parts / Vehicle Production	ENERGY modeling for Use stage	ENERGY modeling for End-of-Life
Level 1	strategy	multiple approaches possible	Method: Location based or market based*	Method: Location based or market based*	Method: Location based or market based*	Method: Location based or market based*
			Time: Static or dynamic	Time: Static or dynamic	Time: Static or dynamic	Time: Static or dynamic

			Geography: Country/region/others	Geography: Country/region/others	Geography: Region where the vehicle is registered	Geography: Country/region/others
			Data: secondary or primary *	Data: secondary or primary *	Data: secondary or primary *	Data: secondary or primary *
Level 2	strategy	multiple approache s possible	Method: location based or market based*	Method: location based or market based*	Method: location based or market based*	Method: location based or market based*
			Time: Static or dynamic	Time: Static or dynamic	Time: Static or dynamic	Time: Static or dynamic
			Geography: Country/region/others	Geography: Country/region/others	Geography: Region where the vehicle is registered	Geography: Region where the vehicle is registered
			Data: secondary or primary *	Data: secondary or primary *	Data: secondary or primary *	Data: secondary or primary *
Level 3	reporting	single fixed approach	Method: Market-based (Hotspot) & location-based	Method: Market-based (Hotspots) & location-based	Method: Location based or market based**	Method: Location based or market based **
			Time: Static	Time: Static	Time: Static or Dynamic***	Time: same approach thas was used for Use stage
			Geography: Production place	Geography: Production Place	Geography: Region where the vehicle is registered	Geography: same approach thas was used for Use stage
			Data: Secondary and primary (Hotspots)	Data: Secondary and primary (Hotspots)	Data: Secondary or primary	Data: Secondary and primary ****
Level 4	reporting	single fixed approach	Method : Market-based	Method : Market-based	Method: Location based or market based**	Method: Location based or market based **
			Time: Static	Time: Static	Time: Static or Dynamic***	Time: same approach thas was used for Use stage
			Geography: Production place	Geography: Production Place	Geography: Region where the vehicle is registered	Geography: same approach thas was used for Use stage
			Data: Primary	Data: Primary	Data: Secondary or primary	Data: Secondary and primary ****

* if appropriate

** possibility to declare specific contracts as additional information
(e.g. contract with customers, statistic data)

*** to be defined by the regional authorities or IEA

**** at the time of first-time vehicle registration

5.11.2 Waste treatment, disposal and recycling modelling

Any GHG emissions arising from the treatment of production waste shall be included in the total CFP. Waste can be generated during different stages of a product's life cycle (cradle-to-grave), including:

- Resource extraction, raw material sourcing;
- Production of materials, semi-finished products;
- Production of vehicles, vehicle parts and components;
- Logistics to supplier, OEM, customer and recycler (including internal logistics);
- Use stage
- EoL of the vehicle.

All inputs and outputs shall be fully considered in the calculation of the product carbon footprint. Cut-off rules as described in 5.8 shall be applied.

The party generating waste is responsible for treatment until final disposal (e.g. incineration or landfill). This is also referred to as the "polluter pays principle".

If there is no final disposal, then the further processes are attributed to the company using the recycled or reused material flow as a secondary material (see section 5.11.2.1).

The impact of preparatory steps and supporting activities such as collection, transportation, sorting, dismantling, or shredding shall be added to the inventory results of the product system generating the waste.

The impact of the process treating waste with energy recovery (e.g., incineration) shall be added to the inventory results of the product system that generated the waste treated in the process. Burdens and benefits coming from energy recovery are calculated based on section 5.11.2.2.

Production processes may also generate material scrap that is recycled. In this case, please see section 5.11.2.1.

Use stage waste and EoL waste should be treated as described in 5.11.2.2 and 5.11.2.3.

5.11.2.1 Material recycling modelling

The Circular Footprint Formula (CFF) or Recycled Content Method (RCM) shall be applied to the evaluation of material recycling for all levels, based on regulation or market observation. The selected method shall be clearly indicated in the vehicle CFP declaration.

The material part of the CFF, as originally introduced in the EC recommendation 2021/2279 Annex I, can be rearranged as sum of the three components, having, overall, the same mathematical results of the original CFF introduced in the EC 2021/2279 Annex I⁸ and “UNECE A-LCA CFF”³⁰ concept.

The rearranged CFF is composed by the following three elements:

- (a) Production burdens (this term constitutes the RCM method);
- (b) Burdens and benefits related to secondary material input;
- (c) Burdens and benefits related to secondary material output.

CFF term:

$$(1 - R_1)E_V + R_1 \times \left(AE_{rec} + (1 - A)E_V \times \frac{Q_{sin}}{Q_p} \right) + (1 - A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right) \quad (7)$$

Rearranged structure of the CFF, as introduced in these guidelines.

1.) Production burdens:

$$(1 - R_1)E_V + R_1 \times E_{rec} \quad (8)$$

as Recycled Content Method (RCM)

2.) Burdens and benefits related to secondary material input:

$$-(1 - A)R_1 \times \left(E_{rec} - E_V \times \frac{Q_{sin}}{Q_p} \right) \quad (9)$$

3.) Burdens and benefits related to secondary material output:

$$(1 - A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right) \quad (10)$$

as Modular Burdens and Benefits method (MBBM) which is the sum of 2) and 3)

30 <https://wiki.unece.org/spaces/trans/pages/172852228/Automotive+-+Life+Cycle+Assessment+A-LCA>

When applying the CFF related to material, in the production stage for materials and parts, the RCM term (corresponding to CFF part 1) shall be evaluated. For the complete vehicle (Cradle-to-Grave scope) CFF in addition to CFF part 1, the emission shares from recycling (corresponding to CFF parts 2 and 3) shall be evaluated with the Modular Burdens and Benefits Method (MBBM) term in the EoL stage.

Overall, the terms of the CFF concept for material recycling have been defined as follows:

$$CEF_M = CEF_{M,CFF} = CEF_{M,RCM} + CEF_{M,MBBM} \quad (11)$$

Where:

- CEF_M means GHG emission factor of a material in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]
- $CEF_{M,CFF}$ means GHG emission factor of a material calculated with the CFF in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]
- $CEF_{M,RCM}$ means GHG emission factor of a material calculated with the RCM in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]
- $CEF_{M,MBBM}$ means GHG emission factor of a material calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

The $CEF_{M,RCM}$ and $CEF_{M,MBBM}$ emission contributions are defined as follows:

$$CEF_{M,RCM} = (1 - R_1)E_V + R_1 \times E_{rec} ; CFF \text{ part 1} \quad (12)$$

$$CEF_{M,MBBM} = -(1 - A)R_1 \times \left(E_{rec} - E_V \times \frac{Q_{sin}}{Q_p} \right) + (1 - A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right); CFF \text{ part 2 and 3} \quad (13)$$

Where:

- A means the allocation factor of burdens and credits between supplier and user of recycled materials.
- Q_{sin} means the quality of the ingoing secondary material or parts, i.e. the quality of the recycled material at the point of substitution.
- Q_{sout} means the quality of the outgoing secondary material or parts, i.e. the quality of the recyclable material at the point of substitution.
- Q_p means the quality of the primary material or parts, i.e. quality of the virgin material.
- R_1 means the proportion of material input to the product that has been recycled from a previous system. [%]
- R_2 means the proportion of the material in the product that will be recycled (or reused) in a subsequent system. [%]
- E_{rec} means the specific emissions and resources consumed (per unit of analysis) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process. [kg CO₂eq/kg_{material}]
- E_{recEoL} means the specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process. [kg CO₂eq/kg_{material}]

- E_V means the specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material [kg CO₂eq/kg_{material}]
- E_V^* means the specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials. [kg CO₂eq/kg_{material}]

In the case of CFF application, both $C_{M,RCM}$ which is total RCM value specified in section 6.1. and $C_{M,MBBM}$ which is total MBBM value specified in section 6.4. shall be reported as the part of the total vehicle CFP. The materials to which the CFF is applied shall be reported.

In the case of RCM application, only $C_{M,RCM}$ shall be evaluated in the material production stage and reported in the total vehicle CFP.

The meaning and definition of the parameters of the CFF are the same as those reported in the EC recommendation 2021/2279 Annex I.

Data set ($E_V, E_V^*, E_{rec}, E_{recEoL}$) to be used in CFF and CFF parameters ($A, R_1, R_2, Q_{sin}, Q_{sout}, Q_p$) may be referred to the secondary data set and reference documents in section 6.4.

Parts recycling modelling is specified in section 6.4.

5.11.2.2 Incineration with energy recovery

The incineration with energy recovery shall be evaluated by following the energy formula in the Circular Footprint Formula (CFF, see equation (14)).

In the case in which only RCM was applied in the material recycling modelling defined in section 5.11.2.1, the incineration with energy recovery shall be evaluated by following equation:

$$CEF_I = (1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) = (1 - B)R_3 \times (E_{ER} - CEF_{I,MBBM}) \quad (14)$$

Where:

- CEF_I means the specific GHG emissions of a material arising from incineration with energy recovery in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]
- $CEF_{I,MBBM}$ means the specific GHG emissions related to the credit obtainable by an energy recovery process calculated per MBBM for energy in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]
- B means the allocation factor of energy recovery processes.
- R_3 means the proportion of the material in the product that is used for energy recovery at EoL.
- E_{ER} means the specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery). [kg CO₂eq/kg_{material}]
- $E_{SE,heat}$ means the specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source (heat). [kg CO₂eq/MJ]
- $E_{SE,elec}$ means the specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source (electricity). [kg CO₂eq/MJ]

$X_{ER,heat}$ means the efficiency of the energy recovery process for heat.
 $X_{ER,elec}$ means the efficiency of the energy recovery process for electricity.
 LHV means the Lower Heating Value of the material in the product that is used for energy recovery. [MJ/kg_{material}]

Thermal energy deduction ($-LHV \times X_{ER,heat} \times E_{SE,heat}$) and electric energy deduction ($-LHV \times X_{ER,elec} \times E_{SE,elec}$) shall be evaluated and merged as Modular Burdens and Benefits method for energy.

C_I which is total GHG emissions arising from incineration with energy recovery shall be reported as the part of the total vehicle CFP. In addition, $C_{I,MBBM}$ which is total MBBM value for energy specified in section 6.4. shall be reported separately, as single contributions to the overall C_I . The materials contained in the product that are sent to incineration with energy recovery shall be reported.

The meaning and definition of the parameters of the CFF are the same of the ones reported in the EC recommendation 2021/2279 Annex III.

Data set ($E_{ER}, E_{SE,heat}, E_{SE,elec}$) to be used in CFF and CFF parameters ($B, R_3, X_{ER,heat}, X_{ER,elec}, LHV$) may be referred to the secondary data set and reference documents in section 6.4.

5.11.2.3 Disposal

The disposal shall include all of residue treatment except for the material recycling and the incineration with energy recovery, which leaves e.g. landfill. The disposal shall be evaluated by following disposal formula in Circular Footprint Formula (CFF, see equation (15))

In the case in which only RCM was applied in the material recycling defined in section 5.11.2.1, the disposal shall be evaluated by following equation:

$$CEF_D = (1 - R_2 - R_3) \times E_D \quad (15)$$

Where:

CEF_D means GHG emission factor of a material arising from the disposal in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

R_2 means the proportion of the material in the product that will be recycled (or reused) in a subsequent system. [%]

R_3 means the proportion of the material in the product that is used for energy recovery at EoL.

E_D : means the specific emissions and resources consumed (per functional unit) arising from disposal of residue material at the EoL of the analysed product, without energy recovery. [kg CO₂eq/kg_{material}]

The meaning and definition of the parameters of the CFF are the same of the ones reported in the EC recommendation 2021/2279 Annex III.

Dataset (E_D) to be used in CFF and CFF parameter (R_2, R_3) may be referred to the secondary data set and reference documents in section 6.4.

5.11.3 Transport and Logistics

Government authorities may establish, within their respective territories, how emissions from transport and logistics are calculated.

In addition to emissions from production, manufacturing, use stage and EoL, there are also emissions from the transport and logistics of vehicles, products, or materials.

Emissions from transport shall cover emissions from well to wheel, i.e., the system boundaries span from energy provision, production and distribution ending at the transport operation itself, and should be compliant with section 5.7. Emissions from all means of transport, such as ships, planes, and trucks, shall be included.

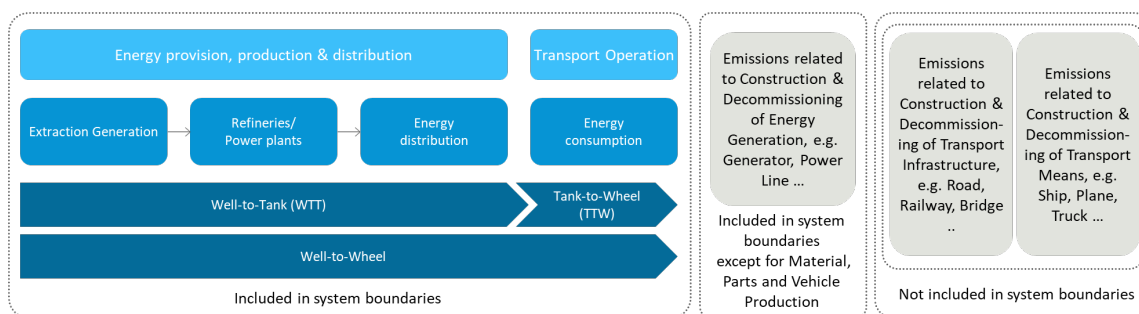


Figure 11: System boundaries for transport

In case of transport chains (transport of a product by more than one transport mode) the chain links shall be individually quantified and subsequently summed up.

The ultimate approach of quantifying transport emissions shall be based on measuring the fuel and energy consumption of a trip and multiplying it by the emission factor of the fuel/energy that covers all upstream emissions of the fuel/energy. Only transport emissions quantified on the basis of measured fuel/energy consumption shall be considered as primary data. In case of collective transport, the primary data based transport emissions require allocation to the individual product. Such allocations do not change the classification of emission data as being primary data.

Direct measurement of fuel/energy consumption of a transport operation may however not always be possible and modelling transport emissions is required. Calculation of transport emissions shall follow the recommendation set out in the GLEC Framework V3.1 or latest, except for the mandate to include emissions from the construction and dismantling of energy infrastructure. The GLEC framework allows for three approaches to establish transport distances: Shortest feasible distance (SFD), great circle distance (GCD) and actual distance. These approaches shall be used according to the following hierarchy:

- (a) Actual distance
- (b) SFD
- (c) GCD

Emissions reduction from the use of low-carbon fuels may only be claimed if a statement of sustainability (origin and emissions reduction) for the fuel is provided as issued by a bonded warehouse.

5.12 Determination of Vehicle CFP

Accurately estimating the CFP of vehicles is essential for understanding their environmental impact and guiding efforts to reduce emissions, ultimately contributing to the decarbonisation of the automotive industry.

Vehicles are highly complex products composed of numerous parts manufactured through complex supply chains. Each vehicle's unique configuration and customisable options make providing and managing LCAs for individual vehicles administratively burdensome for OEMs and authorities. To address this, the concept of a modular approach is introduced.

Comparability is a central challenge. For Level 1 and Level 2 LCA studies, different options (vehicles, technologies, powertrains, materials) are compared

within one A-LCA study. In contrast, for Level 3 and Level 4 it is the aim to allow comparability between the individual vehicle LCA studies.

Level 1 and Level 2 LCAs are mainly conducted to support strategic decisions. It is recommended to model a vehicle which is representative of the considered entity of vehicles / vehicle fleet. Regarding all parameters relevant for the intended research question, it should have generic & average value depending on the availability of the data (e.g. public studies or literature data). For comparison of vehicle LCAs this requires special attention.

For level 3 & level 4, the objective is to rationalise the high administrative burden of LCA reporting, while a modular approach (5.12.1) ensures that the declared vehicle accurately reflects the characteristics and impacts of the entire group of vehicles, which is clearly defined. The level of detail provided should be appropriate to the level of LCA undertaken and sufficient to ensure accuracy in the determination of CO₂ emissions of the representative vehicle and comparability across reported vehicles. In moving from a generic assessment toward a more granular evaluation (level 4), the rigour, specificity and completeness of the inputs should correspondingly increase.

5.12.1 Modular Approach

Given the complexity of vehicle production and use, a ‘modular approach’ is considered for carbon footprint calculation in these guidelines. This involves separately calculating each stage of the vehicle lifecycle, according to the methodology described in “6 Methodology per life cycle stages”, and then combining the results for the given vehicle.

- (a) Production stage GHG Emissions: These emissions are associated with production, including material production, part production and vehicle assembly, they depend on the production region.
- (b) Use stage GHG Emissions: These emissions, which occur during the use stage, are well-documented in certified fuel and energy efficiency data under the specific test procedure in each region. Discrepancy between the certified value and real-world value, consumables and parts used for the scheduled maintenance, according to the manufacturer specifications, shall be considered under consistent boundaries defined by regional authority.
- (c) EoL stage GHG Emissions: These emissions, which occur during the recycling processes, depend on region of sale/use or recycling

5.12.2 Production Stage GHG emissions

Due to the large number of equipment variants for vehicles it is impractical to quantify production emissions for each vehicle individually. Alternatively, a ‘LCA group – Production’ (LGP) approach is introduced. From this LGP a representative vehicle (RV) is chosen, for which the GHG-emissions are quantified following the methodology defined in section 6.1 and 6.2.

To report on a specific vehicle configuration that is member of the LGP (declared vehicle) the GHG-emissions for production of that vehicle are calculated by a mass-based extrapolation described in section 5.12.2.3.

The procedure to identify the RV from the LGP is described in section 5.12.2.2.

The criteria that define the LGP are detailed in section 5.12.2.1.

5.12.2.1 Definition of LCA Group – Production stage

The LCA group definition shall be determined in a conservative manner, based on specific parameters as detailed below and in a way that accurately reflects the characteristics and impacts of the entire LCA group.

The representative vehicle can be more accurately reflected over time as monitoring and data collection allow for generic or proxy assumptions to be replaced with evidence-based inputs. These parameters listed below are provisional and must be subject to review. Following evaluation and sensitivity analysis, the parameters shall be reviewed and may be refined as necessary to ensure robustness, accuracy, representativeness and alignment with evolving data. The revision of the parameters should remain conservative to avoid underestimation of emissions and to safeguard the credibility and representativeness of reported outcomes.

The main factors that greatly impact the production carbon footprint of a vehicle are the body structure, powertrain, energy storage system (only in case this is present in the drivetrain system) and region of vehicle value chain.

Based on these factors, vehicles can be grouped into clusters (LCA group – production):

- (a) Vehicle Structure Family: Means a cluster of vehicles of an automobile manufacturer's vehicle fleet shall consist of vehicles that have the following features in common:
 - (i) The mass of vehicles (excluding traction battery mass) within a group should not deviate by more than $\pm 20\%$ from the midpoint mass between the lightest and heaviest vehicle in the group. This threshold should be rechecked in the next version of these guidelines.
 - (ii) Vehicles shall have a similar material composition within a clearly defined body-in-white (BIW) scope. For the purposes of defining the LCA group, the BIW scope shall include the vehicle body structure, while excluding glazing, trim, interior components, and chassis or powertrain subassemblies. Vehicles with substantially different proportions of steel and aluminium within this BIW scope shall not be grouped in the same LCA group.
 - (iii) Additional parameters will be declared by the OEMs (with justifications) if required to specify the definition of the LCA group (e.g. characteristics like vehicle type, model name, brand, marketing division, or roof line, number of doors, seats, windows or level of décor etc)
- (b) Powertrain (drive System) type: to reflect the impact of the energy storage system/traction system e.g. ICE, OVC-HEV, NOVC-HEV, PEV, FCEV and FCHV.
- (c) The region of the vehicle value chain shall primarily be defined by the location of the final vehicle assembly plant, representing a macro region or country (e.g. European Union, United States, Japan, Korea).

The defined region shall serve as a representative basis for the vehicle's value chain, reflecting typical regional production processes, energy mixes, and supply structures associated with the assembly location. Where sufficiently granular and verifiable data are available, manufacturers may refine the modelling of upstream supply chain contributions by incorporating location-specific information for key processes or components.

The modelling of the supply chain shall follow the level concept and shall ensure a level of granularity consistent with data availability and the scope of the study.

The representative vehicle's supply chain shall be demonstrably representative of the LCA group. Where supply chain data is considered relevant for demonstrating representativeness, the underlying

assumptions shall be appropriately evidenced and documented. Where representative data are used, conservative assumptions shall be applied to avoid underestimation of emissions.

If vehicles are assembled in multiple regions, separate LCA groups shall be defined accordingly.

Manufacturers shall specify the production approach (e.g. CKD, SKD, CBU), where relevant, and consider its impact on the regional representativeness of the value chain.

5.12.2.2 Representative Vehicle selection during production stage

A Representative vehicle characterizes all vehicles within a defined LGP, as specified in section 5.12.2.1.

To ensure that the *pars pro toto* approach³¹ of a RV does not deliver skewed results on GHG emissions of production within that LGP, vehicles that deviate from the standard series purpose of the LGP can be excluded from the selection with respective evidence. The RV during production stage is selected based on the highest technical mass, considering all series-available options and configurations. This mass-based approach ensures a consistent and conservative representation, independent of fluctuating customer preferences or market trends. The relevant reference parameter is the maximum curb mass excluding the driver, i.e. the minimum curb mass of the fully operational vehicle (all operating fluids, fuel tank filled to at least 90 %, without driver) plus the additional mass resulting from all series-available optional equipment. If multiple vehicles exhibit the same curb mass excluding driver within a range of $\pm 5\%$, any of these may be selected as the RV.

Additionally, equipping the vehicle with options until the maximum vehicle mass is reached secures the usage of a technically clear and conservative vehicle setup.

This approach ensures that the RV:

Reflects a conservative configuration in terms of global warming impact,

Supports consistency and comparability across vehicle LCA studies,

Aligns with the principles of transparency, technical clarity, and conservative estimation as outlined in these guidelines.

When a new vehicle development requires the creation of a new LGP comprising multiple vehicles, the representative vehicle is defined based on the vehicle with highest mass within that group.

If a newly launched vehicle configuration qualifies for inclusion within an existing LGP, its highest mass may exceed the mass of the representative vehicle by up to 5 %, consistent with the principle that within a range of $\pm 5\%$ any of these vehicles may be selected as the RV. If this allowance is used, the entire mass range shifts upwards accordingly, i.e. the lower boundary is raised by the same 5 % and vehicles below are excluded, unless declared vehicles in this lower part have already been calculated. If this threshold or the thresholds in 5.12.2.1 is exceeded, a reassessment of the representative vehicle or the creation of a new LGP shall be required.

Documentation for the choice and configuration of the representative vehicle shall be provided during the third-party certification (see verification section 8).

Important Considerations:

³¹ The phrase "*pars pro toto*" is a Latin expression meaning "a part (taken) for the whole." It refers to a figure where a specific part of something is used to represent the entire thing.

- (a) If the LGP includes vehicles with a traction battery, the battery shall be excluded from the calculation of the production emission factor. This is due to the fact that the capacity of a traction battery and its mass do not have a proportional relationship, which would distort the correlation via vehicle mass.
- (b) The carbon footprint of the traction battery, if applicable, must be calculated separately.
- (c) For the calculation of the total vehicle carbon emissions, the carbon footprint of the traction battery shall be subsequently added to the carbon emission of the vehicle production (CFP).
- (d) A same approach (a – c) should also be adopted for vehicles which have a high-pressure hydrogen storage vessel.

