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**Economic Commission for Europe**

Inland Transport Committee

**World Forum for Harmonization of Vehicle Regulations**

**Consolidated Resolution No. 8 (R.E.8) concerning** **Automotive Life Cycle Assessment (A-LCA)**

The text reproduced below was prepared by the Informal Working Group on Automotive - Life Cycle Assessment (A-LCA) and was adopted on XX XXXX 202X by the World Forum for Harmonization of Vehicle Regulations (WP.29). It is based on document ECE/TRANS/WP.29/202X/XXX.

**3.2. General Methodology**

**3.2.1. Level Concept [SG1]**

**Background**

The Level Concept was developed in UNECE IWG A-LCA to reflect the different motivations and goals to tackle a vehicle 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 takes into account the increasing demand for LCA results based on primary data. 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 3.2.1‑1.: Life cycle assessment framework according to ISO 14040

Interpretation

Life cycle assessment framework

Impact assessment

Inventory analysis

Goal and scope definition

Direct applications:

* Product development and improvement
* Strategic planning
* Public policy making
* Marketing
* Other

According to ISO 14040 standard, a life cycle assessment (LCA) consists of four steps (Figure 3.2.1‑1.). 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.”[[1]](#footnote-2)

In a nutshell, it is crucial to know the intended purpose and application of an LCA to define appropriate requirements for modelling the product system.

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 OEM’s (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 (compare Figure 3.2.1‑1, box on the right). Currently, an extension of applications towards reduction measure implementation and reporting – especially in the context of decarbonization and circular economy (CE) – can be observed by various stakeholders with different expectations from automotive LCAs ~~(see Figure 3.2.1‑2.)~~.

Stakeholders:

* Society/ Policy makers
* Green finance & ESG rating
* Customer
* OEM
* Suppliers

Motivations

* Decision support of policy making
* Comparison / rating
* Communication /marketing
* Fair competition
* Incentivation
* Internal steering of decarbonization
* Proof of decarbonization
* Identification of reduction potentials

~~Figure 3.2.1‑2 : Evolution of implementation areas for vehicle LCAs and involved stakeholders~~

„incentivising“

„decision support for policy making“

„communication / marketing”

„comparison / rating“

„internal steering of decarbonisation“

„proof for decarbonisation effort & results“

„identification of hotspots & reduction potentials“

„fair competition“

Green finance

Society /

Policy makers

& ESG ratings

Example of OICA input

Different stakeholders, different expectations from automotive LCAs

Ein Bild, das Symbol, Kreis, Logo, Grafiken enthält.

Automatisch generierte Beschreibung

As a consequence, this resolution on vehicle LCA addresses different types of vehicle use cases and highlights where these require different scope definitions and requirements concerning methodology and data granularity.

**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 phases in the foreground system (supply chain and vehicle production).

In general, every LCA practitioner who has the necessary data (granularity) available for the respective level / purpose, may conduct an LCA study for this level. However, in practice mainly OEMs have access to the bills of material (BOM) which are required as basis of the vehicle models for Levels 2 to 4.

In addition, following the product development cycle, in an early stage of product/technology development such specific information is also missing and therefore Level 1 LCA study provides possibility to support strategic decisions. During technical development, data on BOM becomes available and allows for Level 2 analysis. Once the product under study reaches start of production product specific primary data becomes available and Level 3 LCA study can be conducted.

Level 1 (multiple approaches possible)

* Purpose:
  + - General uses, including research and strategic public policy making potentially without involvement by industry
    - Industry strategic planning: future projection, fleet modelling, etc.
* Vehicle modelling:
  + - Generic fuel-powertrain model normalized by vehicle mass
    - Generic part and material composition
    - User-defined concept of vehicle modelling
    - General guidance can be found in ‘3.2.5 Representative vehicle’
* Approach for the application of the level concept:
  + - Flexible in applying “mix&match” of ~~levels~~methodologies from different life cycle stages in this resolution, depending on the purpose of the study, availability of data, etc.
    - For comparability and transparency, practitioners should specify and maintain the discrete ~~levels~~combination of methodologies (“mix&match”) used for their applications

Level 2 (multiple approaches possible)