5.12.2.3 Production stage: Estimated value for the declared vehicles

The production emissions factors within an LGP correlate to the mass of the vehicle for a given LGP, due to similar production characteristics. The RV serves as the baseline for estimating the carbon footprint for the values of the other vehicles from the LGP, for which declaration is required.

The Production Emission Factors (EF_{Prod}) (i.e. carbon emission per kilogram of vehicle mass) is calculated by the ratio between the production stage carbon emissions of the RV and its mass (excluding the mass of the traction battery and/or hydrogen storage vessels).

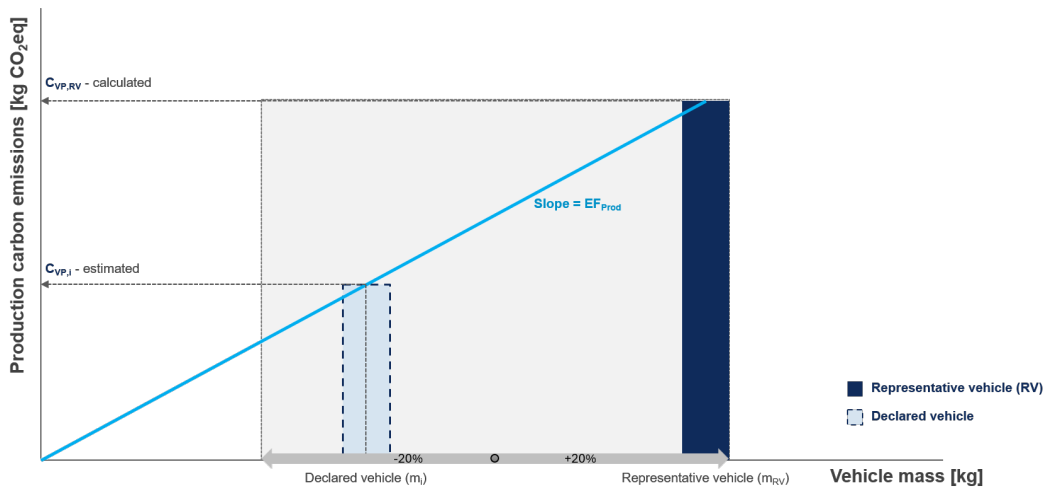


Figure 12: Explanation of the estimated value for the declared vehicle – production carbon emissions

The correlation of CFP value according to the ‘RVs’, should be allowed both below and beyond the mass of the RV,

The production stage GHG emissions for the declared vehicles within the same LGP is estimated using the following formulas:

$$C_{VP,i} = EF_{Prod} \times m_i \quad (16)$$

$$C_{VP,i} = C_{MP} + C_{PVA} + C_{TP} \quad (17)$$

Where:

$C_{VP, i}$	means the production stage carbon emission of the declared vehicle i , [kg CO ₂ eq]; including material production, component and vehicle manufacturing.
C_{MP}	means carbon emissions due to material production in kilogram of carbon dioxide equivalent [kg CO ₂ eq]
C_{PVA}	means carbon emissions due to parts production and vehicle assembly in kilogram of carbon dioxide equivalent [kg CO ₂ eq]
C_{TP}	means the carbon emissions due to transport of the fully assembled vehicle to customer in kilogram of carbon dioxide equivalent [kg CO ₂ eq]
EF_{Prod}	means the production emission factor, defined in the section 5.12.2.4 [kg CO ₂ eq/kg]; including material production, component and vehicle manufacturing. EF_{Prod} is describing the correlation between vehicle mass and the production CFP value of the RV, as defined below in 5.12.2.4.
m_i	means the actual mass of the declared vehicle (with the accessories & options).

For vehicles with traction batteries and/or hydrogen storage vessels:

$$C_{VP,i} = EF_{Prod} \times (m_i - m_{Bat/Ves}) + C_{VP,Bat/Ves} \quad (18)$$

Where:

$C_{VP,Bat/Ves}$	means the carbon emission of the traction battery or hydrogen storage vessels, [kg CO ₂ eq];
$m_{Bat/Ves}$	means the mass of the traction battery and/or hydrogen storage vessels, [kg];

5.12.2.4 Determination of Production Emission factor for vehicles

The production emission factor for vehicles (EF_{Prod}), shall be calculated as follows:

$$EF_{Prod} = \frac{C_{VP,RV}}{m_{RV}} \quad (19)$$

Where:

EF_{Prod}	means the production emission factor, [kg CO ₂ eq/kg] including material production, component and vehicle manufacturing;
$C_{VP,RV}$	means the production carbon emission of the RV, [kg CO ₂ eq]; including material production, component and vehicle manufacturing;
m_{RV}	means the actual mass of the RV, [kg];

In case of powertrain using traction battery and/or hydrogen storage vessels of the RV the emission factor shall be calculated as follows:

$$EF_{Prod} = \frac{C_{VP,RV} - C_{VP,Bat/Ves}}{m_{RV} - m_{Bat/Ves}} \quad (20)$$

Where:

$C_{VP,RV}$	means the production carbon emission of the RV, [kg CO ₂ eq]; including material production, component and vehicle manufacturing;

$C_{VP,Bat/Ves}$	means the production carbon emission of the traction battery or hydrogen storage vessels of the RV, [kg CO ₂ eq];
m_{RV}	means the actual mass of the RV, [kg];
$m_{Bat/Ves}$	means the mass of the traction battery and/or hydrogen storage vessels of the RV, [kg];

The EF_{Prod} shall be included in all relevant test reports.

The EF_{Prod} shall be rounded to 2 points of decimal, the unit is kg CO₂eq/kg.

5.12.3 Use stage GHG Emission of vehicles

GHG emissions related to use stage of the declared vehicle should be calculated according to the method described in section 6.3. These emissions are typically derived from certified fuel consumption and energy consumption data, which are included in official homologation documents and regulatory certifications.

5.12.3.1 Use stage GHG emission: Energy consumption

It is recommended to group vehicles and or powertrains in a manner consistent with emissions certification and/or type approval criteria of the region. In case of WLTP it is defined in UN GTR 15 / UN Regulation No. 154. The vehicle 'energy consumption value' of the declared vehicle should be as described in the Certificate Of Conformity or equivalent document for that vehicle.

5.12.3.2 Use stage GHG emission: Maintenance and leakage

The carbon footprint during the maintenance and leakage does not vary across powertrain families and hence it can determine this value for the selected RV of the powertrain family.

5.12.4 EoL stage GHG Emission

Due to the large number of equipment configurations for vehicles it is impractical to quantify EoL emissions for each vehicle individually. Alternatively, a 'LCA group - EoL' (LGE) approach is followed. From this LGE a representative vehicle (RV) is chosen, for which the GHG-emissions are quantified following the methodology defined in section 6.4.

To report on a specific vehicle configuration that is member of the LGE (declared vehicle) the GHG-emissions for EoL of that vehicle are calculated by a mass-based extrapolation described in section 5.12.4.3.

The procedure to identify the RV from the LGE is described in section 5.12.4.2.

The criteria that define the LGE are detailed in section 5.12.4.1.

5.12.4.1 Definition of LCA group EoL stage

The main factors that greatly impact the end-of-life carbon footprint of a vehicle is same as that of the production stage except the region of recycling. Based on these factors, vehicles can be grouped into clusters (LCA group – EoL) according to their common traits such as:

- All criteria defined for production stage emission except the region of production (see section 5.12.2.1)
- Expected region of vehicle end-of-life: the region refers to a single macro region, such as European Union, Japan, Korea, or the United States

5.12.4.2 Representative Vehicle selection during EoL stage

EoL stage representative vehicle selection is following the same process, as defined in 5.12.2.2 the “Representative Vehicle selection during production stage”

5.12.4.3 EoL stage: Estimated value for the declared vehicles

The EoL emissions factors within an LGE correlate to the mass of the vehicle for a given LGE, due to similar EoL characteristics. The RV serves as the baseline for estimating the carbon footprint for the values of the other vehicles from the LGE, for which declaration is required.

The EoL Emission Factors (EF_{EoL}) (i.e. carbon emission per kilogram of vehicle mass) is calculated by the ratio between the EoL stage carbon emissions of the RV and its mass (excluding the mass of the traction battery or hydrogen storage vessels).

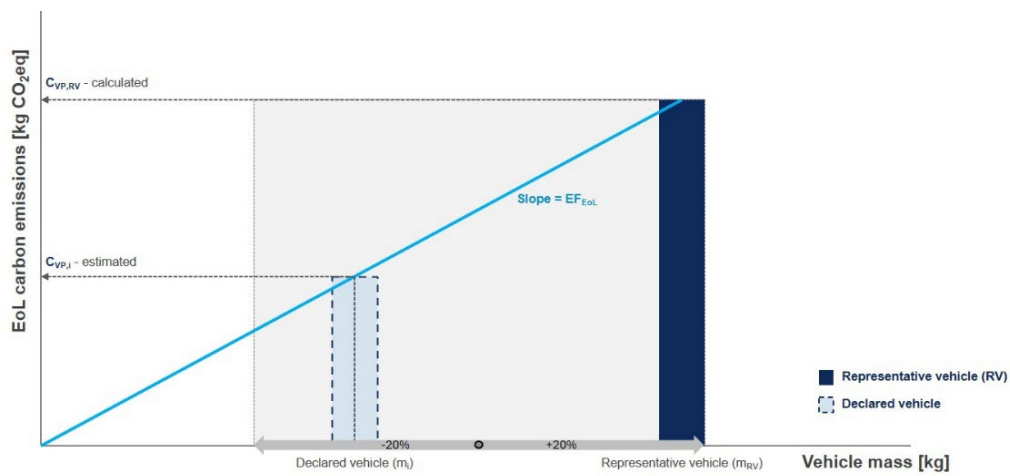


Figure 13: Explanation of the estimated value for the declared vehicles – EoL carbon emissions

The correlation of CFP value according to the ‘RVs’, should be allowed both below and beyond the mass of the RV,

The EoL stage GHG emission for the declared vehicles within the same LGE is estimated using the following formula:

$$C_{EoL,i} = EF_{EoL} \times m_i \quad (21)$$

Where:

$C_{EoL,i}$ means the EoL carbon emission of the declared vehicle, [kg CO₂eq];

EF_{EoL} means the EoL emission factor, [kg CO₂eq/kg], defined in section 5.12.4.4. Determination of EoL stage Emission factor EF_{EoL} is describing the correlation between vehicle mass and the EoL CFP value of the RV, as defined below in 5.12.4.4.

m_i means the actual mass of the declared vehicle

For vehicles with traction batteries and/or hydrogen storage vessels:

$$C_{EoL,i} = EF_{EoL} \times (m_i - m_{Bat/Ves}) + C_{EoL,Bat/Ves} \quad (22)$$

Where:

$C_{EoL,Bat/Ves}$	means the EoL carbon emission of the traction battery or hydrogen storage vessels, CO ₂ eq, [kg];
$m_{Bat/Ves}$	means the mass of the traction battery or hydrogen storage vessels, [kg];

5.12.4.4 Determination of EoL stage Emission factor

The EoL emission factor, EF_{EoL} , shall be calculated as follows:

$$EF_{EoL} = \frac{C_{EoL,RV}}{m_{RV}} \quad (23)$$

Where:

EF_{EoL}	means the EoL emission factor, [kg CO ₂ eq/kg];
$C_{EoL,RV}$	means the EoL carbon emission of the RV, [kg CO ₂ eq];
m_{RV}	means the actual mass of the RV, [kg].

In case of powertrain using traction battery or hydrogen storage vessels of the RV the emission factor shall be calculated as follows:

$$EF_{EoL} = \frac{C_{EoL,RV} - C_{EoL,Bat/Ves}}{m_{RV} - m_{Bat/Ves}} \quad (24)$$

Where:

$C_{EoL,RV}$	means the EoL carbon emission of the RV, [kg CO ₂ eq];
$C_{EoL,Bat/Ves}$	means the EoL carbon emission of the traction battery and/or hydrogen storage vessels of the RV, [kg CO ₂ eq];
m_{RV}	means the actual mass of the RV, [kg];
$m_{Bat/Ves}$	means the mass of the traction battery or hydrogen storage vessels of the RV, [kg];

The EF_{EoL} shall be included in all relevant test reports.

The EF_{EoL} shall be rounded to 2 points of decimal, the unit is kg CO₂eq/kg.

5.12.5 Total carbon footprint of declared vehicle

The configuration of a declared vehicle shall be approved by the regionally responsible authorities.

The total carbon footprint of a vehicle is the sum of:

- Production stage Emissions (see 5.12.2.)
- Production stage Emissions: Traction Battery or hydrogen storage vessels Emissions (if applicable see 5.12.2.)
- Use stage Emissions: energy consumption and maintenance (see 5.12.3.)
- End-of-Life Emissions (see 5.12.4.)
- End-of-Life Emissions: Traction Battery Emissions or hydrogen storage vessels (if applicable see 5.12.4.)

5.12.5.1 Steps to determine carbon footprint value of the ‘declared vehicle’

Step 1: Production carbon footprint (depend on mass)

- Step 1.1: Define/Identify the ‘LCA Group – Production (LGP)’ (see 5.12.2.1.)
- Step 1.2: Define/Identify an RV out of the LGP (see 5.12.2.2.)

- (c) Step 1.3: Calculate the production carbon footprint of the RV (excl. traction battery or hydrogen storage vessels)
- (d) Step 1.4: Calculate the Production Emission Factor (EF_{Prod}) of the LGP (see 5.12.2.4.)
- (e) Step 1.5: Calculate the production carbon footprint of declared vehicle (see 5.12.2.3.)
- (f) Step 1.6: Add production carbon footprint of traction battery or hydrogen storage vessels if available (see 5.12.2.2)

Step 2: Use stage carbon footprint (depends on the regional approach)

- (a) Step 2.1: Calculate the use stage carbon emissions of selected vehicle (RV or the declared vehicle) (see 5.12.3.). In cases where the WLTP is applicable the energy consumption value shall correspond to the highest emitter (vehicle test mass high) of the respective interpolation family.

These emissions are typically derived from certified fuel consumption and energy consumption data, which are included in official homologation documents and regulatory certifications.

Step 3: EoL carbon footprint (depend on mass)

- (a) Step 3.1: Define/Identify the 'EoL LCA group (LGE)' (see 5.12.4.1.)
- (b) Step 3.2: Define/Identify an RV out of the LGE (see 5.12.4.2.)
- (c) Step 3.3: Calculate the EoL carbon footprint of the RV (excl. traction battery or hydrogen storage vessels)
- (d) Step 3.4: Calculate the EoL Emission Factor (EF_{EoL}) of the LGE (see 5.12.4.4.)
- (e) Step 3.5: Calculate the EoL carbon footprint of declared vehicle (see 5.12.4.3.)
- (f) Step 3.6: Add EoL carbon footprint of traction battery or hydrogen storage vessels if available (see 5.12.4.)

Step 4: total carbon footprint

The total carbon footprint of the declared vehicle should be calculated as follows :

$$C_{tot} = C_{VP} + C_{Use\ Stage} + C_{EoL} \quad (25)$$

$$C_{VP} = C_{MP} + C_{PVA} + C_{TP} \quad (26)$$

Where:

C_{tot}	means the total carbon emission of the declared vehicle, through its entire life cycle [kg CO ₂ eq]
C_{VP}	means the production stage carbon emission of the declared vehicle, [kg CO ₂ eq], including material production, component and vehicle manufacturing
C_{MP}	means carbon emissions due to material production [kg CO ₂ eq]
C_{PVA}	means carbon emissions due to parts production and vehicle assembly [kg CO ₂ eq]
C_{TP}	means the carbon emissions due to transport of the fully assembled vehicle to consumer [kg CO ₂ eq]
$C_{Use\ Stage}$	means the use stage carbon emissions of the declared vehicle [kg CO ₂ eq];

C_{EoL}

means the EoL stage carbon emissions of the declared vehicle, [kg CO₂eq]

6. Methodology per life cycle stage

6.1 Material production stage

6.1.1 System boundaries

Figure 14 shows a system boundary of the material production stage.

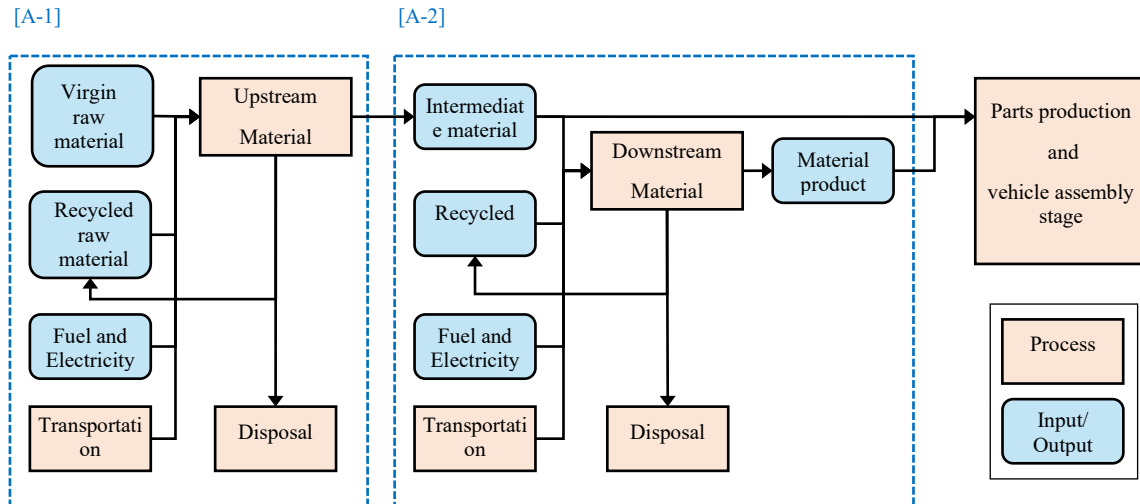


Figure 14: System boundary for materials production stage

To enable the assessment of technological progress in materials toward carbon neutrality, it is instructive to quantify the emission factors separately in accordance with the supply chain structure for upstream [A-1] and downstream [A-2] processes

[A-1] Processes related to material mining, refining, and impurity removal (defined as upstream process in material production)

[A-2] Processes related to material production (defined as downstream process in material production)

In the material production stage, an actual production flow for each automotive part shall be reflected.

These materials production stages are mainly divided into two processes.

The first is ‘upstream process in material production’ which has mining, refining, and impurity removal with relatively high CO₂ impact.

Then, ‘downstream process in material production’ which has from the intermediate material stage (e.g. crude steel, aluminium ingot) to the material product stage (e.g. steel sheet, aluminium extruded bars).

The [A-1]/[A-2] distinction is an analytical process-mapping and hotspot-management structure used to prioritise primary data collection and improvement actions; it does not constitute separate reporting categories, and the results shall be aggregated in the reported carbon footprint of the material production stage. After that, it is transferred to the Parts production and vehicle assembly stage.

System boundaries of the main dominant materials (steel, aluminium, copper, plastic, Lithium-Ion Battery) in automotive are shown in Figure 15, Figure 16, Figure 17, Figure 18 and Figure 19.

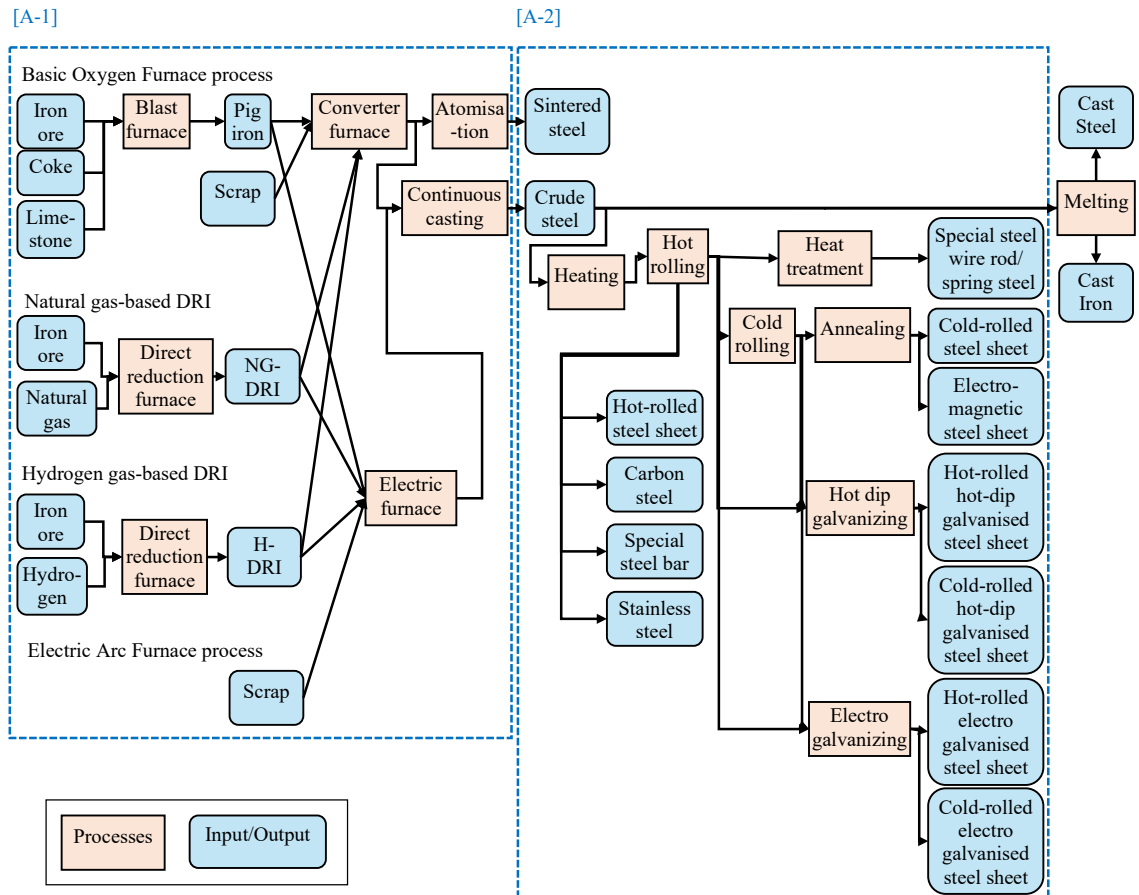


Figure 15: Example of a system boundary for steel material production

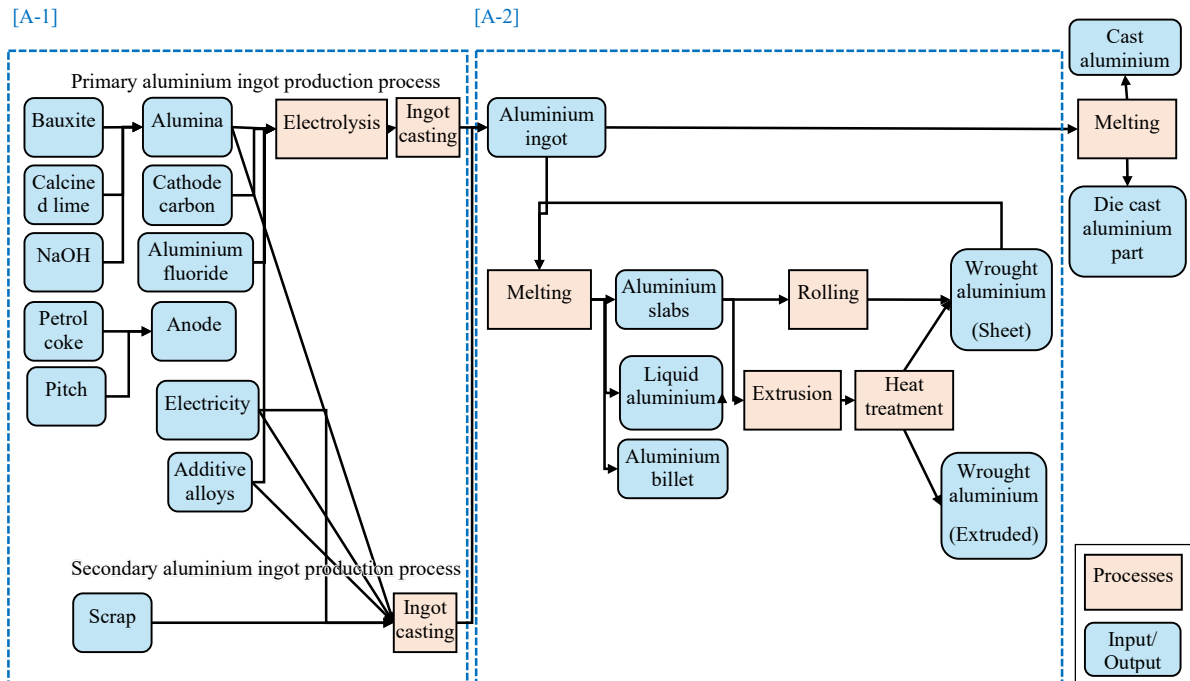


Figure 16: Example of a system boundary for aluminium material production

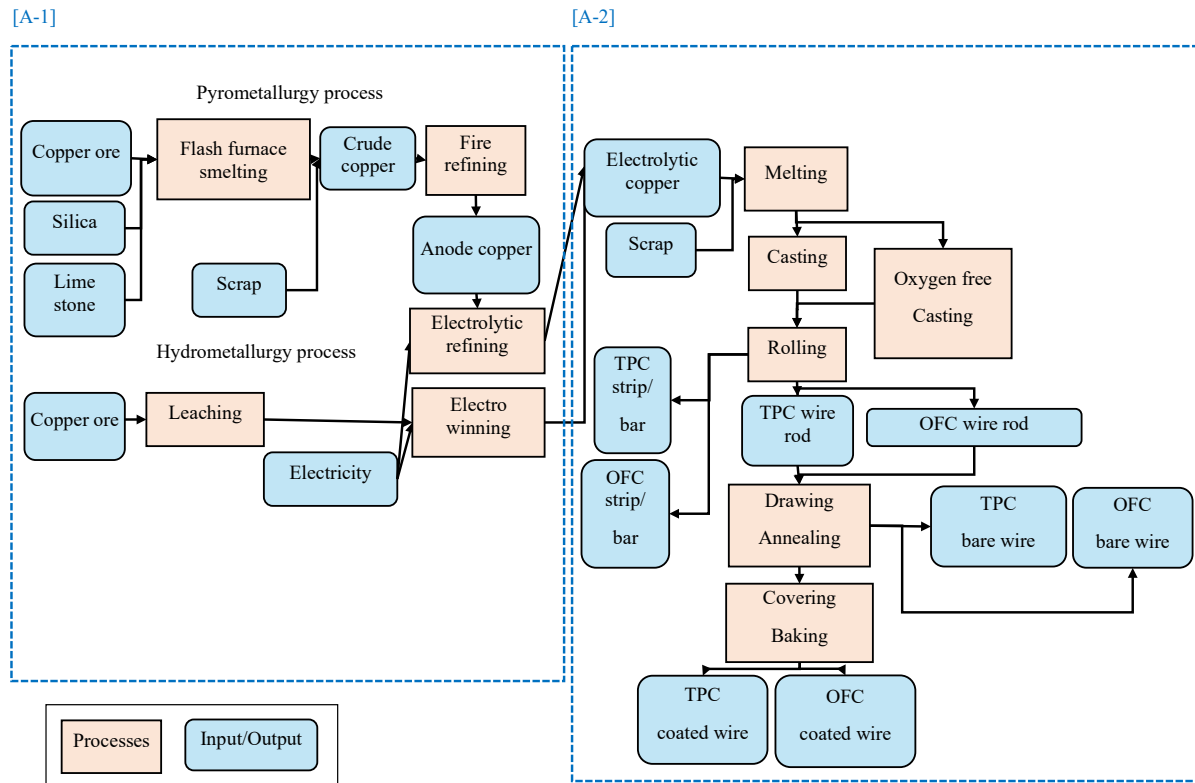


Figure 17: Example of a system boundary for copper material production

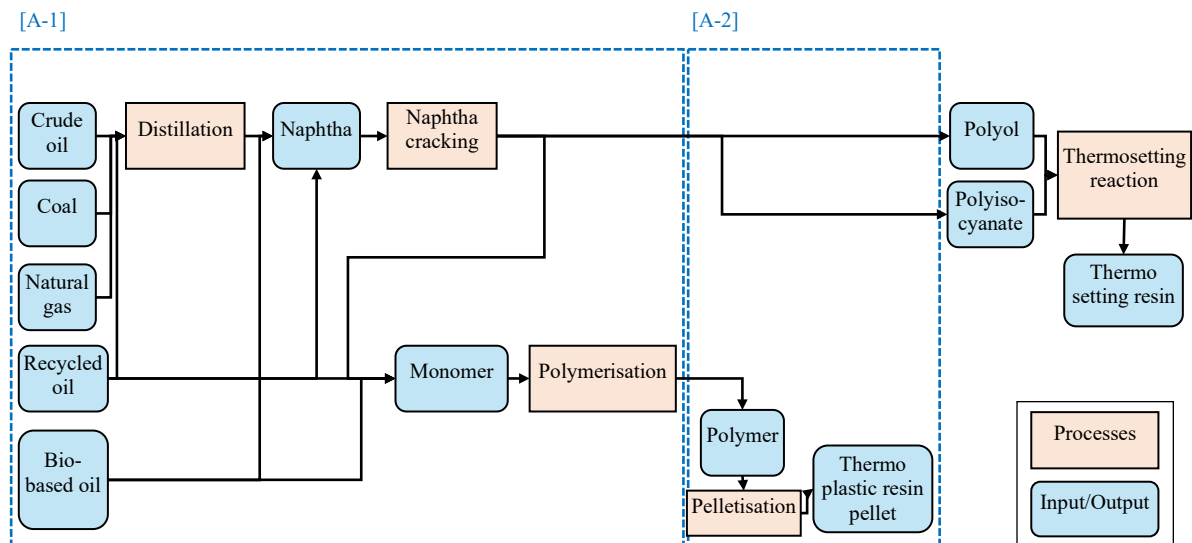


Figure 18: Example of a system boundary for plastic material production

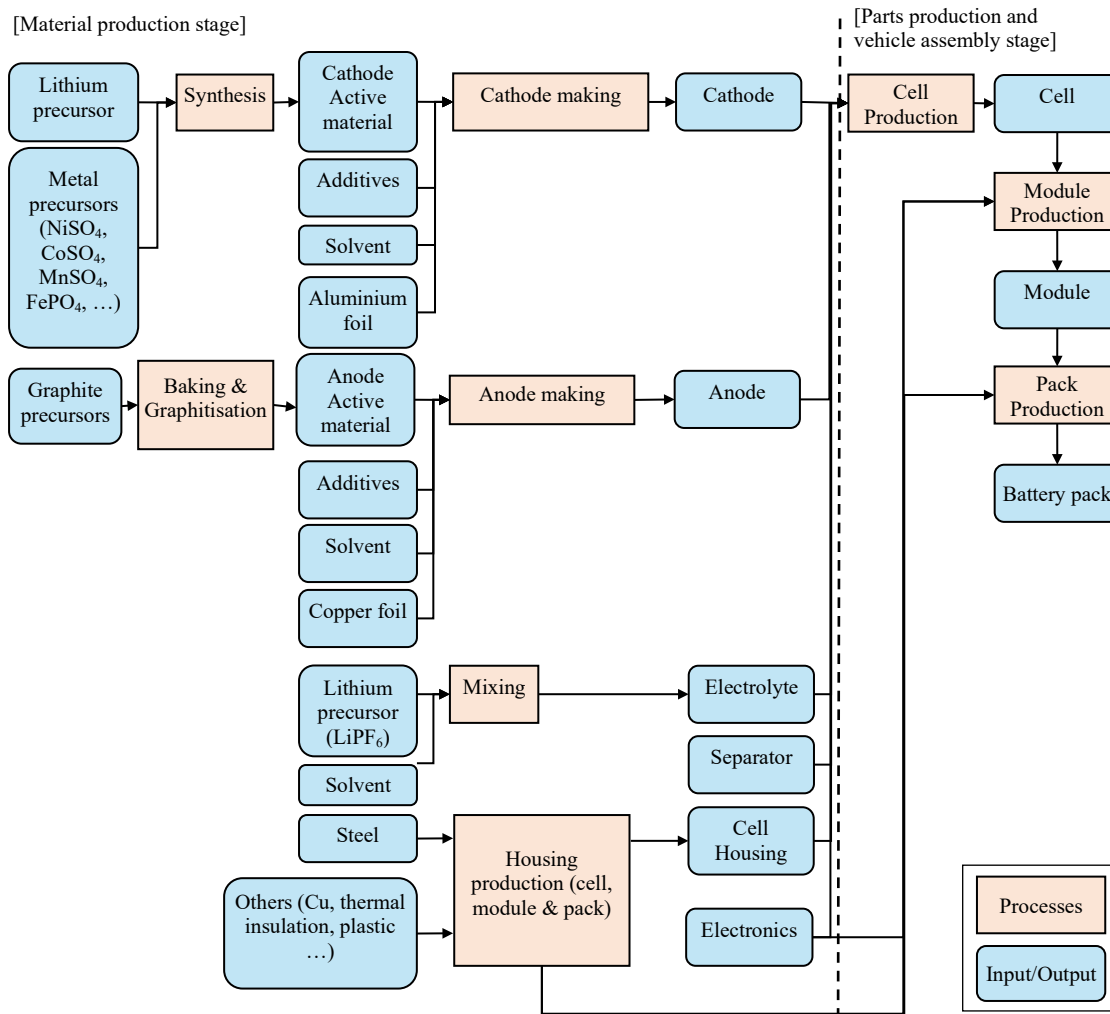


Figure 19: Example of a system boundary for Lithium-Ion Battery material production

6.1.2 Automotive material classification

Material classification is basically extracted by investigating composed materials species in typical automotive vehicle models, i.e., ICE, HEV, FCV and PEV. As material information, such as BoM, IMDS and others are referenced in worldwide automotive industry. The material classification shall be consistent throughout the life-cycle stages.

The number of material types shall be set by taking cut-off into account after practitioners calculated GHG emissions of each material to total vehicle. The cut-off criteria should be in line with section 5.8.

As a base example of material classification Table 6 shows an automotive material list.

To identify GHG emission hotspots in the material production stage, LCA practitioners shall determine the material classification and associated cut-off criteria in accordance with section 5.8 and define the system boundaries of the relevant material production processes. Especially, material upstream process is known to be relatively higher GHG emissions than material downstream process in Figure 14.

System boundaries of typically high GHG emissions materials (steel, aluminium, copper, plastic and Lithium-ion battery materials) are shown in Figure 15, Figure 16, Figure 17, Figure 18 and Figure 19 referring to the documents from international institutions e.g., worldsteel, IAI (International

Aluminium institute), EA (European Aluminium), ICA (International Copper Association), and TfS (Together for Sustainability). Since the material classification and the system boundary depends on a target vehicle specification, procedures to select material classification and to assign carbon emission factor shall be reported.

Table 6: Automotive material list

<i>Material group</i>	<i>Material classification</i>
Steel	Cast iron, cast steel, hot-rolled steel sheet, cold-rolled steel sheet, electromagnetic steel sheet, hot-rolled hot-dip galvanised steel sheet, hot-rolled electro-galvanised steel sheet, cold-rolled hot-dip galvanised steel sheet, cold-rolled electro-galvanised steel sheet, carbon steel bar/wire rod, special steel bars, special steel wire rod/spring steel, stainless steel sheet/bar, sintered steel
Aluminium	Cast aluminium, die cast aluminium, wrought aluminium (sheet), wrought aluminium (extruded)
Copper	Tough pitch bare/coated copper wire, Oxygen free bare/coated copper wire, tough pitch copper strip/bar, oxygen free copper strip/bar
Plastic	PP (Polypropylene), PE (Polyethylene), PVC (Polyvinyl Chloride), ABS (Acrylonitrile Butadiene Styrene), PA (Nylon), PC (Polycarbonate), PET (Polyethylene Terephthalate), PBT (Polybutylene Terephthalate), PUR (Polyurethane), POM (Polyacetal), ASA (Acrylonitrile Styrene Acrylate), PMMA (Acrylic resin), EP (Epoxy resin), PPS (Polyphenylene Sulphide), TPO (Thermoplastic Olefin), TPV (Thermoplastic Vulcanisate)
Non-ferrous metals	Magnesium alloy, zinc alloy, platinum/rhodium, lead, rare earth metals, other metals
Other organic materials	SBR (Styrene-Butadiene Rubber), EPDM (Ethylene Propylene Diene Monomer), other thermoplastic resins, other thermosetting resins, natural rubber, synthetic rubber, anti-rust oil, leather, adhesives
Other materials	Laminated glass, paints, electrodeposition Coating, electronic components (Populated PCB: Printed Circuit Board, i.e. substrate plus associated components like capacitors, resistors, integrated circuits etc.), engine oil, brake fluid, coolant, refrigerant, other inorganic materials, tyres, battery materials (lead-acid battery, Ni-MH battery, LiB: Lithium-ion battery)

6.1.3 Data collection and data type

Material data collection for activity and emission factor are conducted with data types of primary and secondary, and their related information as follows; material name, material classification (VDA, ISO code, and other standards), the number of materials, material mass, chemical substance composition, recycled material content, bio-based content, yield, electricity, and fuel consumption, etc.

For a material production stage, the carbon footprint shall be calculated based on per 1 kg of material products, in its respective shape but regardless of the state of matter, as its specific density is considered.

6.1.3.1 Primary data collection

The mass of the material used, its yield, and material carbon emission factor are collected as primary data e.g., BOM, MDS, and teardown data, as much as possible, considering hotspots in the system boundary. The following points should be considered to ensure transparency and accuracy.

- (a) High GHG emissions in the system boundary should be identified to clarify hotspots.
- (b) Unit process data of material production process should be confirmed
 - (i) country or region where material production was conducted
 - (ii) amount of electricity and fuel used, rate of renewable energy used
 - (iii) usage rate of recycled material and bio-based material to total material mass

The quality of primary data shall be assessed and documented, according to ISO 14067. Compliance with the relevant prerequisites shall be demonstrated either through self-declaration provided by practitioners and associated companies or through certification by independent third parties.

6.1.3.2 Secondary data collection

If primary data cannot practically be collected, secondary data shall be collected. When collecting secondary data from available databases, data quality shall be explained, and the following points should be considered to ensure transparency and accuracy.

- (a) High GHG emissions in the system boundary should be identified to clarify hotspots.
- (b) Unit process data in material production process should be confirmed.
- (c) It shall be utilised as attributional data and not be utilised as consequential data to avoid an assumption in the future
- (d) Material GHG emission factor using an allocation to multiple life cycles shall not be utilised to assure data consistency.

6.1.4 Energy Modelling

For general rules refer to section 5.11.1.

6.1.4.1 Energy Mix

Practitioners shall account for the fuel or electricity production pathways associated with the production locations of each material. (detailed methodology shall be considered)

The energy mix shall be based on the latest dataset associated with the location or region of production in question.

The methods described in section 5.11.1.2 shall guide the modelling of fuel and electricity for these regions.

6.1.5 Levels in material production stage

Table 7 shows a level concept of material production stage. The development of the assessment method will be focused only on Level 3, and for other levels, only the concept and overview will be described.

Table 7: Level concept of material production stage

<i>Level</i>	<i>Activity Data</i>	<i>Emission factor Data</i>
	<i>Material mass [kg]</i>	<i>Carbon Emission factor of Material production [kg CO₂eq/kg]</i>
Level 1	Secondary or Primary data	Secondary data

Level	Activity Data	Emission factor Data
	Material mass [kg]	Carbon Emission factor of Material production [kg CO ₂ eq/kg]
Level 2	Primary data	Secondary data
Level 3	Primary data	Primary and secondary data
Level 4	Primary data	Mainly primary data

6.1.5.1 Level 1,2

The specific GHG emissions of a material are basically calculated with material mass multiplied by carbon emission factor of the material production.

In Level 1, the material mass of the vehicle and the carbon emission factor of each material (in kg CO₂eq per kg) are secondary data. LCA practitioner should assume a proportion of each material to vehicle mass.

In Level 2, the material mass of the vehicle are primary data. The carbon emission factor of each material production are secondary data.

$$C_{M,RCM} = \sum_i (C_{MPi,RCM}) = \sum_i \left(m_{MPi,RCM} \times \frac{1}{Y_{MPi}} \times CEF_{MPi,RCM} \right) \quad (27)$$

Where:

$C_{M,RCM}$	means the specific GHG emissions of a material in carbon dioxide equivalent [kg CO ₂ eq]
i	means each material classification
$m_{MPi,RCM}$	means material mass which is mass of a material product output [kg]
Y_{MPi}	means yield which is the mass proportion of material product output compared to the material input used in material production.
$CEF_{MPi,RCM}$	means carbon emission factor of a material calculated with the RCM in kilogram of carbon dioxide equivalent per kilogram of input material production process [kg CO ₂ eq/kg _{material}] (Specified in section 5.11.2.1 Material recycling modelling)

6.1.5.2 Level 3,4

In Level 3, the specific GHG emissions of a material should be calculated with virgin material and recycled material separately based on the equation 28. When that's not possible, it is applicable to the equation 27 with the description of recycled material information.

The mass of the material and carbon emission factor should be collected as primary data as much as possible considering hotspots in the system boundary. The environmental impact shall be assessed compared to the actual process.

Another factor which affects critically GHG emissions is the electricity utilised during material production stage. LCA practitioners should account for the impacts of electricity consumption in their calculations, including regional variations in electricity grids and the use of renewable energy sources.

Finally, in Level 4 the ambition is an ideal LCA, with the goal of compiling the basic carbon emission factor of all materials as primary data. However, it is challenging to collect data on hundreds of thousands of items per vehicle. Secondary data applied due to any reason must be justified accordingly.

$$C_{M,RCM} = \sum_i (C_{MPI,RCM}) = \sum_i \left[m_{Mi} \times \frac{1}{Y_{MPI}} \times \{ R_{1i} \times CEF_{MPI,RCM,RMP} + (1 - R_{1i}) \times CEF_{MPI,RCM,VMP} \} \right] \quad (28)$$

Where:

R_1 means the proportion of material input to the product that has been recycled from a previous system. [%]

$CEF_{MPI,RCM,VMP}$ means carbon emission factor of virgin material primary data [kg CO₂eq/kg_{material}]

$CEF_{MPI,RCM,RMP}$ means carbon emission factor of recycled material primary data [kg CO₂eq/kg_{material}]

6.2 Parts production and vehicle assembly stage

6.2.1 System boundaries

The system boundary of the parts and vehicles production stage is outlined in Figure 20.

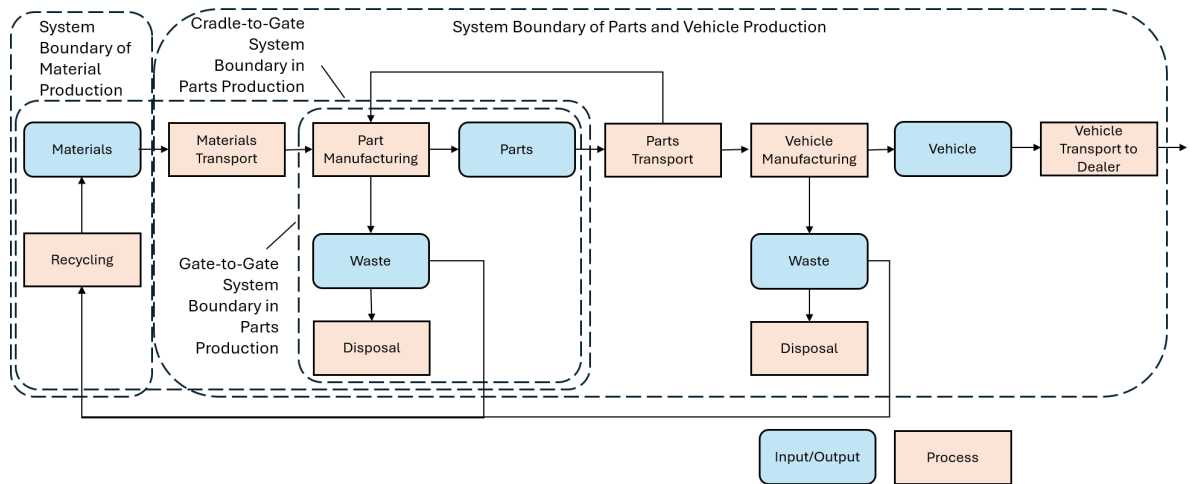


Figure 20: System boundaries for material, parts, and vehicle in production.

The system boundary for material production is generally defined by the outbound gate of the production facility where material inputs are processed to finished material or an initial semi-finished product in a tradable form, e.g. steel bar, aluminium ingot, plastic granulate.

For reporting in the supply chain, the cradle-to-gate CFP includes all attributable upstream emissions and direct emissions up to the supplier outbound gate, including all upstream transport activities.

Transport of the final assembled vehicle to the end customer is also included in the parts and vehicle production for the vehicle-level CFP and therefore to be included in the CFP of the vehicle in production.

When accounting for emissions all attributable processes shall be listed to clearly define the cradle-to-gate boundary of their studied product.

The system boundaries for parts/components and vehicle production therefore include:

- (a) Production of, semi-finished products
- (b) Production of vehicle parts and components
- (c) Auxiliary production processes (e.g., lighting, air conditioning, storage facilities)
- (d) Disposal of production waste (see 5.11.2)
- (e) Packaging of vehicle parts and components, including all operations required for performing packaging
- (f) Disposal of packaging waste (see 5.11.2)
- (g) Transport and logistics (including internal logistics and transport packaging, see 5.11.3 and 6.2.5)
- (h) Quality control in production
- (i) Energy consumption of IT for process and manufacturing control

Despite being included in the system boundaries in principle, insignificant processes may be excluded based on the cut-off rules (see 5.8).

In general, GHG emissions not connected directly to the production system relevant for the product shall be excluded from the system boundaries. These are amongst others:

- (a) Employee commuting and work travel
- (b) Research and development, administration, or sales processes
- (c) Auxiliary inputs not directly related to the production process (such as heating and lighting of associated office rooms, secondary services like maintenance, sanitary facilities, canteen services, facility management e.g., plant security and fire safety and general IT)
- (d) Auxiliary inputs to maintain the manufacturing equipment
- (e) Emissions from construction or dismantling of capital good (such as buildings, manufacturing equipment or any other infrastructure for transport, media or energy distribution and energy generation, within or outside the control of the reporting company).