* + - Purpose
    - Research and strategic public policy development supported by OEM’s documentation (Bill of material (BOM) & material information system (IMDS/CMDS) for composition)
    - OEM’s internal assessment and strategic planning
    - Product development and improvement
    - Marketing, e.g. of technology choices
* Vehicle modelling
  + - Existing vehicle model of choice for assessment
    - Bill of material (BOM) & material information system (IMDS/CMDS) for composition to be provided by OEMS
    - General guidance can be found in ‘3.2.5 Representative vehicle’
* Approach for the application of the level concept
  + - Flexible in applying “mix&match” of ~~levels~~methodologies from different life cycle stages in this resolution, other than vehicle modelling, depending on the purpose of the assessment
    - For comparability and transparency, practitioners should specify and maintain the discrete ~~levels~~combination of methodologies (“mix&match”) used for their applications

Level 3 (single fixed approach)

* Purpose
  + - OEM’s official reporting for public information, marketing, etc.
    - OEM’s reporting for government programs
* Vehicle modelling
  + - Representative vehicle for reporting (as described in ‘3.2.5 Representative vehicle)
    - Bill of material (BOM) & material information system (IMDS/CMDS) for composition,
    - for hotspot parts applying “part-by-part” supply-chain modelling instead
    - Harmonized material classification
* Approach for the application of the level concept
  + - Each lifecycle stage should specify one fixed, proper ~~level~~methodology for one harmonized A-LCA approach.

Level 4 (single fixed approach)

* Purpose
  + - OEM’s and supplier’s official reporting for public information, marketing, etc.
    - OEM’s and supplier’s official reporting for government programs
* Vehicle modelling
  + - Representative vehicle for reporting (as described in ‘3.2.5 Representative vehicle)
    - Full supply-chain and vehicle production modelling
* Approach for the application of the level concept
  + - Full lifecycle modelling (material production, part & vehicle production, usage, and end-of-life)
    - Rules required for chain of custody

According to questions of the assessment granularity, product specificity and scope of 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 category 1-1 vehicles, Level 4 is more focused on the fine variations of individual vehicle models.

The choice of representativity and specificity also concerns downstream life cycle phases (Well To Wheel (WtW) / use phase, End of Life (EoL)) or background system processes (e.g. energy production). Also, for the use phase or EoL the data for a specific vehicle could be used. This implies however that the LCA is done retrospective. 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 milage) should be used. For predictive data there is no way to provide primary data, as you cannot measure something that happens in the future.

Table 3.2.1‑1 : General structure of the level concept

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Purpose** | **Industry involvement** | **Degree of freedom** | **vehicle model** | **supply chain model** | **Possible audiences** |
| Level 1 | strategy | No | multiple approaches possible | generic | generic | policy makers, researchers |
| Level 2 | strategy | Yes, through OEM’s documentation | multiple approaches possible | BOM1 & MDS2 | generic | company strategy/product developers, customers |
| Level 3 | reporting | OEM’s reporting, including hotspot suppliers’ reporting | single fixed approach | BOM1 & MDS2 | partly specific | government programs, customers |
| Level 4 | reporting | OEM’s and extensive suppliers’ reporting | single fixed approach | BOM1 & MDS2 | mainly specific | government programs, customers |

The vehicle representing a big population of vehicles in Level 1 are very often no real but virtually defined vehicles. Consequently, no primary data exists, and only secondary data can be used to model e.g. supply chain emissions. On the other hand, Level 4 profits from more and more use of primary data representing the real / company specific supply chains.

So far there is the general observation, the more granular and detailed a system model for a LCA is, the higher the identified emissions are. The situation could change if ~~Unless~~ there is an abundance of LCA data to derive highly representative and high-quality secondary data~~, situation will stay like that~~.

It is crucial to understand that the magnitude of emissions is only comparable between studies on the same level. Vehicle LCAs with different level choice may not be compared on a quantitative basis. The methodology for modelling, including primary/secondary data share, of the different lifecycle phases might differ between levels due to the scope change.

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”.



**3.2.2.**

Data set () to be used in CFF and CFF parameter () may be referred, among others, to the following data set and reference documents.

- Data set ; EF compliant data sets, IDEA

- Reference documents; PEFCR Annex C, JAMA CFP guideline

**3.2.10.2. Incineration with energy recovery [SG5]**

The incineration with energy recoverry shall be evaluated by following energy formular in Circular Footprint Formula (CFF).