6.2.1.1 Data collection and data types

Emissions shall by default be reported for the most recent year (reporting or calendar year). In case there is the intention to extend the validity period of the CFP report beyond the reference year of reporting, an annual check is recommended to ensure that data is up to date.

To perform the annual check, the screening analysis should be updated based on data for the most recent year. An update of report is recommended if the GHG emissions increase by 10% or more based on the screening analysis compared to the previous reporting period. Additionally, an update of data is mandatory in the following situations.

- (a) Structural changes in operation to the product system under study, including significant process change in operation, change in production technologies or technology advancement, as well as changes in raw material or energy supply.
- (b) Changes in calculation methodology or improvements in the accuracy of emission factors or activity data or inclusion of new types of sources that result in a significant impact on the emissions data.
- (c) Discovery of significant errors, or a number of cumulative errors that are collectively significant.

Emissions shall by default be reported as granular as the purpose of the CFP study allows for. Averaging globally or over a region, country, continent may be considered but shall be flagged as such. Reasoning shall be provided if continental or global average values are used in cases where the use of primary data is recommended.

6.2.2 Declared unit

The product carbon footprint shall be assessed for a declared unit. A functional equivalent is established by the data recipient and is defined from a product use perspective.

For countable products, i.e., a component or part, the declared unit shall be 1 piece as described in the part description including a defined mass and a unique identifier (part number).

For materials, i.e., mass products or commodities, the declared unit shall be 1 kg of products, in its respective shape but regardless of the state of matter (solid, liquid, gas), as its specific density is considered.

If packaging is included, the declared unit is 1 kg or 1 piece of unpackaged product at the factory gate. The PCF however includes the PCF contribution of packaging.

For parts suppliers (Tier 1 to n), the declared unit shall be 1 piece (or 1 kg for materials) at the factory gate under a Cradle-to-Gate scope. For the vehicle manufacturer the declared unit is the fully assembled vehicle delivered to customer.

6.2.3 Life Cycle Group of Parts

Components or parts in the automotive supply chain are often customized, so that suppliers have a large number of variants of almost identical parts. It is impractical to quantify production emissions for each part individually. Therefore, analogous to the LCA group – Production for vehicles, an ‘LCA group’ approach is introduced also for parts (LGPP).

To report on a specific part (declared part) that is a member of the LGPP the GHG-emissions for production of the declared part is calculated by interpolation as described in section 6.2.3.2.

Unlike for vehicles the part group approach is limited to the production of parts and is not applied to subsequent life cycle stages.

6.2.3.1 Definition of Part Group (LGPP)

The LCA group definition for parts shall be determined in a conservative manner, based on common features to ensure that GHG impact of parts from that group can be accurately reflected by a specific characteristic.

Part Group: Means a cluster of parts that have the following features in common:

- i. The same main function
- ii. The same product standards and technical specifications
- iii. The same manufacturing technology, processes, and materials
- iv. The same supply routes:

Materials and intermediate products are purchased from the same suppliers. The GHG emissions which occur at each location must be proportionally considered based on the location’s specific contribution to the part’s manufacturing

emissions. The modelling of the supply chain should follow the level concept, and should ensure the use of appropriately granular information, in line with the level at which the study is undertaken. If parts are assembled in multiple regions, weighing by part numbers shall be applied.

Additional parameters will be declared by the supplier (with justifications) if required to specify the definition of the LGPP. The LGPP must be appropriately evidenced and documented. The concept of LGPP is referred to as “homogeneous parts” in other CFP-guidelines.

A part group can be substantiated if a physical product characteristic can be identified that differentiates otherwise similar parts systematically with respect to GHG emissions and can be proven by a sensitivity analysis. The physical characteristic could e.g. be the mass of parts as it is done on vehicle level. It is however justified for parts to not limit the physical characteristic to the mass of parts only. Further examples for the physical characteristics could be diameter, length, volume etc. of parts.

GHG emissions for part group allow for a linear regression with respect to the differentiating characteristic that renders a coefficient of determination $R^2 > 90\%$. Cut-off rules (see 5.8) apply for the calculated GHG emissions.

The sample size to prove interpolation quality shall be $n \geq 5$.

6.2.3.2 GHG emissions of the declared part from a LGPP

GHG emissions for the declared part from a LGPP shall be calculated by interpolation only as shown in Figure 21. A LGPP may be defined on the basis of an intermediate product, if the final product to market is produced by varying add-on parts to the intermediate product or additional process steps, e.g., specific painting processes, additional leak tests or washing processes. For the additions in parts or processes to the intermediate product the respective CO₂ contribution shall be added to the final GHG emissions. For the calculation of the primary data share, data does not need to originate from the product system under study, because primary data might relate to other part from the LGPP.

The proof of a LGPP shall be documented and provided to customers on request. A review of the proof shall be performed after five years at the latest.

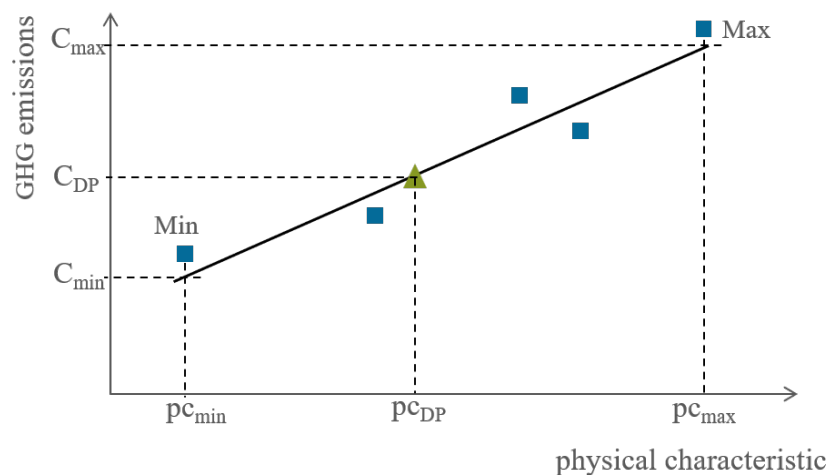


Figure 21: Interpolation for GHG emissions of the declared part

The calculation of GHG emissions declared part is given by:

$$C_{DP} = C_{min} + EF_{LGPP} * (pc_{DP} - pc_{min}) \quad (29)$$

Where:

C_{DP}	means carbon emissions of the declared part [kg CO ₂ eq]
C_{min}	means carbon emissions at the minimum of the physical characteristic interval that defines the LGPP [kg CO ₂ eq]
EF_{LGPP}	means carbon emissions factor that results from the linear regression analysis of the LGPP
pc_{DC}	means the value of the physical characteristic representative for the declared part
pc_{min}	means minimum value of the physical characteristic interval that defines the LGPP

6.2.4 Energy modelling

For the general rules reference is made to section 5.11.1.

6.2.5 Transport & logistics

This section deals with transportation from a supplier to its customer. The general rules for logistics apply (see 5.11.3).

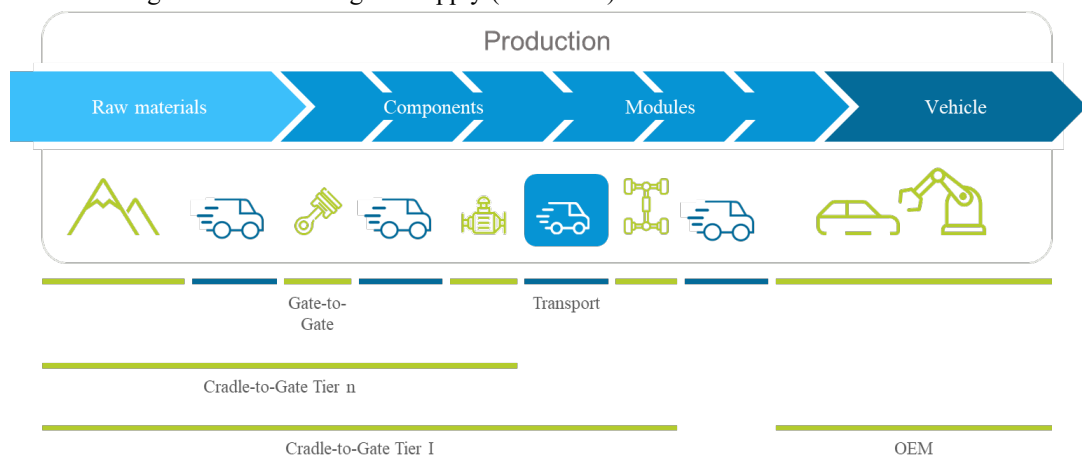


Figure 22: Definition of scopes

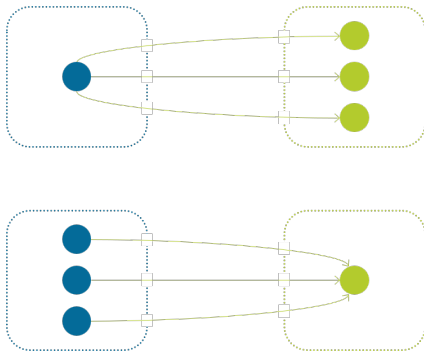
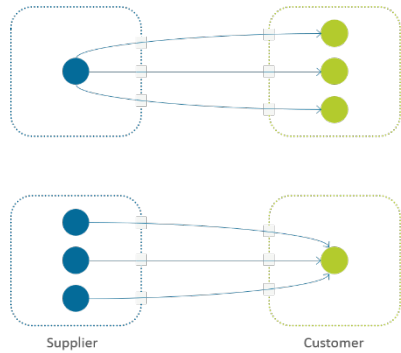
As for the product carbon footprint, the cradle-to-gate boundaries end at the suppliers' outbound gates (cf. section 6.2.1). This boundary applies independently from the responsibilities in economic or operative terms for transportation processes.

In case the transport details are known the following paragraph defines the reporting responsibilities of supplier and customer.

Nonetheless, if a supplier is responsible in economic or operative terms for the outbound logistics (i.e., transportation from the supplier to its customer), the supplier shall report the product carbon footprint from this transportation in addition to and separately from the product carbon footprint (Table 8). Otherwise, the customer shall account for transportation between the supplier's and its own shipping site (factory gate or distribution centre, see Figure 23 and Figure 24).

The table below describes different cases of responsibility and accountability for transportation from supplier to next tier:

Table 8: Transportation between supplier and customer.

Case	Description	Economic/operative responsibility for transportation from supplier to customer	Accounting for transportation emissions
1	Multiple shipping sites, and/or multiple unloading sites  Supplier Customer	Inbound transportation contracted or operated by customer	Customer responsible for quantification of transportation emissions. As for multiple transportation relations, emissions shall be attributed by mass between the respective products
2	Multiple shipping sites, and/or multiple unloading sites  Supplier Customer	Outbound transportation contracted or operated by supplier	Transportation emissions to be reported separately by supplier to the customer (additionally to supplier's PCF). As for multiple transportation relations, emissions shall be attributed by mass between the respective product

Transports from production sites to suppliers' distribution centres are deemed as suppliers' in-house logistics, i.e., the distribution centre is regarded as the shipping point. Transports from customers' distribution centres to production sites are deemed as customers' in-house logistics, i.e., the distribution centre is regarded as the unloading point (see Figure 23).

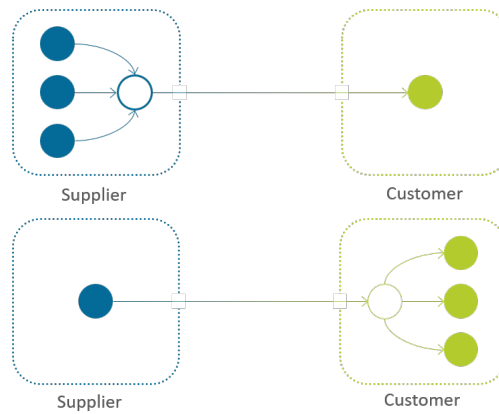


Figure 23: Distribution centre on supplier or customer side

Regardless of whether transportation emissions are quantified by a supplier or a customer, they shall be consolidated within the customers' CFPs. Transport of the fully assembled vehicle from the final assembly site to customer shall be covered

6.2.6 Levels in parts production and vehicle assembly

The analysis of global warming potential can also be carried out for parts production and vehicle assembly in different levels of detail. In case the goal of the analysis is e.g. concerned with mobility concepts rather than individual vehicles or the specific details of the vehicle production are not the main interest, an archetypal vehicle production is included in the analysis. The carbon footprint of parts production or vehicle manufacturing can thus reflect:

- (a) an average for a vehicle fleet (various segments, models on global or national level) → typical for Level 1
- (b) an average for vehicles of a specific segment (various models on global or national level) or a vehicle chosen as representative for a specific segment both based on BoM-Data → typical for Level 2
- (c) an average for specific vehicle models (with different equipment variants on global, national or local production site level) → typical for Level 3
- (d) a specific vehicle model. → typical for Level 4

In the ideal case, the average values are calculated as weighted averages of a population of individual vehicles. If the analysis of the individual vehicle were based on real emission data (primary data), even the averages would reflect the correct averages of real emissions. As there is no abundance of analysis data on individual vehicles very often the average vehicle is defined by assumptions and modelling, and secondary data is used to quantify the environmental impact.

Within these guidelines four levels detail are differentiated.

6.2.6.1 Level 1

As described in section 2.2 there are multiple approaches possible for Level 1, this section describes the minimum standard for calculation. GHG emissions due to the production of vehicle parts and vehicle assembly are quantified with a (lump) carbon emission factor which is a related of net vehicle mass. All specific emission effects due to different materials, gross material input, different production processes or transport of parts or vehicles are included in the carbon emission factor. The calculation of GHG emissions from vehicle parts production and vehicle assembly is given by:

$$C_{PVA} = CEF_{PVA} \times m_{NM} \quad (30)$$

Where:

C_{PVA}	means carbon emissions due to parts production and vehicle assembly up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]
CEF_{PVA}	means carbon emission factor of parts/components and vehicle manufacturing per kilogram of vehicle net mass [kg CO ₂ eq/kg _{NM}]
m_{NM}	means the net mass of the vehicle in kilogram [kg], i.e. mass of the vehicle in running order minus the mass of the driver minus the mass of any fluids and fuels.

The CEF_{PVA} may be determined from literature, OEM publications or secondary databases. The factor may reflect geographical differences, if there is evidence that parts/component and vehicle production is more CO₂eq-intensive in some parts of the world than in others. For transparency all the factors used in calculation shall be reported.

6.2.6.2 Level 2

GHG emissions due to the production of vehicle parts and vehicle manufacturing are quantified by breaking down the vehicle as delivered to the customer by mass of materials. Breaking down by material is common in automotive industry because material and mass declaration systems are mandatory for decades.

The calculation of GHG emissions from vehicle parts production and vehicle assembly is given by:

$$C_{PVA} = C_{OP} + \sum_i (CEF_{PVA,i} \times m_{i,i}) \quad (31)$$

Where:

C_{PVA}	means carbon emissions due to parts production and vehicle assembly up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]
C_{OP}	means carbon emissions due to manufacturing processes at the OEM [kg CO ₂ eq]
$CEF_{PVA,i}$	means carbon emission factor of parts/component manufacturing of material i [kg CO ₂ eq/kg _i]
m_i	means the net mass of material i in the vehicle [kg].

All specific emission effects due to different production processes, production rejects or transport of parts or vehicles are included in the carbon factor. C_{OP} may be determined from literature or OEM communication. For transparency all the factors used in calculation should be reported.

6.2.6.3 Level 3

The contribution of different subsystems of a vehicle to the GHG emissions of vehicle production is by far not evenly distributed. Accounting for these most relevant subsystems in terms of GHG emissions from vehicle production (so called 'hotspots') in a more detailed manner differentiates Level 3 from Level 2 in the calculation of the cradle-to-gate vehicle carbon footprint.

For a hotspot, company-specific (OEM-specific / supplier-specific) data shall be used for at least one material or component of choice.

This means, for the selected component / material:

- (a) for at least one process at OEMs' and/or preceding suppliers' production sites (depending on availability and vertical integration);

- (b) it is required to collect primary information,
- (c) which is then utilised for the calculation of the cradle-to-gate carbon footprint.

The selected component as well as the chosen process or material or supplier component shall be named including type of primary information collected.

As a recommendation for the choice of hotspots, the following aspects should be considered:

- (a) parts/components of interest: e.g. body-in-white, traction battery, wheel rims, tyres,
- (b) parts/components with high content of materials of interest: e.g. steel, aluminium,
- (c) parts/components with production processes of interest: e.g. painting, deep drawing.

For hotspot primary data-based reporting is the preferred approach and the use of available site-specific primary data is mandated. In case primary data cannot be obtained, secondary data shall be used. Secondary data shall be traceable and based on field survey data and designated by government authorities or intergovernmental institutions (e.g. UNEP GLAD), if available.

The calculation of GHG emissions from vehicle parts production and vehicle assembly is given by:

$$C_{PVA} = \sum_i (C_{HS,i}) + C_{BV} \quad (32)$$

Where:

C_{PVA}	means carbon emissions due to parts production and vehicle assembly in kilogram of carbon dioxide equivalent up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]
C_{HS}	means the carbon emissions due to manufacturing of hotspot subsystems and their assembly to the vehicle up to the vehicle manufacturer's outbound gate [kg CO ₂ eq] Index i refers to a specific hotspot subsystem. For the GHG calculation method refer to 5.10.2.
C_{BV}	means all carbon emissions due to component production, and vehicle manufacturing except for those components and parts of the vehicle defined as hotspots up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]. For the GHG calculation methods for each component, refer to 6.2.6.2.

C_{HS} is calculated according to Level 4 definitions. C_{BV} for the remaining vehicle materials, parts and production processes excluding hotspots follow the calculation defined for Level 2. Intermediate transport operations are covered by C_{HS} and C_{BV} .

6.2.6.4 Level 4

GHG emissions due to the production of vehicle parts and vehicle assembly are quantified by a stepwise attributional reporting of real emissions (site-specific, primary data) for the material and components along the supply chain until the final assembly in the vehicle. For each Tier level this requires to add the GHG emissions for the manufacturing of a product in its own operations to the sum of GHG emissions of the purchased parts or materials for that product. Transport within the supply chain is accounted according to the definitions in sections 5.11.3 and 6.2.5.

The calculation of GHG emissions from vehicle parts production and vehicle assembly is given by:

$$C_{PVA} = \sum_i (C_{TP1,i} + C_{T1,i}) + C_{op} \quad (33)$$

$$C_{Tj} = \sum_i (C_{TPj-1,i} + C_{Tj-1,i}) + C_{op,j} \quad (34)$$

Where:

C_{PVA}	means carbon emissions due to parts production and vehicle assembly up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]
C_{op}	means the carbon emissions due to manufacturing processes at the OEM up to the vehicle manufacturer's outbound gate [kg CO ₂ eq]
C_{TP1}	means the carbon emissions due to transport from Tier 1 supplier to the OEM [kg CO ₂ eq] per part
C_{T1}	means the carbon emissions reported from the Tier 1 supplier for supplied parts [kg CO ₂ eq] per part
C_{Tj}	means the carbon emissions reported from the Tier j supplier for the component production of supplied parts [kg CO ₂ eq]
C_{TPj}	means the carbon emissions due to transport of parts from Tier j-1 supplier to Tier j [kg CO ₂ eq] per part
$C_{op,j}$	means the carbon emissions due to manufacturing processes at the Tier j [kg CO ₂ eq] per part

In case primary data cannot be obtained, secondary data shall be used. Secondary data shall be traceable and based on field survey data and designated by government authorities or intergovernmental institutions (e.g. UNEP GLAD), if available.

Any product during parts and vehicle production generating material/parts for recycling, reuse or remanufacturing follows a cut-off approach in a cradle-to-gate scope, i.e. only the RCM methodology is applied. Preparatory steps for recycling shall generally be allocated to the residual receiving system (i.e., the product system using the (to be) recycled material/parts). This deviation from the polluter pays principle is a pragmatic exemption as following the polluter pays principle in this context would require defining material and component specific system boundaries. Other than the emissions from the respective preparatory steps and the recycling, reused or remanufactured treatment emissions, to be recycled, to be reused, or to be remanufactured materials/parts enter the product system using recycled material/parts burden-free.

For pre-consumer scrap, preparatory steps shall be accounted for by the producer of the residue (they might be insignificant; cut-off rules apply, see 5.8).

6.2.6.5 Level overview

Table 9 gives an overview how relevant aspects in vehicle and parts production should/shall be handled in the different levels.

Table 9: Level overview for parts production and vehicle assembly stage

	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>
Residue or Waste	Included in CEF _{PVA}	Included in CEF _{PVA}	Hotspot: Considered explicitly. Rest of vehicle: Included in CEF _{PVA}	Considered explicitly

	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>
Gross vs. net material input (Scrap/yield)	Included in CEF _{PVA}	Included in CEF _{PVA}	Hotspot: Considered explicitly. Rest of vehicle: Included in CEF _{PVA}	Considered explicitly
Transport	Included in C _{TP} & CEF _{PVA}	Included in C _{TP} & CEF _{PVA}	Transport from OEM gate to customer reported explicitly. Hotspot: Considered explicitly. Rest of vehicle: Included in CEF _{PVA}	Considered explicitly
Temporal validity	Most recent data	Most recent data	Hotspot: Reference year Rest of vehicle: Most recent data	Reference year
Geographical Representativity	As specific as possible for the study purpose	As specific as possible for the study purpose	Hotspot: Plant level Rest of vehicle: As specific as possible	Plant level
Energy Modelling	Recommendation: Location-based	Recommendation: Location-based	Hotspot: Market based Rest of vehicle: Location-based	Marked based approach

6.3 Use stage

6.3.1 System boundaries

When defining the system boundaries, it is pivotal to highlight that the scope is to provide a comprehensive methodology for calculating realistic GHG emissions and energy consumption over vehicle use stage at various levels of detail and considering the availability of different information and datasets. As outlined in the figure below, the use stage encompasses the operation of the vehicle itself and direct impacts from this, as well as impacts from the production and distribution of fuel/electricity, and for impacts relating to vehicle maintenance and replacement parts.

Impacts directly from the energy used in operation of the vehicle include in the CO₂ equivalent calculation the tank to wheel (TtW) contribution are hereby addressed, hence:

- (a) Electric energy: from vehicle charging port to the wheels, if already included in the certification protocol i.e. includes vehicle internal charging losses);
- (b) Fuel: CO₂eq emissions related to fuel use from tank to wheel.

Conversely, impacts resulting from the production and distribution of fuel and electricity for the operation of the vehicle, i.e. well to tank (WtT), shall follow the methodology outlined in section 5.11.1.1.

These latter WtT GHG emissions shall be covered in the conversion factor of each energy type according to section 5.11.1.1.

Use stage boundaries are depicted in the figure below:

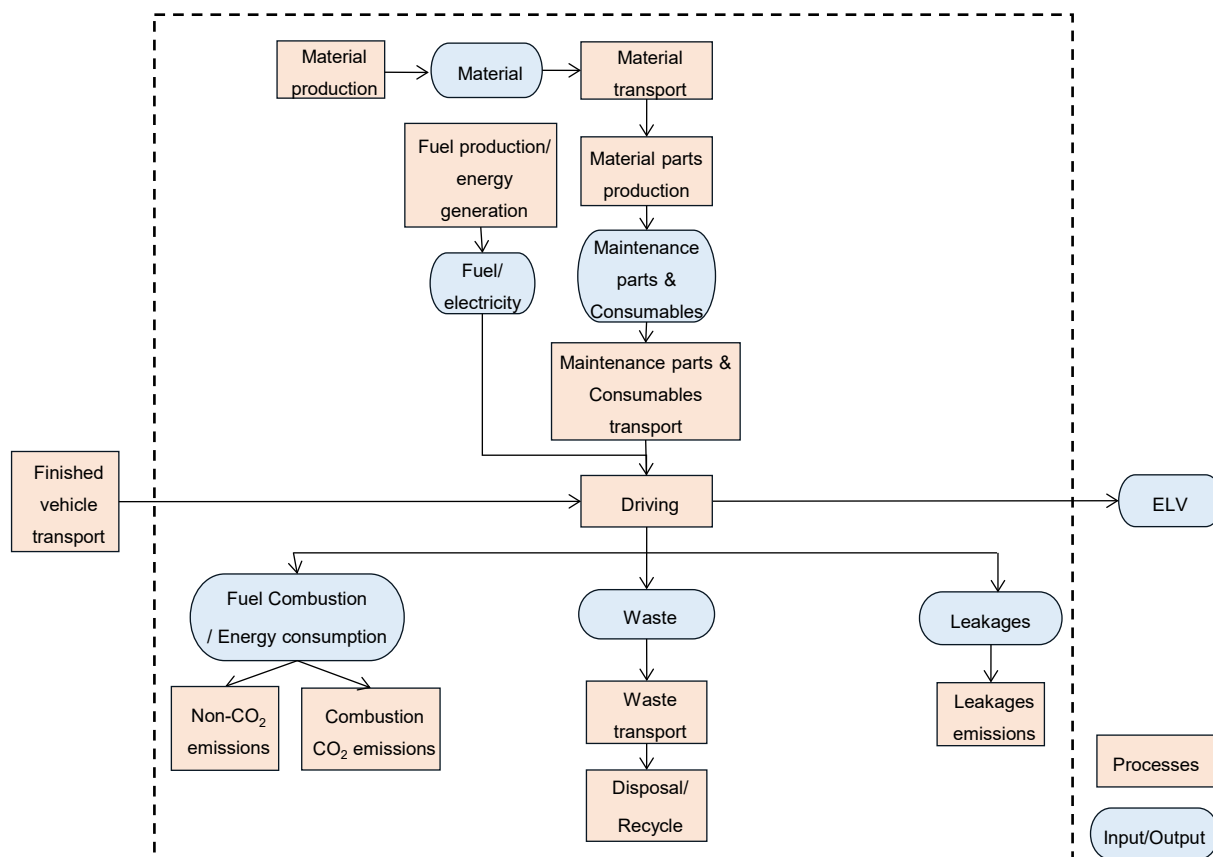


Figure 24: Use stage Life cycle flow schematic

As a matter of fact, the use stage covers mainly two aspects of the whole life cycle, such as the “In-use energy consumption and GHG emissions” (covering WtT and TtW impacts), and the “Maintenance and consumables” impacts. It is relevant to address also leakages such as emissions of methane and other hydrocarbons, together with emissions of climate active species from the vehicles (e.g. methane leakage from CNG cars) and the formation of non-CO₂ GHG gasses (e.g. N₂O) during the fuel combustion. More in detail, the figure below shows the system boundaries related to vehicle operation.

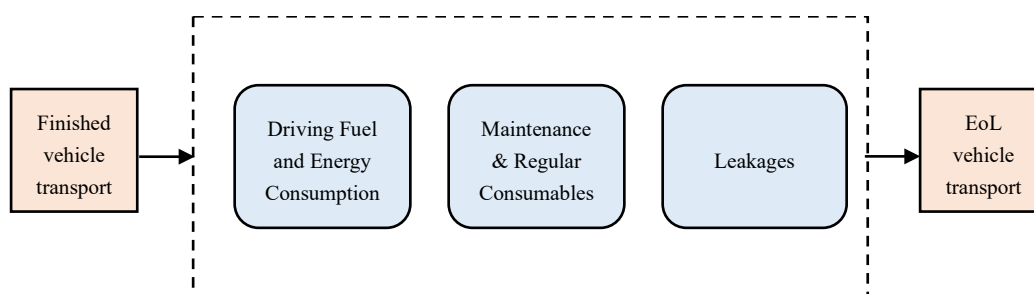


Figure 25: Vehicle operation system boundaries

The handover point from the “Parts Production and Vehicle Assembly” stage is defined at the point of delivery to the final customer, once the finished vehicle has been handed over. On the disposal and recycling side, GHG emissions after the vehicle service lifetime fall within the EoL (End-of-Life) domain. Therefore, it is acknowledged that the transportation of the vehicle to EoL treatment facilities is included within the EoL domain.

Considering the proposed system boundaries, the CO₂ equivalent emissions for the use stage comprise emissions from in-use consumption, emissions due to maintenance parts and consumables, and the contribution of leakages and fluorocarbon emissions. The following equation highlights these components:

$$C_{Use\ Stage} = C_{Energy} + C_{Leakages} + C_{Maintenance} \quad (35)$$

Where:

$C_{Use\ Stage}$	means carbon emissions for the whole use stage [kg CO ₂ eq];
C_{Energy}	means carbon emissions due to the electricity consumption at vehicle level and/or fuel combustion, including both CO ₂ and non-CO ₂ exhaust emissions [kg CO ₂ eq];
$C_{Maintenance}$	means carbon emissions due to maintenance and consumables [kg CO ₂ eq];
$C_{Leakages}$	means carbon emissions due to leakages, including unburnt GHG species emissions [kg CO ₂ eq];

In the following sections, the methodology for assessing each term of the equation is detailed.

6.3.1.1 Quantification of vehicle emissions exported out of region of sales

Ideally, the GHG emissions related to operation of vehicles exported from the country where they are sold/used shall be evaluated by using energy consumption performance (and fuel mix) and vehicle lifetime (and km activity) of the country where they are exported, used and eventually disposed/recycled. However, to avoid unnecessary complexity, if data in the region to which they are exported cannot be tracked down or it is difficult to grasp the needed values of the country where they are exported, used and eventually disposed/recycled, a simplified approach can be adopted. Hence, the full lifetime period (and km activity) shall be considered but the energy consumption performance (and fuel mix) and vehicle life (activity) of the primary region of sale/use are adopted for the calculations. For those countries and regions that export used vehicles, the actual average vehicle lifetime is higher than the average period during which the vehicles are used domestically.

Therefore, for all vehicles, the lifetime used to calculate life cycle emissions shall align with the average age of vehicles at the time of recycling, considering only those registered and recycled within the same country.

6.3.2 Service life/Vehicle lifetime activity

The vehicle lifetime (or service life) is defined as the full period of time during which a vehicle is operated and thereby contributes to GHG emissions. This lifetime is expressed in terms of kilometres (km) driven and is chosen to represent typical usage patterns. Alongside the distance travelled, the years of operation for a vehicle is defined as the assumed total number of years a vehicle remains in active use between the point of sale and the point of recycling/scraping. Both are relevant for the purpose of the methodology.

Vehicle lifetime mileage is required to translate vehicle production emissions (in tonnes of CO₂eq) into the functional unit defined in section 5.5 Vehicle lifetime in years is needed to calculate the lifetime mileage, but also to determine the period of time over which the changes in the emission factor of the fuel and electricity will be accounted for. Lifetime duration is also needed to calculate the number of replacements/refills for certain maintenance and consumable items.

6.3.2.1 Service life: methodology and guidelines

Precisely assessing these values for each region may present further challenges, underscoring the need for flexibility and regional adaptation in their definition and application.

The actual service life and lifetime distance reference flow of a vehicle can vary significantly depending on the region and its specific applications. This variability makes it challenging to accurately estimate these values universally. Therefore, the guidelines propose to define service life for each region or country of usage.

De-registration in a country (i.e., as indicated by “survival curves”) can be significantly earlier than reaching end-of-life. In some countries, a significant share of vehicles is exported before reaching the end of service life. Hence, the average age when being de-registered is lower than the average age when being recycled. In general, these guidelines recommend to consider statistical evidence on the average vehicle age at the point of recycling. For the reasons discussed above, statistics on the average age at the point of de-registration in a country is not recommended, as these values exclude the potential export and continued operation of a proportion of the vehicle in other countries. Therefore, for all vehicles, the lifetime used to calculate life cycle emissions should align with the average age of vehicles at the time of recycling, considering only those registered and recycled within the same country.

Some frameworks adopt different lifetime values by vehicle segment. There are both advantages and disadvantages to offering differentiation by segments. (1) Differentiation offers a more accurate representation of the typical usage expected, which also partly highlights the greater potential utility that larger vehicles can provide. (2) However, near the boundaries between segments, it may unintentionally influence consumer decisions (for instance, a specific user is unlikely to choose a vehicle solely because it belongs to a different segment – it's typically bought for a particular use). Until further in-depth analysis is conducted, the guidelines do not recommend differentiating service life by segment.

Since one of the objectives of LCA is to compare different powertrains, based on the same functionality, i.e., the same use case, these guidelines do not recommend assigning different service lives to different powertrains.

Generally, the annual mileage of vehicles decreases as they age. Therefore, it is important to assign greater weight to the higher mileage recorded in the initial years, as the emission factor of electricity mixes is generally higher during this period. For regions that have officially adopted a method for modelling the distribution of annual vehicle activity over time, data from government authorities should be prioritised.

Although the methodologies do not prescribe a specific method to model the annual mileage distribution as function of the vehicle age, it is permissible to assume a constant value only in cases where the public authority does not require to use official data regarding age-dependent vehicle annual mileage. In that case, the constant average annual mileage should be based on gathered data on total vehicle activity (in kilometres) and vehicle lifetime (i.e., L/N km are driven each of the N years of lifetime operation, where L = total lifetime activity in km). The method should be clearly documented and transparently reported. Section 6.3.2.2 deals with the calculation for the average representative energy mix composition over the full-service life of the vehicle, for both homogeneous and age-dependent annual mileage approaches.

Some vehicles, such as special purpose or sports vehicles, have very low usage, leading to a significantly reduced service life. Practitioners could in principle indicate a shorter service life, where justified and supported by primary data, for communication purposes (in addition to default value). On the other side,

the guidelines currently do not advise declaring a longer service life than the regional default value.

6.3.2.2 Service life values

Service life (in both km and years) will be defined by each region according to officially available data on vehicle service life until point of recycling.

In the absence of the above values, the following values as defined in official databases or peer-reviewed reports can be used as an indication of typical service life as fallback option for passenger cars only.

Table 10: Average age of end-of-life vehicles reported in a selection of countries

<i>Region / Country</i>	<i>Year of publication</i>	<i>Duration (Years)</i>	<i>Source</i>
EU27	2024	20	Multiple sources as in the Annex 1 to these guidelines
United Kingdom	2022	18	LSE Centre for Economic Performance (Nguyen-Tien et al., 2025) ³²
Japan	2024	17	Ministry of Economy, Trade and Industry, 2025 - Status of the Enforcement of the Automobile Recycling Law
USA ³³	2025	varies	Motor Vehicle Emission Simulator (MOVES) ³⁴
Brazil	2020	22	Ministry of Science, Technology and Innovations of Brazil, 2020

32 Data for the UK from the Centre for Economic Performance (Nguyen-Tien et al. (2025) does not reflect a full vehicle lifetime, but instead estimates the average period that vehicles are used on UK roads. “Nguyen-Tien, V., Zhang, C., Strobl, E. et al. The closing longevity gap between battery electric vehicles and internal combustion vehicles in Great Britain. *Nat Energy* 10, 354–364 (2025). <https://doi.org/10.1038/s41560-024-01698-1>”

33 Annual vehicle distance travelled and vehicle scrappage are functions through an analytical end date (e.g., 2050 for AEO 2025) and vary by vehicle type and by location (U.S. state)

34 U.S. EPA (2024). Population and Activity of Onroad Vehicles in MOVES5. EPA-420-R-24-019. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockkey=P101CUN7.pdf>.

Table 11: Average annual mileage of end-of-life vehicles reported in a selection of countries

<i>Region / Country</i>	<i>Year of publication</i>	<i>Service Life (km)</i>	<i>Annual Mileage (km)</i>	<i>Source</i>
EU27	2024	240,000 km	12,000 km	Kraftfahrt-Bundesamt (2025); Agence de la Transition Écologique, Enerdata, & Fraunhofer ISI (2025) ACEA 2025 ³⁵ https://www.acea.auto/fact/fact-sheet-cars/ *
United Kingdom	2022	210,000 km	11,424 km (7,100 miles per year for all powertrains)	Vehicle mileage and occupancy - GOV.UK (2025)
Japan	-	-	-	No statistics available
USA	2025	Varies	Varies	Motor Vehicle Emission Simulator (MOVES)34)34
Brazil	2012	288,000 km	13,000 km (Derived from service life over the first 22 years of usage)	Ministry of Environment (2013)

6.3.3 Use stage consumption

Usage of passenger cars depends on regional customer behaviour. To provide a standard approach that ensures repeatability, comparability and verifiability by authorities, each region has defined homologation driving cycles and test conditions to be followed. In some regions, these certification values are repeatedly found to underestimate the average fuel consumption in real-life operation. In this regard, Table 14 provides an overview of the primary certification protocols used globally. This table serves as an illustrative example of the methodologies employed in key regions to determine fuel and energy consumption for passenger cars, depending on the powertrain type. The selection and verification of the appropriate homologation procedure remain the responsibility of each authority, to be determined on a case-by-case basis. As a result, using regional certification values is considered to be a good starting point to later reach an accurate representation of in-use energy consumption. Table 12 presents the Level Concept for selecting regional certification values utilised for energy consumption representation.

Table 12: Level Concept for Use stage Energy Consumption values*

<i>Level</i>	<i>Representativeness</i>	<i>Energy Consumption Certification</i>
Level 1		

35 ACEA 2025 fact sheet reports the average European travels around 12,000 km per year.

<i>Level</i>	<i>Representativeness</i>	<i>Energy Consumption Certification</i>
Level 2	Specific model or powertrain configuration	Regional typical consumption values or other local representative realistic data** or OEM public data
Level 3	Specific vehicle configuration	Official certification values or OEM-specific data in case the former are not available, if allowed and approved by relevant government authorities.
Level 4		

Note *: in defining regional discrepancy and deterioration factors for different modes of operation based on real-world energy consumption monitoring, care should be taken to avoid double counting of the effects of the Utility Factor.

Note **: for Level 1 and Level 2, these guidelines are considered as minimum requirements and do not prevent the use of more realistic or detailed data to better characterise vehicle behaviour.

The scientific community widely acknowledges that there remains a substantial disparity between certification values and actual energy or fuel consumption in real-world conditions across all types of powertrains in some regions. The gap may vary per powertrain, region, driving behaviour and other variables that have to be taken into account. However, in some regions such as Europe and Japan, real-world fuel consumption can be monitored through on-board systems. This data is compiled annually and shows the gap between certified values and actual usage for each powertrain. To address this, the guidelines propose using a "discrepancy factor". In regions where on-board systems data is available, the discrepancy factor shall be based on such data. If such data are not available for a specific region, then the appropriate discrepancy factor for different vehicles should be determined by the authority based on best available data and expert qualified assumptions with a minimum value of '1' to ensure the real-world performance is appropriately represented. Practitioners shall follow these guidelines based on the selected level concept, as described in section 6.3.3.1. For vehicles that have more than one mode of operation (e.g. OVC-HEVs working in Charge-Depleting and Charge-Sustaining mode), distinct discrepancy factors should be applied to accurately characterise each operational mode.

As a matter of fact, for Level 1 and Level 2 analysis, projections or estimations can be made based on available information such as certification values. These should be considered as minimum requirements and do not prevent the use of more realistic or detailed data to better characterise vehicle behaviour, where such data is available. For Level 3 and Level 4, where stricter requirements are in place, please refer to methodologies in Table 12.

In a 'Level 4' calculation context (see section 2.2.) the substitution of publicly available official data, such as the EU OBFCM data, with OEM-specific average data is not permitted. In instances where publicly available official data is unavailable for a particular manufacturer or model, related to a specific powertrain type or region under consideration, OEM-specific average data, if allowed and approved by relevant government authorities may be employed to determine the "Discrepancy Factor." This factor should be based on an analysis of real-world data from vehicles with similar powertrains (e.g., internal combustion engine vehicles (ICEVs) or zero-emission/electric powertrains such as plug-in electric vehicles (OVC-HEVs), fuel cell hybrid vehicles (FCHVs), etc.) and aligned with the specified region of operation (i.e., sale region). OEM-specific average data, if allowed and approved by relevant government authorities may also be utilized to provide supplementary information. It is imperative to disclose detailed information about the fleet

sample used to derive the data, including, but not limited to, the sample size and period of data collection. These factors should be defined and updated regularly by the relevant authorities.

Vehicle performance and efficiency may change over time due to wear, component deterioration and other factors, thus affecting fuel consumption and CO₂ emission. If "Deterioration factors"³⁶ for the specific modules are available for a particular region, they should be used to account for this issue. Deterioration factors based upon measurement and used for vehicle emissions certification and/or type approval shall be considered primary data. If a deterioration factor is not available for a region, then a deterioration factor could be calculated based on best available data and expert-qualified assumptions with a minimum value of '1'. Practitioners shall follow these guidelines, as described in section 6.3.3.2. Since the deterioration effect covers vehicle aging, it is important to note that this factor may also be reflected in on-board fuel consumption monitoring data used to quantify the "Discrepancy factor", and hence double counting shall be avoided.

As far as the mere Fuel and/or Energy consumption is considered, the in-use consumption, C_{Energy} shall be calculated as follows for vehicles with powertrains with only one mode of operation:

$$C_{Energy} = \sum C_{certification} \times f_{discrepancy} \times f_{deterioration} \times Service\ life \quad (36)$$

$$C_{certification} = EC_{certification} \times CEF_{energy} \quad (37)$$

Where:

C_{Energy}	means carbon emissions due to the electricity consumption at vehicle level and/or fuel combustion, including both CO ₂ and non-CO ₂ exhaust emissions, considering in vehicle life [kg CO _{2eq}].
$C_{certification}$	means carbon emissions due to the electricity consumption at vehicle level and/or fuel combustion, including both CO ₂ and non-CO ₂ exhaust emissions, such as certification CO ₂ or target CO ₂ , reflected carbon emission factor each year in energy.
$EC_{certification}$	means the energy consumption as described in Table 13 [MJ/km]
$f_{discrepancy}$	means the discrepancy factor (refer to 6.3.3.1 for the calculation of the "Discrepancy factor")
$f_{deterioration}$	means the deterioration factor (refer to 6.3.3.2 for the calculation of the "Deterioration factor")
CEF_{energy}	means carbon emission factor in electricity or fuel.
Service life	means service life as defined in section 6.3.2.2 [km]

For the powertrains with two modes of operation, same calculation scenario shall be used while taking into account of each mode operation share during use stage (Utility Factor).

36 While the term "deterioration factor" is commonly used for emissions certification, note that emissions deterioration may be expressed as a multiplicative term, an additive term, or a complex polynomial

Table 13: Energy consumption and GHG certification protocols for main regions

<i>Region</i>	<i>Powertrain</i>	<i>Protocol</i>
EU27	ICE, HEV, OVC-HEV, FCHV, PEV	WLTP (WLTC 4 phases) ³⁷
United Kingdom	ICE, HEV, OVC-HEV, [FCHV], PEV	WLTP (WLTC 4 phases) ³⁸
Japan	ICE, HEV, OVC-HEV, FCHV, PEV	WLTP (WLTC 3 phases) ³⁹
China	ICE, HEV, OVC-HEV	WLTP (WLTC 4 phases) ⁴⁰
	FCHV, PEV (Pass. Car)	CLTC-P
	FCHV, PEV (Vans/LCV)	CLTC-C
Korea	ICE, HEV, OVC-HEV, FCHV, PEV	Combined (FTP-75 and HWFET weighted average) ⁴¹
US	ICE, HEV, OVC-HEV, PEV, FCHV	FTP and HFET combined-weighted-average ⁴²
Canada	ICE, HEV, OVC-HEV, PEV, FCHV	Combined (FTP-75+HWFET) ⁴³

Accurate characterization of methane (CH₄) emissions is critical for comprehensive LCA, ensuring alignment with climate policy targets and improving the accuracy of GHG mitigation strategies.

In regions where methane is monitored as a pollutant and the tailpipe and evaporative methane emissions are determined during the homologation procedure, the emissions measured in the official tests shall be factored into the CO₂eq calculation.

In regions where methane is not monitored (directly or indirectly) as a pollutant and the tailpipe methane emissions are not measured in the homologation procedure, methane emissions shall be included with default values provided by Contracting Parties. If these are not provided, Level 1 and 2 analyses shall use values derived from peer-reviewed literature, provided that they refer to new and fully functional vehicles, while Level 3 and 4 can either use such literature data and sources or ignore methane emissions to ensure that result variability does not impact official reporting or comparisons between vehicles.

As an example, based on studies on Euro 6 cars in Europe (Prussi et al., 2020); Valverde & Giechaskiel, 2020; Vojtíšek-Lom et al., 2018; Hagos & Ahlgren,

37 COMMISSION REGULATION (EU) 2017/1151

38 The Passenger Car (Fuel Consumption and CO₂ Emissions Information) Regulations 2001

39 Notice Determining the Details of Safety Standards for Road Transport Vehicles - Attachment 42 (Measurement Methods for Light and Medium-Duty Vehicle Exhaust Gas)

40 (https://www.miit.gov.cn/zwgk/zcwj/flfg/art/2020/art_2337a6d7ca894c5c8e8483cf9400ecdd.html)

41 KR Notification on Test Methods for Energy Consumption Efficiency and GHG Emissions of Automobiles (<https://www.law.go.kr/LSW/admRulInfoP.do?admRulSeq=2100000198221&chrClsCd=010201#AJAX>)

42 U.S. Title 40 CFR Part 600. Fuel Economy and Greenhouse Gas Exhaust Emissions of Motor Vehicles. <https://www.ecfr.gov/current/title-40/chapter-I/subchapter-Q/part-600>.

43 Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations

2018), the methane emissions from gasoline, diesel, and CNG cars can be considered with 5 mg CH₄/km, 9 mg CH₄/km, and 60 mg CH₄/km. This corresponds to about an additional 0.15 g CO₂eq/km, 0.12 g CO₂eq/km, and 1.81 g CO₂eq/km for the 100-year GWP.

6.3.3.1 Calculation of ‘Discrepancy Factor’

A significant gap remains between certification values and real-world energy or fuel consumption across all powertrains in some regions. To address this, this methodology suggests applying a "discrepancy factor" where official regional data exists. If unavailable, the factor should be estimated using the best available data and expert assumptions, with a minimum value of 1.