-; Proportion of the material in the product that is used for energy recovery at EoL.

-; 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, …). [kgCO2e/kg]

-,

; Specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity respectively. [kgCO2e/MJ]

-,

: The efficiency of the energy recovery process for both heat and electricity.

- ; Lower Heating Value of the material in the product that is used for energy recovery. [MJ/kg]

Thermal energy deduction and electric energy　deduction () shall be evaluated and merged as energy Modular Burdens and Benefits method. Energy Modular Burdens and Benefits method shall be merged to material Modular Burdens and Benefits method. Modular Burdens and Benefits method separately reported and included into total vehicle CFP .

Data set (,) to be used in CFF and CFF parameter (,) may be referred, among others, to the following data set and reference documents.

- Data set ; EF compliant data sets, IDEA

- Reference

documents; PEFCR Annex C, JAMA CFP guideline

**3.2.10.3. Disposal [SG5]**

The disposal shall include all of waste treatment except for the material and parts recycling and the incineration with energy recovery, e.g. landfill. The disposal shall be evaluated by following disposal formular in Circular Footprint Formula (CFF)

-; Proportion of the material in the product that will be recycled (or reused) in a subsequent system. [%]

-; Proportion of the material in the product that is used for energy recovery at EoL.

-: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.

Dataset (ED) to be used in CFF and CFF parameter (R2, R3) may be referred, among others, to the following datasets and reference documents.

- Data set; EF compliant data sets, IDEA

- Reference documents; PEFCR Annex C, JAMA CFP guideline "

**3.2.11. Chain of Custody [SG3]**

Chain of custody is an administrative process by which information about materials is transferred, monitored, and controlled as those materials move through supply chains [ISO 22095:2020]. There are, in principle, four possible chain of custody models, illustrated in Figure 3.2.11‑1. Their common objective is to guarantee correct accounting and corroborate a link between ingoing content, e.g., ‘sustainable’, ‘recycled’ or ‘organic’ by harmonized definitions, and the final outgoing product. They differ whether it is a physical or administrative link. Furthermore, they differ in the set of rules for balancing, and the option to keep materials streams segregated or not[[2]](#footnote-3).

Figure 3.2.11‑1 : Overview of chain of custody models

Mass Balance

Identity Preservation

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Automatisch generierte Beschreibung

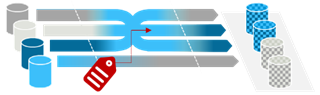
Out

Process

In

In

Out



Segregation

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Out

Out

In

In

The following table was adapted from Ellen Macarthur Foundation Whitepaper [ref] and provides high-level explanations and differentiations for the four chain of custody models:

Table 3.2.11‑1: Explanation chain of custody models

[adapted from the above-cited [EMF Whitepaper](https://emf.thirdlight.com/link/f1phopemqs36-8xgjzx/@/preview/1?o), page 11]

| **Model** | **Explanation** | **Example** |
| --- | --- | --- |
| **Identity preservation** | It is possible to physically track the product to its desired origin, ensuring unique trace­ability and physical separation of products from other sources along the supply chain. | Buying food from a single certified producer. |
| **Segregation** | Consists in the aggregation of volumes of products of identical origin or produced accor­ding to the same standards in one stock item. | Buying food from a trader that exclusively handles identically certified supplies |
| **Mass balance** | Considering the output, no physical or che­mical difference exists between in-scope and out-of-scope. It involves balancing volume reconciliation to ensure the exact volumes of in and out-of-scope source is maintained along the supply chain. Given that the volume or the ratio of sustainable material integrated is reflected in the product produced and sold to customers. This model requires that a reconciliation period is defined (e.g., a month, a year). | Buying a certain percentage of a supply from certified origin. Applies to, e.g., sustainable forestry for wooden materials, recycled, bio-based or renew­able materials, organic cotton |
| **Book and claim – restricted certi­ficate trading** | The certified product/component is disconnected from the certification data but belongs to the same production system or value chain. The certified product evolves in separate flows from the certified supply. Certificates are issued at the beginning of the supply chain by an independent body reflecting the sustainable content of supplies. The intended outcome is that outputs from one supply chain is associated with total claims corresponding to the certified input. | Buying material with renewable/recycled/ biobased content.  Certificates with guarantee of origin **or comparable certifications** declaring e.g., recycled, renewable, biobased content.  CO2 capture certificates from a production system con­trolled by the company, e.g., carbon capture and storage. |

To calculate the PCF according to this Resolution, all types of models may be taken into account if the requirements listed below are met and an independent third-party chain of custody verification for the balance of materials is available. The balance between input and output shall be correct.