Table 14: Level Concept for discrepancy factor calculation

<i>Level</i>	<i>Discrepancy Factor</i>
Level 1	If OEM/ CPs / supplier-specific data is not available, assume official monitoring info, inventories like EMEP/EEA Guidebook, COPERT, MOVES, APEI, etc...
Level 2	
Level 3	Default values provided by CPs based on methodology development/impact assessment/internal studies on real-world gap (OBFCM or equivalent standardised)
Level 4	Default values provided by CPs shall be used. As a regional option, verifiable OEM-specific average data from all vehicles of the same powertrain type operating in the real-world (e.g. PEVs, FCHVs, etc.), matched to the region of operation, may be used for additional informational purposes, but cannot replace the default values provided by CPs.

Note *: in defining regional discrepancy and deterioration factors for different modes of operation based on real-world energy consumption monitoring, care should be taken to avoid double counting of the effects of the Utility Factor

6.3.3.2 Calculation of ‘Deterioration Factor’

The degradation effects could be significant. Therefore, the following overall methodological approach is proposed.

Approach 1: Where emissions deterioration factors are already incorporated into vehicle emissions official reporting or in the certificate of conformity, or can be derived from tests carried out for certification purposes (e.g. durability test) those factors shall be adopted in the calculation of vehicle in-use consumption as per equation 36. This ensures alignment with regulatory requirements and harmonization across jurisdictions.

Approach 2: In cases where a deterioration factor is not mandated or available for a specific region, given the current state of technical knowledge and data availability, practitioners may apply a minimum “Deterioration factor” of 1.0 where no region-specific data exists. Future revisions to this methodology will incorporate advancements in measurement methodologies and data collection.

6.3.3.3 Application of the energy modelling schemes

For general rules, refer to section 5.11.1.

6.3.3.3.1 Application of the energy modelling schemes for dynamic scenario

If a dynamic scenario is used, the energy mix composition for each year of vehicle operation shall be estimated (i.e., the shares $S_{i,n}$ of energy supplied

by each technology i in the year n), by applying linear interpolation between the respective energy supply shares reported for the nearest pre-defined time horizons in the scenario selected. The average representative grid mix composition over the full service life of the vehicle shall be calculated as follows:

- (a) As the arithmetic average of the individual electricity supply shares at point 2 above. Doing so entails the implicit simplifying assumption that the vehicle's use is distributed homogeneously over its full service life (i.e., L/N km are driven each of the N years of operation, where L = total lifetime activity).
- (b) Alternatively, if there is reason to expect that the vehicle's use intensity will change over time, and if year-specific activities may be estimated with sufficient confidence, then a more refined (and accurate) modelling approach may be adopted, employing a weighted average (as opposed to a simple arithmetic average) of the individual shares $S_{i,n}$ of electricity supplied by each technology i in the year n , i.e.: $\sum_{n=1}^N W_n S_{i,n}$, where $W_n = A_n/L$ (A_n = vehicle activity in year n , L = total lifetime activity).

A bespoke grid mix model shall finally be built using the grid mix composition calculated above and leveraging the most up to date database processes available for the individual electricity generation technologies. The resulting grid mix thus modelled shall be used to estimate the Emission Factor of the electricity input to the use stage of the vehicle.

6.3.4 Quantification of Leakages

This section deals with GHG emissions arising from the fuel system, such as evaporation, hydrogen and methane leakages.

6.3.4.1 Evaporative emissions

Evaporative emissions occur in vehicles due to the nature of the fuel system and the volatility of petrol fuel. As part of the homologation process, vehicles are subjected to emissions testing to ensure compliance with regulations, including limits on evaporative emissions.

Limits of evaporative emission and duration of measurement vary between different regions of the world.

Given the very low impact on the entire use stage GHG emissions, this methodology neglects the emissions arising from fuel evaporation.

6.3.4.2 Hydrogen leakages

Hydrogen emissions primarily occur during production and distribution, mainly due to fugitive leakage. To a lesser extent, emissions can also arise directly from hydrogen-fuelled vehicles, although standardised test methods to quantify these emissions are currently lacking. Hydrogen can also escape from combustion engines and storage systems, particularly in the case of liquefied hydrogen.

Recent research suggests that hydrogen leakage rates across the supply chain may be comparable to methane losses in the natural gas supply chain. Estimates indicate that green hydrogen supply chains could experience net leakage rates between 2.6% and 6.9% (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022).

Hydrogen emissions are not commonly included in life cycle inventory (LCI) datasets, and a characterisation factor for hydrogen is currently absent from established impact assessment methods (e.g., the Environmental Footprint (EF) method), due to its omission from the explicit list of greenhouse gases in

the latest IPCC Assessment Report. As such, it is recommended that the inclusion of hydrogen as a greenhouse gas in default LCA calculations be deferred until formal consensus is reached on its global warming potential (GWP) and/or its integration into the EF method.

In the interim, for Level 1 and Level 2, practitioners are required to account for hydrogen emissions as a mandatory flow indicator until a standardised GWP value is formally adopted. From both the supply chain and vehicle use, where available, practitioners should use official governmental estimates or supplier-specific data on typical fugitive hydrogen emissions. These should differentiate between various hydrogen production pathways, local versus imported hydrogen, and distinct hydrogen vehicle types. For Levels 3 and 4 LCA, practitioners may apply the methodology for Levels 1 and 2 or omit hydrogen leakage until future guidelines revisions mandate inclusion, due to current data limitations and evolving measurement standards.

6.3.4.3 Methane leakages

Methane fugitive emissions from vehicle storage systems can significantly impact use-stage greenhouse gas inventories for certain vehicles using methane as a fuel. In the absence of harmonized measurement standards, practitioners should prioritize official governmental estimates of CH₄ leakage when available. Supplementary data from OEMs or suppliers may be used to corroborate these estimates. For Level 1 and Level 2 assessments where official governmental data remains unavailable, validated peer-reviewed literature may constitute an acceptable alternative, provided they are appropriately documented.

6.3.4.4 Quantification of fluorocarbons emissions

Refrigerant fluids have a direct environmental impact, primarily due to the use of hydrofluorocarbons (HFCs), a class of synthetic gases that replaced hydrochlorofluorocarbons (HCFCs). However, there is no standardized leakage measurement methods are available; and refrigerant leakages are considered to be very low. For this reason, this methodology neglects the GHG emissions arising from fluorocarbons.

On the other side, refrigerant emissions shall be included in the life cycle inventory as elementary flows pertaining to the maintenance and consumables area, as explained in section 6.3.5.

6.3.5 Maintenance

Vehicle maintenance encompasses the periodic replacement of components and the replenishment or replacement of operational fluids necessary to ensure reliable and safe vehicle performance throughout its service life. Maintenance schedules may be defined based on elapsed time, distance travelled, predictive algorithms, periodic inspections, or more generally on wear, degradation, or depletion. Maintenance in the use stage of a vehicle's life cycle can have a non-negligible impact on its carbon footprint. Recent life cycle assessment studies estimate that the greenhouse gas emissions produced by vehicle maintenance during the use stage can have a significant impact on total vehicle carbon footprint, depending on the powertrain type and vehicle segment.

6.3.5.1 Maintenance scope

Two types of maintenance are included in this methodology:

- (a) **Consumables:** These are materials, fluids, and components that are regularly used, replaced, or replenished during the operation and maintenance of a vehicle. These items typically have a limited lifespan and require periodic replacement to ensure the vehicle's proper functioning, safety, and performance. This includes items such as

engine oil, transmission fluid, brake fluid, windshield washer fluid, filters, brake pads and discs, etc.. Carbon footprint related to material, production and EoL shall be considered.

- (b) Maintenance parts: This refers to the replacement of parts due to normal wear and tear, including components that are not designed to last the entire lifespan of a vehicle, such as the brakes, clutch, tyres, starter battery, etc.. The range of parts that need to be replaced during maintenance varies between different cars, depending on factors such as the driver's behaviour, road conditions and other variables (weather etc.). Hence, it is difficult for OEMs to recommend a frequency of exchange of these parts to the customer. The frequency of maintenance of such parts can only be estimated with acceptable probability through statistical analysis and a generic frequency of these parts shall be used for the purpose of carbon footprint estimation. For these parts recycling aspects must be considered and are same as that of original production parts.

Other repair or maintenance activities not included in the methodology are:

- (a) Unexpected repairs (i.e., accident): Vehicle accidents is not considered as a part of maintenance activities within the scope of these guidelines but may be included via future amendment if sufficient data is available
- (b) Cleaning operations: Effect of car wash may not be a significant factor in the calculation as it is a very small fraction of the overall carbon footprint of a car. Hence, the guidelines do not address cleaning operations.

6.3.5.2 Maintenance carbon emission estimation

Since the carbon footprint related to maintenance occurs after the vehicle is placed on the market, it can only be calculated based on the known frequency specified by the vehicle manufacturer.

To account for maintenance and consumables emissions, there are two possibilities (considered in a hierarchical order):

- (a) List of maintenance parts/consumables and associated frequencies provided by the manufacturer.
- (b) List of maintenance parts/consumables not available

For Level 3 and Level 4, section 6.3.5.2.1. shall be applied.

For Level 1 and Level 2, the approach for maintenance and consumables emissions estimation may instead alternatively follow section 6.3.5.2.2. where a suitable methodology may be defined and documented by the practitioner (e.g. based on assumptions on the parts replaced and the number/frequency, or alternative methods).

6.3.5.2.1 Maintenance Data Availability

If a list of maintenance parts/consumables and associated frequency is provided by the manufacturer or parts supplier, then the following estimation shall be used.

As this will reflect the effort from the manufacturer to reduce carbon footprint of maintenance, the manufacturer or part supplier should provide all the assumptions (list, frequency, carbon emission) used for carbon footprint estimation.

$$C_{\text{maintenance}} = \sum_{i=1}^n CEF_i * f_{i.\text{maintenance}} \quad (38)$$

Where:

i means consumable/ maintenance parts

$f_{i,maintenance}$ means the maintenance frequency of the consumable/maintenance parts defined

CEF_i means the carbon emission factor of the consumable/maintenance parts as used for calculation of upstream and end of life (waste or recycle) emissions [kg CO₂eq].

6.3.5.2.2 Determination of list of consumables and parts

The following table provides a list of consumables and parts for guidance and should not be considered as exhaustive. The manufacturer should provide the list adapted to the powertrain and vehicle segment for which the carbon footprint is calculated. However, for Level 3 and Level 4, last column of the table indicates items responsible for the most significant potential impacts that shall be included if a replacement is needed (to be justified) in the considered lifetime of the vehicle.

Table 15: List of consumables and maintenance parts

		<i>Petrol</i>	<i>Diesel</i>	<i>CNG</i>	<i>NOVC-HEV</i>	<i>OVC-HEV</i>	<i>Pure EV</i>	<i>FCHV</i>	<i>OVC-FCHV</i>	<i>H2-ICE</i>	<i>Level 3/Level 4</i>
Consumables	Engine coolant	✓	✓	✓	✓	✓	N/A	N/A	N/A	✓	
	Engine lubricant	✓	✓	✓	✓	✓	N/A	N/A	N/A	✓	
	Screen wash	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Brake fluids	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Engine air/oil filter	✓	✓	✓	✓	✓	N/A	N/A	N/A	✓	
	AdBlue/Urea/Reagent	N/A	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	YES
Maintenance parts	Passenger air filter	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	HVAC Refrigerants	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Spark plug	✓	-	✓	✓	✓	N/A	N/A	N/A	✓	
	Windshield wiper blades	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Tyres	✓	✓	✓	✓	✓	✓	✓	✓	✓	YES
	Brake linings	✓	✓	✓	✓	✓	✓	✓	✓	✓	YES
	Brake discs	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	SLI battery (i.e. 12V)	✓	✓	✓	✓	✓	✓	✓	✓	✓	YES
	Aftertreatment	✓	✓	✓	✓	✓	N/A	N/A	N/A	✓	

The impacts resulting from different maintenance items can vary greatly, with some items being less significant and others usually accounting for a significant proportion of overall impacts. It is therefore proposed that the following items should be mandatorily included (where relevant for a given vehicle powertrain type):

- Consumables: AdBlue/Urea, Refrigerants for HVAC (heating, ventilation and air conditioning) systems
- Maintenance and wear parts: Tyres, SLI battery, brake pads, brake discs, additional auxiliary batteries (if relevant for commercial vehicles – e.g. for refrigerated containers).

Refrigerant emissions shall be included if the refrigerant used has a GWP₁₀₀ value of 150 or higher⁴⁴. Practitioners may also choose to report refrigerant emissions with a GWP₁₀₀ below this threshold as non-exhaust emissions.

⁴⁴ Value based on “Regulation (EU) 2024/573” on fluorinated GHGs, which includes specific measures for MAC systems in cars and commercial vehicles. For instance, the use of refrigerants like HFC-134a, is being phased out.

Additionally, these guidelines require the assessment of key components for potential replacement, such as the internal combustion engine in conventional and/or hybrid vehicles, traction or storage battery in electric vehicles and the fuel cell stack in fuel cell electric vehicles in the case that the practitioners provide the justifications to be included.

For certain items, including mandatory items, replacements might not be needed in the vehicle's typical operational lifetime based on the supplier assessment. In these cases, exclusions made on this basis shall be justified.

6.3.5.2.3 Determination of Frequency

For most maintenance items frequency can be simply calculated by the following two approaches:

Frequency by distance

$$Frequency_{distance} = \frac{Service\ life\ [km]}{Maintainence\ interval\ [km]} \quad (39)$$

Frequency by duration

$$Frequency_{duration} = \frac{Service\ life\ [years]}{Maintainence\ interval\ [years]} \quad (40)$$

In case the manufacturer/supplier recommends frequency by both distance and duration, both calculations should be performed, and the most conservative (i.e. the highest) frequency shall be considered for the carbon footprint estimation.

6.3.6 Data Collection and data type

Data shall be collected for the items outlined below. Where applicable, activity data shall be collected as primary data. In case of difficulty, secondary data may be applied to activity data. GHG emission factor data shall be collected as secondary data. Secondary data source shall be reported. The following data shall be collected:

Table 16: Processes and Data to be included in Use stage

<i>Processes</i>	<i>Activity data</i>	<i>GHG emissions Factor Data</i>
	<i>(Primary Data basis)</i>	<i>(Secondary Data basis)</i>
Driving	Certified Fuel consumption [l/100km] and/or electricity consumption [kWh/100km]	
		Discrepancy factor RW data
		Deterioration factor
	Separate Certified fuel/electricity consumption for the charge-depleting (CD) and charge-sustaining (CS) modes for OVC-HEVs	
	Utility Factor definition for dual-mode powertrains (e.g. OVC-HEVs)	
	Certified charge-depleting (CD) range [km] for dual-mode powertrains (e.g. OVC-HEVs)	
	Vehicle lifetime (years), and activity (km)	Vehicle recycling statistics/ Nationally authorised statistics/OEMs average vehicle life
		GHG emission factor for burning fuel

		Vehicle occupancy rates for potential scenario analysis
Leakages	Hydrogen, Methane	
Maintenance and Consumables Production	List of maintenance parts and consumables	
	Frequency of replacement/service intervals	
		GHG emission factor for producing maintenance parts, in line with section (6.2 Parts production and vehicle assembly stage)
Maintenance and Consumables Transportation	List of maintenance parts and consumables	
	Frequency of replacement/service intervals	
	Transport Mass [kg] Transport Distance [km]	GHG emission factor for transporting maintenance parts
Maintenance and Consumables End-of-Life	To be evaluated in line with section (6.4. EoL)	To be evaluated in line with section (6.4. EoL)
Vehicle activity out of region of sales	Out of scope	Out of scope
Second life of components	Out of scope	Out of scope

6.4 EoL

6.4.1 System boundaries

The system boundary of the disposal and recycling stage as well as its calculation method are outlined below.

Data collection applies to the processes outlined below.

- E1; End-of-life vehicle (ELV) dismantling and shredding/sorting process
- E2; Recovered parts disposal and recycling process
- E3; Automobile shredder residue (ASR) disposal and recycling process
- E4; Materials recycling processes
- E5; Transport processes

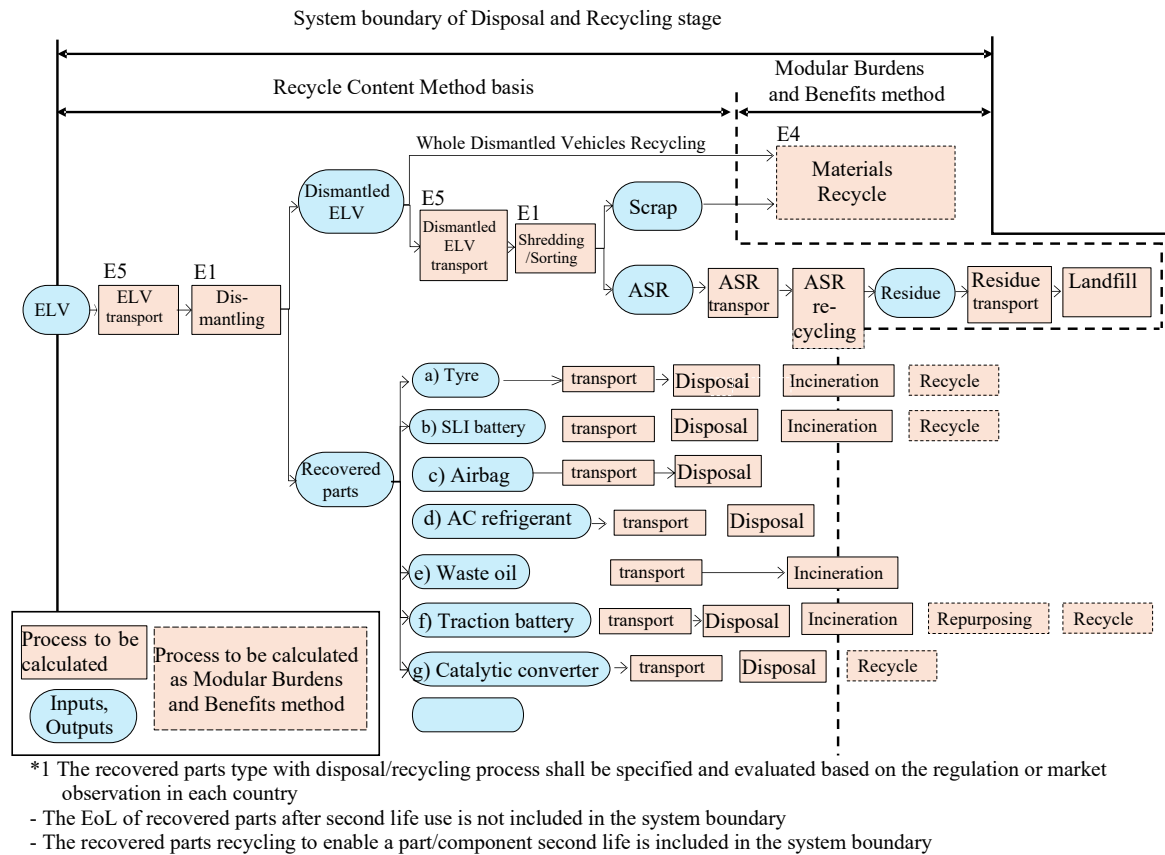


Figure 26: System boundaries of Disposal and Recycling stages

6.4.2 Levels in disposal and recycling stage

As introduced in section 2.2., the analysis of global warming potential can also be carried out for Disposal and recycling stage in different levels of detail according to the chart below. Please note that, for application of MBBM, authority-provided parameters are required in Level 3 and Level 4.

Table 17: Level concept of disposal and recycling stages

Level Concept of Disposal and Recycling stage			
	1. Activity data of each EoL processes	2. Carbon emission factor data of each EoL processes	3. Recovered parts disposal and recycling process
	e.g. Mass of vehicle, parts, material etc	e.g. Dismantling and shredding/sorting, ASR thermal recovery, Materials. recycle etc	e.g. Tyre, SLI battery, Traction battery, etc
Level 1	Global or Generic secondary data	Global or Region or Country primary data or secondary data can be chosen, depend on the study	Global or Region or Country process can be chosen, depend on the study
Level 2	Primary data (BoM & MDS)	Global or Region or Country primary data or secondary data shall be specified and provided by authorities	Global or Region or Country process shall be specified and provided by authorities
Level 3			
Level 4			

6.4.3 Data collection and data types

Data shall be collected for the item outlined below. Activity data shall be collected as primary data in level 2 or 3 or 4. The secondary data may be

applied to activity data in level 1. GHG emission factor data shall be collected as primary or secondary data in all levels. Scenarios for secondary data and secondary data source shall be reported. Secondary data may be referred, among others, to the following data set;

- (a) Environmental Footprint (EF) compliant data sets
- (b) AIST-IDEA
- (c) JAMA CFP guidelines

Table 18: Data types for disposal and recycling stages with each symbol

<i>Processes</i>			<i>Activity data</i>	<i>GHG emissions factor data</i>
			<i>(Primary data basis)</i>	<i>(Secondary data basis)</i>
E1; End-of-life vehicle (ELV) dismantling and shredding/sorting process (C_{E1})			• ELV mass [$\text{kg}_{\text{component}}$] ($m_{E1}$)	• ELV dismantling and shredding/sorting [$\text{kg CO}_2\text{eq/kg applicable ELV}$] ($CEF_{D,E1}$)
E2; Recovered parts disposal and recycling process Remarks) The recovered parts type with disposal and recycling process shall be specified and evaluated based on regulations or market observation in each country	(a) Tyre (C_{E2a})	(a-1) Disposal, Incineration (C_{E2a-1})	• Tyre mass [$\text{kg}_{\text{component}}$] ($m_{E2a}$) • Wearing ratio [%] (R_{E2a}) • Mass fractions of each material in the tyre [$\text{kg}_{\text{material}}/\text{kg}_{\text{component}}$] ($T_{I,E2a}, T_{D,E2a}$)	• Tyre incineration with thermal and electricity recovery [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{I,E2a}$) and disposal [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{D,E2a}$) which may include residue landfill and transport.
		(a-2) Recycle ($C_{M,MBBM,E2a}$)	• Material mass to which CFF is applied [$\text{kg}_{\text{material}}$] ($m_{Mi,E2a}$)	• Modular Burdens and Benefits method (MBBM) of each material [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{Mi,MBBM}$)
	(b) SLI battery (C_{E2b})	(b-1) Disposal, Incineration (C_{E2b-1})	• SLI battery mass [$\text{kg}_{\text{component}}$] ($m_{E2b}$) • Mass fractions of each material in the battery [$\text{kg}_{\text{material}}/\text{kg}_{\text{component}}$] ($T_{I,E2b}, T_{D,E2b}$)	• SLI battery incineration with thermal and electricity recovery [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{I,E2b}$) and disposal [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{D,E2b}$) which may include lead scrap treatment and electrolyte neutralisation treatment and transport.
		b-2) Recycle ($C_{M,MBBM,E2b}$)	• Material mass to which CFF is applied [$\text{kg}_{\text{material}}$] ($m_{Mi,E2b}$)	• MBBM of each material [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{Mi,MBBM}$)
	(c) Airbag (C_{E2c})		• Airbag mass [kg] [$\text{kg}_{\text{component}}$] ($m_{E2c}$)	• Airbag proper disposal [$\text{kg CO}_2\text{eq/kg}_{\text{component}}$] ($CEF_{Mi,MBBM}$)
	(d) Air conditioner (AC) refrigerant (C_{E2d})		• AC refrigerant mass [$\text{kg}_{\text{material}}$], filled in air conditioner at vehicle production. (m_{E2d})	• AC refrigerant (fluorocarbons) disposal [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{D,E2d}$) which may include fluorocarbons destruction, CO_2 from destruction and transport
	(e) Waste oil (C_{E2e})		• Waste oil mass [$\text{kg}_{\text{material}}$] ($m_{E2e}$)	• Waste oil incineration with thermal and electricity recovery [$\text{kg CO}_2\text{eq/kg}_{\text{material}}$] ($CEF_{I,E2e}$)

Processes		Activity data	GHG emissions factor data	
		(Primary data basis)	(Secondary data basis)	
	(f) Traction battery (C_{E2f})	(f-1) Disposal, Incineration (C_{E2f-1})	• Used battery pack mass[kg] (m_{E2f}) • mass fractions of each material in the battery [kg_{material}/kg_{component}] ($T_{Ii,E2f}, T_{Di,E2f}$)	• Used battery pack proper treatment which includes battery pack incineration (where allowable) with thermal and electricity recovery ($CEF_{Ii,E2f}$) and disposal ($CEF_{Di,E2f}$) which may include residue landfill and transport. [kg CO₂eq/kg_{material}]
		(f-2) Secondary use (Repurposing) ($C_{TBR,MBBM}$)	• Number of Driving battery pack	• MBBM for the battery repurposing [kg CO₂eq/pack] ($C_{TBR,MBBM}$)
		(f-3) Material recycle ($C_{M,MBBM,E2f}$)	• Material mass to which CFF is applied [kg_{material}] ($m_{Mi,E2f,Material}$) and battery cell mass to which CFF is applied [kg_{battery cells}] ($m_{E2f,cells}$)	• MBBM of each single material [kg CO₂eq/kg_{Material}] ($CEF_{Mi,MBBM,Material}$) recovered from the battery disassembly process and sent to material recycling, and Modular Burdens and Benefits method of battery cells specific recycling process [kg CO₂eq/kg_{battery cells}] ($CEF_{MBBM,cells}$), if applicable according to regional regulations
	(g) Catalytic converters (C_{E2g})	(g-1) Disposal (C_{E2g-1})	• Catalytic converters mass [kg_{component}] (m_{E2g}) • Mass fractions of each material in the converters [kg_{material}/kg_{component}] ($T_{Di,E2g}$)	• Catalytic converters disposal [kg CO₂eq/kg_{material}] ($CEF_{Di,E2g}$), which may include residue landfill after recycling process
		(g-2) Material recycle ($C_{M,MBBM,E2g}$)	• Material mass to which CFF is applied [kg_{material}] ($m_{Mi,E2g}$)	• MBBM of each material [kg CO₂eq/kg_{material}] ($CEF_{Mi,MBBM}$)
E3; Automobile shredder residue (ASR) disposal and recycling process(C_{E3})	ASR	• ASR combustible material material mass [kg_{material}] ($m_{i,ASR}$)	• ASR incineration with thermal and electricity recovery [kg CO₂eq/kg_{material}] ($CEF_{Ii,ASR}$) and disposal [kg CO₂eq/kg_{material}] ($CEF_{Di,ASR}$) which may include the residue landfill	
E4; Materials recycling processes ($C_{M,MBBM,E4}$)		• Material mass to which CFF is applied [kg_{material}] ($W_{Mi,E4}$)	• MBBM of each material [kg CO₂eq/kg_{material}] ($CEF_{Mi,MBBM}$)	

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3
4

<i>Processes</i>	<i>Activity data</i>	<i>GHG emissions factor data</i>
	<i>(Primary data basis)</i>	<i>(Secondary data basis)</i>
E5; Transport processes (C_{E5})	• Each transported goods mass [t] ($m_{i,E5}$) • Each transport distance [km] ($D_{i,E5}$)	Transport per transport goods mass and per transport distance [kg CO ₂ eq/t-km] (CEF_{Ti})

6.4.4 Recycling modelling for Remanufacturing, Reuse or Repurposing of vehicle parts

The environmental impacts arising from the activities of Remanufacturing, Reuse or Repurposing of vehicle parts and components recovered from EoL vehicles to enable a part/component second life shall be evaluated in all levels based on regulation or market observation, data availability for parameters and verification criteria. In any case the second life parts traceability shall be confirmed with following recommendations of recycling modelling.

Table 19: Recycling modelling recommendations for Remanufacturing, Reuse or Repurposing of vehicle parts

<i>Second life application</i>	<i>Definition</i>	<i>Recycling modelling Recommendation</i>
1. Remanufacturing	ELV parts recycling to new vehicle parts	RCM
2. Reuse	ELV parts recycling to repair vehicle	RCM
3. Repurposing	ELV parts recycling to another function in other industries e.g. Traction battery from EoL PEV repurposed to the stationary battery in a building	CFF

RCM formula for Remanufacturing or Reuse shall be referred to $CEF_{M,RCM}$ formula in 5.11.2.1 Material recycling modelling. CFF formula for Repurposing shall be referred to $CEF_{M,MBBM}$ formula in 5.11.2.1 Material recycling modelling and (f-2) Secondary use (Repurposing) of E2; (f) Traction battery in 6.4.7. GHG calculation for each process. The type of data for RCM or CFF parameter shall be confirmed according to the regional regulation or market observation.

6.4.5 EoL emissions treatment of ELV exported out of region of sales

Ideally, the EoL GHG emissions of vehicles exported from the country where they were originally sold and used shall be evaluated based on the EoL processes of the country where they are eventually used and disposed/recycled. However, to avoid complexity, if the country to which the vehicle is exported cannot be tracked or the EoL process of the country where they were exported, used and disposed/recycled cannot be determined, a simplified approach can be adopted. In such cases, the EoL emissions may be evaluated using the process of the country where the vehicle was first registered and primarily used.

6.4.6 Future recycling process and technology modelling

GHG emissions factor for each disposal and recycling process and CFF parameters should be set in view of the process and recycling technology about 13-17 years later in the future. For recycling, process data should be those available at the point of declaration of the vehicle (first vehicle registration). When a specific recycling process does not yet exist, and assumptions on such a future process cannot be appropriately justified, a scenario based on the current process and recycling technology may be applied.

6.4.7 Energy modelling

For general rules refer to section 5.11.1.2

Specifically, the following recommendations are made on how to model energy inputs to the EoL stage:

1. The same scenario for the expected future evolution of the energy mix in the geographical region of interest shall be adopted, as previously selected the use stage (cf. hierarchical approach in section 5.11.1.3 Prospective Energy modelling)
2. The grid mix composition for the specific year of vehicle decommissioning (i.e., year of vehicle registration + expected lifetime) shall be estimated (i.e., the shares $S_{i,N}$ of energy supplied by each technology i in the year N), by applying linear interpolation between the respective energy supply shares reported for the two nearest pre-defined time horizons in the scenario selected at point 1 above in the case of data for that specific year is not available.
3. A bespoke grid mix model shall be built using the grid mix composition calculated at point 2 above and leveraging the most up to date database processes available for the individual energy generation technologies. The resulting energy mix thus modelled shall be used to estimate the Emission Factor of the energy input to the EoL stage of the vehicle.

In case of the process in the EoL stage is not a hotspot, the static energy modelling may be applied.

6.4.8 GHG calculation for each process

The total GHG emission in the EoL stage shall be calculated and reported by the following equation for the complete vehicle.

$$C_{EoL} = C_{EoL,RCM} + C_{EoL,MBBM} \quad (41)$$

Where:

C_{EoL}	means the total GHG emissions in EoL stage [kg CO ₂ eq]
$C_{EoL,RCM}$	means the GHG emissions arising from the ELV treatment when using the RCM basis system boundaries as defined in Figure 21 [kg CO ₂ eq]

$C_{EoL,MBBM}$ means the GHG emissions arising from the ELV treatment when using the MBBM system boundaries as defined in Figure 21 [kg CO₂eq]

In case of RCM application, only $C_{EoL,RCM}$ shall be calculated, $C_{EoL,MBBM}$ shall not be calculated. In case of CFF application both $C_{EoL,RCM}$ and $C_{EoL,MBBM}$ shall be calculated.

$$C_{EoL,RCM} = C_{E1} + \sum_j C_{E2j,RCM} + C_{E3,RCM} + C_{E5} \quad (42)$$

$$C_{E2j,RCM} = m_{E2j} \times \{ \sum_i (T_{ii,E2j} \times E_{ERi,E2j}) + \sum_i (T_{Di,E2j} \times CEF_{Di,E2j}) \} \quad (43)$$

$$C_{E3,RCM} = \sum_{i,ASR} \{ m_{i,ASR} \times (E_{ERi,ASR} + CEF_{Di,ASR}) \} \quad (44)$$

Where:

C_{E1} means the GHG emissions in ELV dismantling and shredding/sorting process [kg CO₂eq]

$C_{E2j,RCM}$ means the GHG emissions in each recovered parts disposal and incineration process [kg CO₂eq]

m_{E2j} means each parts mass [kg_{component}]

$T_{ii,E2j}$ means the i-th material mass fraction of each parts for the incineration [%]

$T_{Di,E2j}$ means the i-th material mass fraction of each parts mass that is sent to disposal [%]

$E_{ERi,E2j}$ means the specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process of each material in each part in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{Di,E2j}$ means GHG emission factor arising from the disposal of each material in each part in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$C_{E3,RCM}$ means the GHG emissions in the automobile shredder residue (ASR) disposal and incineration process [kg CO₂eq]

$m_{i,ASR}$ means the mass of each combustible material in ASR [kg_{material}]

$E_{ERi,ASR}$ means the specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process of each combustible materials in ASR in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{Di,ASR}$ means GHG emission factor arising from the disposal of combustible materials in ASR in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

C_{E5} means the GHG emissions in the transport processes [kg CO₂eq]

Each MBBM value in $C_{EOL,MBBM}$, which are $C_{M,MBBM}$, $C_{I,MBBM}$ and $C_{TBR,MBBM}$, shall be separately reported with the following equation.

$$C_{EOL,MBBM} = C_{M,MBBM} + C_{I,MBBM} + C_{TBR,MBBM} \quad (45)$$

$$C_{M,MBBM} = \sum_j C_{M,MBBM,E2j} + C_{M,MBBM,E4} \quad (46)$$

Where:

$C_{M,MBBM}$ means the specific GHG emissions calculated per MBBM in the total materials recycling processes [kg CO₂eq]

$C_{M,MBBM,E2j}$ means the specific GHG emissions calculated per MBBM in each parts material recycling [kg CO₂eq]

$C_{M,MBBM,E4}$ means the specific GHG emissions calculated per MBBM in the materials recycling processes [kg CO₂eq]

$$C_{I,MBBM} = \sum_{i,j} (m_{E2j} \times T_{Ii,E2j} \times CEF_{Ii,MBBM,E2j}) + \sum_{i,ASR} (m_{i,ASR} \times CEF_{Ii,MBBM,ASR}) \quad (47)$$

Where:

$C_{I,MBBM}$ means the specific GHG emissions related to the credit obtainable by total material energy recovery process [kg CO₂eq]

m_{E2j} means each parts mass [kg_{component}]

$T_{Ii,E2j}$ means each material mass fraction of each part for the incineration [%]

$CEF_{Ii,MBBM,E2j}$ means GHG emission factor related to the credit obtainable by the energy recovery process of each material in each part calculated per MBBM for energy in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/ kg_{material}]

$m_{i,ASR}$ means the mass of each combustible materials in ASR material [kg_{material}]

$CEF_{Ii,MBBM,ASR}$ means GHG emission factor related to the credit obtainable by the energy recovery process of each combustible materials in ASR calculated per MBBM for energy in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$C_{TBR,MBBM}$ means the specific GHG emissions calculated per MBBM of traction battery repurposing [kg CO₂eq]

6.4.8.1 E1; End-of-life vehicle (ELV) dismantling and shredding/sorting process

$$C_{E1} = m_{E1} \times T_{E1} \times CEF_{D,E1} \quad (48)$$

Where:

C_{E1} means the GHG emissions in ELV dismantling and shredding/sorting process [kg CO₂eq]

m_{E1} means the ELV mass [kg_{component}]

	T_{E1}	means the applicable ELV mass fraction of the ELV mass [%]
	$CEF_{D,E1}$	means GHG emission intensity for ELV arising from dismantling and shredding/sorting in kilogram of carbon dioxide equivalent per kilogram of the applicable ELV mass [kg CO ₂ eq/kg applicable ELV]
6.4.8.2	E2; Recovered parts disposal and recycling process	
	The recovered parts type with disposal and recycling process shall be specified and evaluated based on the regional regulation or market observation in each country following GHG calculation example for each process.	
6.4.8.2.1	Tyre	
6.4.8.2.1.1	Disposal, Incineration	
	$C_{E2a-1} = (1 - R_{E2a}) \times m_{E2a} \times \left\{ \sum_i (T_{Ii,E2a} \times CEF_{Ii,E2a}) + \sum_i (T_{Di,E2a} \times CEF_{Di,E2a}) \right\} \quad (49)$	
	Where:	
	C_{E2a-1}	means the GHG emissions in tyre incineration with thermal and electricity recovery ($C_{I,E2a}$) and disposal ($C_{D,E2a}$), which may include residue landfill and transport [kg CO ₂ eq]
	R_{E2a}	means the percentage of mass loss during total tyre wear based on calculations of tyre specifications [%]
	m_{E2a}	means the tyre mass [kg _{component}]
	$T_{Ii,E2a}$	means the i-th material mass fraction of the tyre mass at $EoL\{m_{E2a} \times (1 - R_{E2a})\}$ that is sent to incineration [%]
	$T_{Di,E2a}$	means the i-th material mass fraction of the tyre mass at $EoL\{m_{E2a} \times (1 - R_{E2a})\}$ that is sent to disposal [%]
	$CEF_{Ii,E2a}$	means GHG emission factor arising from incineration with energy recovery of tyre materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/ kg _{material}]
	$CEF_{Di,E2a}$	means GHG emission factor arising from the disposal of tyre materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/ kg _{material}]
	$CEF_{Ii,E2a}$ and $CEF_{Di,E2a}$ shall be evaluated following sections 5.11.2.2 and 5.11.2.3	
6.4.8.2.1.2	Recycling	
	$C_{M,MBBM,E2a} = (1 - R_{E2a}) \times \sum_i (m_{Mi,E2a} \times CEF_{Mi,MBBM}) \quad (50)$	
	Where:	
	$C_{M,MBBM,E2a}$	means the specific GHG emissions in tyre materials recycling [kg CO ₂ eq]
	$m_{Mi,E2a}$	means each tyre material mass to which CFF is applied [kg _{material}]

$CEF_{Mi,MBBM}$ means GHG emission of a tyre material calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of material. [kgCO₂eq/ kg_{material}]

$CEF_{Mi,MBBM}$ shall be evaluated following section 5.11.2.1.

6.4.8.2.2 SLI battery

6.4.8.2.2.1 Disposal, Incineration

$$C_{E2b-1} = m_{E2b} \times \{ \sum_i (T_{Ii,E2b} \times CEF_{Ii,E2b}) + \sum_i (T_{Di,E2b} \times CEF_{Di,E2b}) \} \quad (51)$$

Where:

C_{E2b-1} means the GHG emissions in SLI battery incineration with thermal and electricity recovery ($C_{I,E2b}$) and disposal ($C_{D,E2b}$), which may include lead scrap treatment, electrolyte neutralisation treatment and transport [kgCO₂eq]

m_{E2b} means the mass of the SLI battery [kg_{component}]

$T_{Ii,E2b}$ means the i-th material mass fraction of the SLI battery mass that is sent to incineration [%]

$T_{Di,E2b}$ means the i-th material mass fraction of the SLI Battery mass that is sent to disposal [%]

$CEF_{Ii,E2b}$ means GHG emission factor arising from incineration with energy recovery of SLI battery materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{Di,E2b}$ means GHG emission factor arising from the disposal of SLI battery materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/ kg_{material}]

$CEF_{Ii,E2b}$ and $CEF_{Di,E2b}$ shall be evaluated following sections 5.12.2.2. and 5.12.2.3.

6.4.8.2.2.2 Recycling

$$C_{M,MBBM,E2b} = \sum_i (m_{Mi,E2b} \times CEF_{Mi,MBBM}) \quad (52)$$

Where:

$C_{M,MBBM,E2b}$ means the specific GHG emissions in SLI battery materials recycling [kg CO₂eq]

$m_{Mi,E2b}$ means the mass of each SLI battery material to which CFF is applied [kg_{material}]

$CEF_{Mi,MBBM}$ means GHG emission factor of a SLI battery material calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/ kg_{material}]

$CEF_{Mi,MBBM}$ shall be evaluated following section 5.11.2.1.

6.4.8.2.3 Airbag

$$C_{E2c} = m_{E2c} \times CEF_{D,E2c} \quad (53)$$

Where:

C_{E2c}	means the GHG emissions in Airbag disposal [kg CO ₂ eq]
m_{E2c}	means the mass of the Airbag(s) [kg _{component}]
$CEF_{D,E2c}$	means GHG emission factor of airbag arising from the proper disposal in kilogram of carbon dioxide equivalent per kilogram of airbag. [kg CO ₂ eq/kg _{component}]

6.4.8.2.4 Air conditioner (AC) refrigerant

$$C_{E2d} = m_{E2d} \times CEF_{D,E2d} \quad (54)$$

Where:

C_{E2d}	means the GHG emissions in AC refrigerant disposal [kg CO ₂ eq]
m_{E2d}	means the mass of the AC refrigerant, filled in air conditioner at vehicle production. [kg _{material}]
$CEF_{D,E2d}$	means GHG emission factor of AC refrigerant arising from the disposal in kilogram of carbon dioxide equivalent per kilogram of material., which may include fluorocarbons destruction, CO ₂ from destruction and transport. [kg CO ₂ eq/ kg _{material}]

$CEF_{D,E2d}$ shall be evaluated following section 5.11.2.3.

6.4.8.2.5 Waste Oil

$$C_{E2e} = m_{E2e} \times CEF_{I,E2e} \quad (55)$$

Where:

C_{E2e}	means the GHG emissions in waste oil incineration with thermal and electricity recovery [kg CO ₂ eq]
m_{E2e}	means the mass of waste oil [kg _{material}]
$CEF_{I,E2e}$	means GHG emission factor of waste oil arising from incineration with energy recovery in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/kg _{material}]

$CEF_{I,E2e}$ shall be evaluated following section 5.11.2.2.

6.4.8.2.6 Traction battery

6.4.8.2.6.1 Disposal, Incineration

$$C_{E2f-1} = (1 - R_{E2f-2} - R_{E2f-3}) \times m_{E2f} \times \{ \sum_i (T_{Ii,E2f} \times CEF_{Ii,E2f}) + \sum_i (T_{Di,E2f} \times CEF_{Di,E2f}) \} \quad (56)$$

Where:

C_{E2f-1}	means the GHG emissions in used battery pack proper treatment which includes battery pack incineration (where allowable) with thermal and electricity recovery ($C_{I,E2f}$) and disposal ($C_{D,E2f}$) which may include waste landfill and transport [kg CO ₂ eq]
R_{E2f-2}	means the battery repurposing ratio [%] in section 6.4.8.2.6.2

R_{E2f-3}	means the battery material recycling ratio [%] in section 6.4.8.2.6.3.
m_{E2f}	means the mass of the used battery pack [$\text{kg}_{\text{component}}$]
$T_{Ii,E2f}$	means the i-th material mass fraction of the traction battery mass at EoL $\{ (1 - R_{E2f-2} - R_{E2f-3}) \times W_{E2f} \}$ that is sent to incineration [%]
$T_{Di,E2f}$	means the i-th material mass fraction of the traction battery mass at EoL $\{ (1 - R_{E2f-2} - R_{E2f-3}) \times W_{E2f} \}$ that is sent to disposal [%]
$CEF_{Ii,E2f}$	means GHG emission factor arising from incineration with energy recovery of traction battery materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [$\text{kg CO}_2\text{eq}/\text{kg}_{\text{material}}$]
$CEF_{Di,E2f}$	means GHG emission factor arising from the disposal of traction battery materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [$\text{kg CO}_2\text{eq}/\text{kg}_{\text{material}}$]
$CEF_{Ii,E2f}$ and $CEF_{Di,E2f}$ shall be evaluated following sections 5.11.2.2. and 5.11.2.3.	

6.4.8.2.6.2 Secondary use (Repurposing)

The repurposing of the traction battery shall be specified and evaluated based on the regional regulation or market observation, data availability for parameters and verification criteria.

Battery repurposing Environmental Footprint (EF) compliant studies shall follow EF recommendations and regional regulations. Battery repurposing for other studies/other regions can follow other recommendations (e.g., the JAMA CFP guidelines)

Strong evidence shall be provided by the industry and the practitioner about the definition of the parameters, the definition of the new product substituted by the repurposed one, and the source of data to be used for modelling

In the case of applying the UNECE A-LCA CFF concept to the repurposing of the traction battery from the vehicle substituting a virgin battery into a different application, the evaluation will be based on the regulation or market observation, and the availability of data for parameters and verification criteria.

The evaluation will consist of two parts, each corresponding to the CFF components outlined in the CFF equation in section 5.11.2.1.

The production burden for the traction battery, which corresponds to CFF part 1, will be evaluated in the production stage of the traction battery. The burdens and benefits related to the output of secondary batteries, corresponding to CFF part 3, will be evaluated in the disposal and recycling stage as the Modular Burdens and Benefits method for traction battery repurposing. The value derived from the Modular Burdens and Benefits method for traction battery repurposing shall be reported and included in the total vehicle CFP.

Modular Burdens and Benefits Method formula for traction battery repurposing

$$C_{TBR,MBBM} = (1 - A_{TBR})R_{2,TBR} \times \left(E_{recEoL,TBR} - E_{V,TBR}^* \times \frac{Q_{sout,TBR}}{Q_{p,TBR}} \right) \quad (57)$$

Where:

$C_{TBR,MBBM}$	means the specific GHG emissions of traction battery repurposing in kilogram of carbon dioxide equivalent per kilogram of battery pack. [kg CO ₂ eq/battery pack]
A_{TBR}	means the allocation factor of burdens and credits between supplier and user of repurposed battery.
$R_{2,TBR}$	means the proportion of the battery at EoL that will be reused in a subsequent system. [%]
$\frac{Q_{sout,TBR}}{Q_{p,TBR}}$	means the quality of outgoing secondary traction battery / quality of virgin battery substituted by the repurposed battery
$E_{V,TBR}^*$	means the specific GHG emissions (per unit of analysis) arising from the production of virgin battery that is going to be substituted by the repurposed battery. [kg CO ₂ eq/battery pack]
$E_{recEoL,TBR}$	means the specific GHG emissions (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process. [kg CO ₂ eq/battery pack]

Datasets ($E_{V,TBR}^*$, $E_{recEoL,TBR}$) to be used in the Modular Burdens and Benefits method for the traction battery repurposing may be collected as primary data. Parameters in the Modular Burdens and Benefits Method for traction battery repurposing (A_{TBR} , $R_{2,TBR}$, $\frac{Q_{sout,TBR}}{Q_{p,TBR}}$) may be defined as default values in reference documents.