The mass balance approach helps enable fossil raw materials to be replaced by more sustainable alternative materials (e.g., with recycled content, bio-content). In contrast to a segregated use of alternative raw materials, mass balance enables the use of existing production networks with low or no investments into new process technologies and production facilities. A book and claim model can be applied when there is no direct connection between the final product and the certified supply. An example of a book and claim model is applied in green electricity markets and receives more attention in other sectors as way to support circular transformation of the industry; therefore, it is accepted as a solution.

In implementing chain-of-custody methods, including mass balancing, the following set of guiding principles shall be fulfilled:

1. The use of chain-of-custody approaches shall achieve significant changes and an effective transition towards a more circular, more bio-based and lower GHG emissions production in complex value chains.

2. The choice and implementation of chain-of-custody approaches and models shall be transparent, clear, and credible – abiding by relevant standards such as ISO and CEN.

Note: Certification schemes are not yet available in all sectors.

3. Labels and claims referring to chain-of-custody controlled specified characteristics and used on products shall fulfil the following requirements:

* description of the chain-of-custody approaches and models
* accurate and appropriate implementation of the chain-of-custody model
* compliant with existing standards and regulations
* non-misleading

If the “specified characteristic” content in products cannot be measured and verified, labels and claims shall mention this. For example, this often applies to mass balancing (e.g., chemically recycled content in plastics).

4. No double counting: A reliable accounting system shall be installed at each operating site to ensure that the claimed volume on the output side exactly matches the actual volume on the input side within the declared time and regional scope.

Additional requirements for a mass balance chain of custody approach:

1. The operating sites in the spatial boundaries for mass balancing are under the operational control of the same company/corporate group/joint venture.

2. It shall be technically possible according to standard industry practice to produce a mass-balanced product from an alternative feedstock. Share of mass-balanced material can be technically lower than the attributed share.

3. Applied emissions factors for the mass-balance system boundaries shall be product and process specific.

[Proposal from SG2 :

The LCA methodology guidelines for automobiles assume that the inputs (input resources), outputs (products), and processes are not each a single system, but a complex system with multiple inputs and outputs. In a complex system, we believe it is necessary to introduce the concept of Chain of Custody to increase the transparency and reliability of distribution.

Chain of Custody is classified into the following five categories, the definitions in [ Chart xx1 ], according to ISO22095.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Definition | Identity preserved | Segregated | Controlled blending | Mass balance | Book and claim |
| Identify source of input material | ✓ | - | - | - | ー |
| Mixing input material with non-specified characteristic | - | - | ✓ | ✓ | ✓ |
| Physical separation of output material to ensure specified characteristics | ✓ | ✓ | ✓ | - | ー |
| Physical connection | ✓ | ✓ | ✓ | ✓ | ー |

Of the five Chain of Custody, we believe that it is necessary to clarify the interpretation and usage of two, Mass balance and Book and claim, as LCA guidelines for automobiles. In addition, although Book and claim is generally used only for electricity, however it should be allowed to be used for purposes other than electricity as well.

|  |  |  |
| --- | --- | --- |
| Definition | Mass balance | Book and claim |
| Need physical connection and output specified characteristic（single location） | ✓ | - |
| Need to stay within same product system | ✓ | ✓ |
| Need input and output balancing between a certain period | ✓ | ✓ |
| Need of traceability | ✓ | ✓ |
| Need self-certification | ✓ | - |
| Need third party certification | - | ✓ |

**3.2.12. Logistics [SG1]**

[Proposal from SG3:

*“In addition to emissions from production, manufacturing, use stage and end of life, there are also emissions from the transportation and logistics of vehicles, products, or materials.*