6.4.8.2.6.3 Material recycling

$$C_{M,MBBM,E2f} = \sum_i (m_{Mi,E2f,Material} \times CEF_{Mi,MBBM,Material}) + \sum_i (m_{E2f,cells} \times CEF_{MBBM,cells}) \quad (58)$$

Where:

$C_{M,MBBM,E2f}$	means the specific GHG emissions arising from traction battery materials recycling. [kg CO ₂ eq]
$m_{Mi,E2f,Material}$	means the mass of each traction battery material to which CFF is applied except battery cells. [kg _{material}]
$m_{E2f,cells}$	means the mass of traction battery cells derived from battery pack dismantling to which CFF is applied. [kg _{battery cells}]
$CEF_{Mi,MBBM,Material}$	means GHG emission factor arising from of the material recycling of a traction battery pack material except for material in cells calculated with the MBBM in

kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{MBBM,cells}$ means GHG emission factor arising from the recycling process applied to traction battery cells calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of traction battery cells. [kg CO₂eq/kg_{battery cells}]

$CEF_{Mi,MBBM,Material}$ or $CEF_{MBBM,cells}$ shall be evaluated following section 5.11.2.1.

In case that the used battery is repurposed, the recycle of the material which is used in the repurposed traction battery shall not be evaluated.

6.4.8.2.7 Catalytic converters

6.4.8.2.7.1 Disposal

$$C_{E2g-1} = m_{E2g} \times \sum_i (T_{Di,E2g} \times CEF_{Di,E2g}) \quad (59)$$

Where:

C_{E2g-1} means the GHG emissions in catalytic converters disposal, which may include waste landfill after recycling process. [kg CO₂eq]

m_{E2g} means the mass of catalytic converters [kg_{component}]

$T_{Di,E2g}$ means the i-th material mass fraction of the catalytic converters mass that is sent to disposal [%]

$CEF_{Di,E2g}$ means GHG emission factor arising from the disposal of catalytic converters materials, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{Di,E2g}$ shall be evaluated following section 5.11.2.3.

6.4.8.2.7.2 Recycle

$$C_{M,MBBM,E2g} = \sum_i (m_{Mi,E2g} \times CEF_{Mi,MBBM}) \quad (60)$$

Where:

$C_{M,MBBM,E2g}$ means the specific GHG emissions in catalytic converters materials recycling [kg CO₂eq]

$m_{Mi,E2g}$ means the mass of each catalytic converter material to which CFF is applied [kg_{material}]

$CEF_{Mi,MBBM}$ means GHG emission factor of a catalytic converter material calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO₂eq/kg_{material}]

$CEF_{Mi,MBBM}$ shall be evaluated following section 5.11.2.1.

6.4.8.3 E3: Automobile shredder residue (ASR) disposal and recycling process

$$C_{E3} = \sum_i \{m_{i,ASR} \times (CEF_{Ii,ASR} + CEF_{Di,ASR})\} \quad (61)$$

Where:

C_{E3} means the GHG emissions in ASR incineration with thermal and electricity recovery ($C_{I,ASR}$) and disposal

	$(C_{D,ASR})$ which may include the waste landfill and the transport [kg CO ₂ eq]
$m_{i,ASR}$	means the mass of each combustible material in ASR [kg _{material}]
$CEF_{Ii,ASR}$	means GHG emission factor arising from incineration with energy recovery of combustible materials in ASR, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/kg _{material}]
$CEF_{Di,ASR}$	means GHG emission factor arising from the disposal of combustible materials in ASR, expressed in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/kg _{material}]

$CEF_{Ii,ASR}$ and $CEF_{Di,ASR}$ shall be evaluated following sections 5.11.2.2. and 5.11.2.3.

6.4.8.4 E4: Materials recycling processes

$$C_{M,MBBM,E4} = \sum_i (m_{Mi,E4} \times CEF_{Mi,MBBM}) \quad (62)$$

Where:

$C_{M,MBBM,E4}$	means the specific GHG emissions in materials recycling [kg CO ₂ eq]
$m_{Mi,E4}$	means the mass of each material to which CFF is applied [kg _{material}]
$CEF_{Mi,MBBM}$	means GHG emission factor of a material calculated with the MBBM in kilogram of carbon dioxide equivalent per kilogram of material. [kg CO ₂ eq/kg _{material}]

$CEF_{Mi,MBBM}$ shall be evaluated following section 5.11.2.1.

6.4.8.5 E5: Transport processes

$$C_{E5} = \sum_i (m_{i,E5} \times D_{i,E5} \times CEF_{Ti}) \quad (63)$$

Where:

C_{E5}	means the specific GHG emissions in transport processes [kg CO ₂ eq]
$m_{Mi,E4}$	means the mass of each transported goods [t]
$D_{i,E5}$	means each transport distance [km]
CEF_{Ti}	means GHG emission factor arising from a transport in kilogram of carbon dioxide equivalent per tonne of transported goods and per kilometre of transport distance. [kg CO ₂ eq/t-km]

Transport processes in disposal and recycling stage may cover the following transport processes.

- (a) Customer → Dismantler

- (b) Dismantler → Shredder
- (c) Shredder → ASR recycler
- (d) ASR recycler → Landfill

$D_{i,E5}$ and CEF_{Ti} shall be evaluated according to section 5.11.2.3.

7. Reporting

The results of the A-LCA based on these guidelines shall be reported without bias to the intended audience and in accordance with section 6 “Reporting” of ISO 14040:2006. The results, data, methods, assumptions and limitations described in the background report shall be presented in sufficient detail to allow the reviewers/verifiers and the targeted audience to comprehend the determination process and its CFP value. Government authorities may introduce additional reporting requirements to reflect the stringency of their specific LCA requirements.

For all levels of the level concept, this background report is the basis for critical review / verification. Additionally, the following information shall be described within the background report as a summary report whenever the results of the A-LCA are available to the public.

All reporting results shall be rounded to whole numbers (x in Table 20 and Table 21) and reporting of emission factor result shall be rounded to two decimals places (x in Table 20 and Table 21).

Table 20: Required information in the summary report

General information		
	Practitioner	Name, affiliation, qualifications
	Date of report	DD-MM-YYYY
Goal of the study:		
	Purpose of the study;	Reporting/strategy
	Target audiences;	
Applicable Methodology Level		1/2/3/4
Applicable Chain of Custody model		if applicable
	Mass Balance	✓/lifestage or no-use
	Book&Claim	✓/lifestage or no-use
Vehicle configuration (Level 3&4)		
	Declared vehicle configuration	Model name and version, vehicle type, powertrain type, specific features or variants considered
	Actual mass	
	Battery configuration, if applicable	Model identifier, battery capacity (kWh), battery chemistry, number of cells or modules, battery mass (kg or lb)
	LCA group ID	Alphanumerical, for example L3XXX
Geographic considerations		

	Location of the vehicle production factory(ies)			
	Use-stage macro regions or country considered			
	Geographical considerations for end-of-life			
	Results (t CO ₂ eq/veh. or g CO ₂ eq/p-km)		x	
	Material & parts & vehicle production stage		x	
	Material production stage		optional	
	Parts and vehicle production stage		optional	
	Use stage		derived from	
		Fuel consumption, if applicable		type approval
		Electric consumption, if applicable		type approval
		Discrepancy factor		
		Deterioration factor		
		Service life (km)		
		Vehicle lifetime (years)		
		Vehicle lifetime (km)		
		Carbon emission factor (fuel), if applicable		
			Modelling	Statistic/dynamic/dispatch
			Sources of the emission factor (e.g. LCI database)	
	Maintenance and consumables list (as attached)			
	End-of-Life stage (Traction battery excluded, MBBM included)		x	
		RCM based EoL result ^{*1}	x	
		MBBM result ^{*2}	Material: x Energy: x	
	Traction batteries			
		Material & production stage		if available
		Material production stage		if available
		Production stage		
		End of Life stage (MBBM included)		
RCM based EoL result ^{*1}				
	MBBM result ^{*2}		Material; Energy; Repurposing;	
Representative vehicle				
	Configuration		Model name and version, model identifier, vehicle type, powertrain type, specific features or variants considered	
	Actual mass without traction battery			
	LCA Group ID		Same as declared vehicle	
		ICE, OVC-HEV, NOVC-HEV, PEV, FCEV and FCHV.		NOVC-HEV
		Emission factor Production EF _{Prod}		y
		Emission factor End of life EF _{EoL}		y
	Material production stage		if available	
Results of RV without traction battery				
	Parts & vehicle production stage		x	
	Applied energy modelling			
	Applied secondary data base or set name		if available	
	Material production and assembly stage:		x	
	Applied energy modelling			
	Applied secondary data base or set name		if available	

	End-of-Life stage	x
	RCM based EoL result *1	x
	MBBM result *2	Material: x Energy: x
	Applicable recycling modelling	RCM or CFF
	In case of CFF application, CFF applied material type according to section 5.11.2.1	Steel, Aluminum, Copper
	Applicable material type sent to incineration with energy recovery to section 5.11.2.2	PP, ABS, Rubber
	Applied energy modelling	
	Applied secondary data base or set name	(if single source applied)

*1 Impacts of the ELV treatment according to RCM basis system boundaries as defined in Figure 26, corresponding to $C_{EoL,RCM}$ specified in section 6.4.8.

*2 Burdens and Benefits of the ELV treatment and material recycling according to MBBM method system boundaries as defined in Figure 26 corresponding to $C_{EoL,MBBM}$ specified in section 6.4.8.

Table 21: Required information in the summary report for parts

General information		
	company	Name
	date of report	DD-MM-YYYY
	product	Name, Product-ID
	declared unit	Piece or Kilogram
	reference period	Production year
Geographic considerations		
	Location of production	City/country/region
Applied Methodology Level		1 / 2 / 3 / 4
Applied Chain of Custody Model		
	Mass Balance	Yes / no
	Book & Claim	Yes / no
Energy Modelling		
	Applied energy modelling	Location/market based
	Applied secondary data base or set name	if available
Data Types		
	Primary Data Share	x %
	Primary Activity Data Share	x %
	LGPP (LCA Group Production Parts)	Yes / no
	GWP including biogenic uptake/removal	Yes / no
	Transport emission to customer included	Yes / no
Results (kgCO ₂ eq/declared unit)		
	GWP total including biogenic uptake	x
	GWP total _{as} including biogenic uptake	x
	GWP total excluding biogenic uptake	x
	GWP total fossil	x
	GWP net biogenic uptake	x
	Biogenic carbon content	x
	Attributed Biogenic carbon content	x

	Transport emissions to customer	
	GWP transport including biogenic uptake	x.or n.a.
	GWP transport excluding biogenic uptake	x or n.a.
	GWP transport total fossil	x or n.a.
	Carbon emission factor (fuel), if applicable	y

As outlined in ISO 14044, data quality considerations and uncertainty shall be documented in the study summary report and assessed using a suitable methodology such as those described by ILCD⁴⁵, ecoinvent, and U.S. EPA^{46 47}.

8. Verification process

Verification shall be conducted to confirm that the results of the A-LCA have been obtained in accordance with these guidelines while ensuring transparency and consistency. Review process and the reviewers need to meet the requirements of ISO 14064-3:2019 and ISO 14071:2024. Therefore, for A-LCA studies of Level 1, 2, 3 and 4 a critical review shall be conducted according to ISO 14040:2006 section 7 („Critical Review“) with additional focus on compliance with these guidelines. The verification statement shall be available on the report of A-LCA studies intended for publication.

Verification thus refers to

- (a) methodology applied,
- (b) input data used,
- (c) interpretation of results,
- (d) interpretation of robustness of the study
- (e) reporting of these topics in the background report and
- (f) check of the numerical results of the calculation.

For Level 1 and 2, LCA practitioners should decide whether to perform an internal or external critical review in accordance with ISO 14040:2006 section 7 whereas for Level 3 and 4 an external third party review is mandatory. For Level 3 and 4, the verification shall be done from the perspective of the vehicle and therefore will be conducted at OEM level. It shall also include the definition of the LCA group production (see 5.12.2.1) as well as the choice of the representative vehicle for which the OEM calculates the LCA. Where the OEMs A-LCA include verified primary information / primary data from suppliers, no re-verification of these data

⁴⁵ European Commission. (2010). ILCD handbook: General guide for Life cycle Assessment - Detailed guidance. Italy: European Union.

⁴⁶ U.S. EPA. (2016). Guidance on Data Quality Assessment for Life Cycle Inventory Data. EPA Document No. EPA/600/R-16/096.
<https://nepis.epa.gov/Exe/ZyPDF.cgi/P100R8JX.PDF?Dockey=P100R8JX.PDF>

⁴⁷ U.S. EPA. (2024). Data Quality Assessment Method to Support the Label Program for Low Embodied Carbon Construction Materials (Version 1).
https://www.epa.gov/system/files/documents/2024-08/dqa-method_v2_final.pdf

is necessary. The verification of the OEMs A-LCA calculation system shall include data collection, internal sources, assumptions, calculation processes and tools applied. In case an LCA calculation system is verified and that verification is still valid, no re-verification of the system is required for an A-LCA study based on the verified LCA calculation system. OEMs shall make the system verification statements available to the authorities according to their requests. The same holds true for suppliers who are responsible for providing data in accordance with these guidelines.

9. Guidelines Maintenance and Revision

The guidelines shall be reviewed and updated as necessary to ensure their continued relevance, consistency, scientific robustness, and alignment with evolving industrial practices, technological developments, international standards, and regulatory requirements.

A review and revision may be initiated when significant developments occur, including the following:

- revision of relevant international standards, including ISO standards;
- introduction or revision of regulatory requirements affecting automotive life cycle assessment;
- publication of substantially improved background datasets, emission factors, or calculation methodologies;
- technological developments or widespread deployment of new technologies with a material influence on life cycle greenhouse gas emissions;
- significant changes in industry practices or supply chains;
- identification of methodological inconsistencies, ambiguities, or implementation challenges.

Where necessary, the calculation methodology, specifications, assumptions, and referenced datasets described in the guidelines shall be reviewed and updated accordingly.

Any revision shall be supported by documented technical justification and, where appropriate, stakeholder consultation.

Annex

The following table summarizes the formulas and equations to use, depending on level, powertrain and method of EoL modelling..

$C_{GHG} = CEF_{GHG} \times A_{GHG}$	(1)	33
$C_{total} = \sum_i C_i$; $C_{as} = \sum_i C_i $	(2)	34
$PDS = \frac{\sum_i Part\ of\ CFP\ based\ on\ primary\ data }{C_{as}}$	(3)	34
$PADS = \frac{\sum_i Part\ of\ CFP\ based\ on\ primary\ activity\ data }{C_{as}}$	(4)	34
$PDS = PDS_{aggregated} = \frac{\sum_i (C_{as,i} \cdot PDS_i)}{\sum_i C_{as,i}}$	(5)	34
$PADS = PADS_{aggregated} = \frac{\sum_i (C_{as,i} \cdot PADS_i)}{\sum_i C_{as,i}}$	(6)	34
$(1-R_1)E_V + R_1 \times \left(AE_{rec} + (1-A)E_V \times \frac{Q_{sin}}{Q_p} \right) + (1-A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right)$	(7)	46
$(1-R_1)E_V + R_1 \times E_{rec}$	(8)	46
$-(1-A)R_1 \times \left(E_{rec} - E_V \times \frac{Q_{sin}}{Q_p} \right)$	(9)	46
$(1-A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right)$	(10)	46
$CEF_M = CEF_{M,CFE} = CEF_{M,RCM} + CEF_{M,MBBM}$	(11)	47
$CEF_{M,RCM} = (1-R_1)E_V + R_1 \times E_{rec}$; <i>CFE part 1</i>	(12)	47
$CEF_{M,MBBM} = -(1-A)R_1 \times \left(E_{rec} - E_V \times \frac{Q_{sin}}{Q_p} \right) + (1-A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{sout}}{Q_p} \right)$; <i>CFE part 2 and 3</i>	(13)	47
$CEF_I = (1-B)R_3 \times (E_{ER-LHV} \times X_{ER,heat} \times E_{SE,heat-LHV} \times X_{ER,elec} \times E_{SE,elec}) =$ $(1-B)R_3 \times (E_{ER} - CEF_{I,MBBM})$	(14)	48
$CEF_D = (1-R_2-R_3) \times E_D$	(15)	49
$C_{VP,i} = EF_{Prod} \times m_i$	(16)	54
$C_{VP,i} = C_{MP} + C_{PVA} + C_{TP}$	(17)	54
$C_{VP,i} = EF_{Prod} \times (m_i - m_{Bat/Ves}) + C_{VP,Bat/Ves}$	(18)	55
$EF_{Prod} = \frac{C_{VP,RV}}{m_{RV}}$	(19)	55
$EF_{Prod} = \frac{C_{VP,RV} - C_{VP,Bat/Ves}}{m_{RV} - m_{Bat/Ves}}$	(20)	55
$C_{EoL,i} = EF_{EoL} \times m_i$	(21)	57
$C_{EoL,i} = EF_{EoL} \times (m_i - m_{Bat/Ves}) + C_{EoL,Bat/Ves}$	(22)	57
$EF_{EoL} = \frac{C_{EoL,RV}}{m_{RV}}$	(23)	58
$EF_{EoL} = \frac{C_{EoL,RV} - C_{EoL,Bat/Ves}}{m_{RV} - m_{Bat/Ves}}$	(24)	58

$C_{tot} = C_{VP} + C_{Use\ Stage} + C_{EoL}$	(25)	59
$C_{VP} = C_{MP} + C_{PVA} + C_{TP}$	(26)	59
$C_{M,RCM} = \sum_i(C_{MPi,RCM}) = \sum_i \left(m_{MPi,RCM} \times \frac{1}{Y_{MPi}} \times CEF_{MPi,RCM} \right)$	(27)	67
$C_{M,RCM} = \sum_i(C_{MPi,RCM}) = \sum_i \left[m_{Mi} \times \frac{1}{Y_{MPi}} \times \{ R_{1i} \times CEF_{MPi,RCM,RMP} + (1-R_{1i}) \times \right.$ $\left. CEF_{MPi,RCM,VMP} \} \right]$	(28)	68
$C_{DP} = C_{min} + EF_{LGPP} * (pc_{DP} - pc_{min})$	(29)	71
$C_{PVA} = CEF_{PVA} \times m_{NM}$	(30)	74
$C_{PVA} = C_{OP} + \sum_i(CEF_{PVA,i} \times m_{i,j})$	(31)	75
$C_{PVA} = \sum_i(C_{HS,i}) + C_{BV}$	(32)	76
$C_{PVA} = \sum_i(C_{TP1,i} + C_{T1,i}) + C_{op}$	(33)	77
$C_{Tj} = \sum_i(C_{TPj-1,i} + C_{Tj-1,i}) + C_{op,j}$	(34)	77
$C_{Use\ Stage} = C_{Energy} + C_{Leakages} + C_{Maintenance}$	(35)	80
$C_{Energy} = \sum C_{certification} \times f_{discrepancy} \times f_{deterioration} \times Service\ life$	(36)	85
$EC_{certification} = C_{certification}/CEF_{energy}$	(37)	85
$C_{maintenance} = \sum_{i=1}^n CEF_i * f_{i,maintenance}$	(38)	90
$Frequency_{distance} = \frac{Service\ life\ [km]}{Maintenance\ interval\ [km]}$	(39)	92
$Frequency_{duration} = \frac{Service\ life\ [years]}{Maintenance\ interval\ [years]}$	(40)	92
$C_{EoL} = C_{EoL,RCM} + C_{EoL,MBBM}$	(41)	100
$C_{EoL,RCM} = C_{E1} + \sum_j C_{E2j,RCM} + C_{E3,RCM} + C_{E5}$	(42)	101
$C_{E2j,RCM} = m_{E2j} \times \{ \sum_i (T_{ii,E2j} \times E_{ERi,E2j}) + \sum_i (T_{Di,E2j} \times CEF_{Di,E2j}) \}$	(43)	101
$C_{E3,RCM} = \sum_{i,ASR} \{ m_{i,ASR} \times (E_{ERi,ASR} + CEF_{Di,ASR}) \}$	(44)	101
$C_{EoL,MBBM} = C_{M,MBBM} + C_{I,MBBM} + C_{TBR,MBBM}$	(45)	102
$C_{M,MBBM} = \sum_j C_{M,MBBM,E2j} + C_{M,MBBM,E4}$	(46)	102
$C_{I,MBBM} = \sum_{i,j} (m_{E2j} \times T_{ii,E2j} \times CEF_{Ii,MBBM,E2j}) + \sum_{i,ASR} (m_{i,ASR} \times CEF_{Ii,MBBM,ASR}) \}$	(47)	102
$C_{E1} = m_{E1} \times T_{E1} \times CEF_{D,E1}$	(48)	102
$C_{E2a-1} = (1-R_{E2a}) \times m_{E2a} \times \{ \sum_i (T_{ii,E2a} \times CEF_{Ii,E2a}) + \sum_i (T_{Di,E2a} \times CEF_{Di,E2a}) \}$	(49)	103
$C_{M,MBBM,E2a} = (1-R_{E2a}) \times \sum_i (m_{Mi,E2a} \times CEF_{Mi,MBBM})$	(50)	103
$C_{E2b-1} = m_{E2b} \times \{ \sum_i (T_{ii,E2b} \times CEF_{Ii,E2b}) + \sum_i (T_{Di,E2b} \times CEF_{Di,E2b}) \}$	(51)	104
$C_{M,MBBM,E2b} = \sum_i (m_{Mi,E2b} \times CEF_{Mi,MBBM})$	(52)	104
$C_{E2c} = m_{E2c} \times CEF_{D,E2c}$	(53)	104
$C_{E2d} = m_{E2d} \times CEF_{D,E2d}$	(54)	105
$C_{E2e} = m_{E2e} \times CEF_{I,E2e}$	(55)	105
$C_{E2f-1} = (1-R_{E2f-2}-R_{E2f-3}) \times m_{E2f} \times \{ \sum_i (T_{ii,E2f} \times CEF_{Ii,E2f}) + \sum_i (T_{Di,E2f} \times CEF_{Di,E2f}) \}$	(56)	105

$C_{TBR,MBBM} = (1-A_{TBR})R_{2,TBR} \times \left(E_{recEoL,TBR} - E_{V,TBR}^* \times \frac{Q_{sout,TBR}}{Q_{p,TBR}} \right) \dots\dots\dots$	(57)	107
$C_{M,MBBM,E2f} = \sum_i (m_{Mi,E2f,Material} \times CEF_{Mi,MBBM,Material}) + \sum_i (m_{E2f,cells} \times CEF_{MBBM,cells}) \dots\dots$	(58)	107
$C_{E2g-1} = m_{E2g} \times \sum_i (T_{Di,E2g} \times CEF_{Di,E2g}) \dots\dots\dots$	(59)	108
$C_{M,MBBM,E2g} = \sum_i (m_{Mi,E2g} \times CEF_{Mi,MBBM}) \dots\dots\dots$	(60)	108
$C_{E3} = \sum_i \{m_{i,ASR} \times (CEF_{Ii,ASR} + CEF_{Di,ASR})\} \dots\dots\dots$	(61)	108
$C_{M,MBBM,E4} = \sum_i (m_{Mi,E4} \times CEF_{Mi,MBBM}) \dots\dots\dots$	(62)	109
$C_{E5} = \sum_i (m_{i,E5} \times D_{i,E5} \times CEF_{Ti}) \dots\dots\dots$	(63)	109