*Emissions from transportation shall cover emissions from well-to-wheel, i.e., the system boundaries span from energy provision, production and distribution ending at the transportation operation itself. Emissions from the production of the transportation means and infrastructure, e.g., roads, vehicles, ships and railways, shall not be included.*

*Figure 3.2.12‑1:System boundaries for transportation.*

Energy provision, production & distribution

Energy related to construction

Transport operation

Vehicles

Infrastructure

Energy consumption

Extraction Generation

Refineries / Power plants

Energy distribution

Not considered

Tank-to-wheel (TTW)

Well-to-tank (WTT)

Well-to-wheel

*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 transportation 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.*

*Alternative1:*

*Global logistic framework used in an LCA study shall be documented.*

*Alternative2:*

*If the calculation of transport emissions does not follow the recommendation set out in the GLEC Framework V3.0, except for the mandate to include emissions from the construction and dismantling of energy infrastructure. Alternative frameworks can be used and to be documented. 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:*

* *Actual distance*
* *SFD*
* *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.”]*

**4. Annex: Specific methodology per life cycle stages**

**4.1. Material production stage [SG2]**

At the material production stage, the development of the assessment method will be focused only on Purpose 3, and for other levels, only the concept and overview will be described.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Level | Activity Data | | | Intensity Data |
|  | Vehicle Wight [kg] | Material Distribution [%] | Scrap Rate of Material [%] | Carbon Intensity of Material Acquisition  [kg-CO2e/kg] |
| Amount of Material Use at the Vehicle [kg] | |
| Purpose 1 | Primary data | All Secondary data | All Secondary data | All Secondary data |
| Purpose 2 | All Primary data | | All Secondary data | All Secondary data |
| Purpose 3 | All Primary data | | Partially Primary data | Partially Primary data |
| Purpose 4 | All Primary data | | All Primary data | All Primary data |

The simplest Purpose 1 assumes a high-level purpose of use such as policy consideration, calculates the average material usage from the vehicle weight, and calculates the CO2 emissions from each material carbon intensity.

Next, Purpose 2 assumes a purpose of use such as strategy cons ideration by each automobile OEM, and estimates the material yield using the weight of each material in the vehicle under development using past experience.

Details of Purpose 3 will be described in a later chapter, but the assessment of the produced vehicle is set as the purpose of use, and the weight of the material used, its yield, and material carbon intensity are collected as much as possible as primary data, and the environmental impact is assessed according to the actual situation.

Finally, Purpose 4 is an ideal LCA, with the goal of compiling the basic carbon intensity of all materials as primary data. However, it is not realistic to collect data on approximately 100,000 items per vehicle, and this is assumed to be an ideal state.

Table 4.1-1: Level concept of material production stage

**4.1.1. 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 material production perspective.

For a material production stage, the declared unit shall be 1 kg of material products, regardless of its state, as its specific density is considered.

**4.1.2. Automotive material classification**

Material classification is described in Purpose 3. It is basically extracted by investigating composed materials species in typical automotive vehicle models, i.e., ICE, HEV, FCV and EV.

Material classification of the vehicle is usually derived by BOM (Bill of Materials) and IMDS (International Material Data Sheet), which are commonly used in worldwide automotive industry.

On the other hand, material classification for PCF shall be set from PCF impact viewpoint and be derived in accordance with other stages as Parts production and vehicle assembly, Use, and End of Life.

From a viewpoint of high PCF impact in automotive materials, system boundaries of these dominant materials (steel, aluminium, copper, and plastic) are defined in Figure 4.1.4-2, Figure 4.1.4-3, Figure 4.1.4-4 and Figure 4.1.4-5 referring to the documents from international institutions e.g., world steel, IAI, EA, ICA, and TfS.Regarding other materials used in a vehicle, the list is shown in Table.4.1.3-1.

Although it depends on a target vehicle specification, prodedures to select material classification should be explained.

As a cut-off criteria, material PCF should be considered within x% of total vehicle PCF. The exception is for materials with very high GHG impacts (e.g. >15 kgCO2e/kg[material]), such as platinum group metals, gold and carbon fibre, where the cut-off should be within x% of the cumulative total impact (in CO2e).

Table 4.1.2-1: Automotive material list

|  |  |
| --- | --- |
| Material group | Material classification |
| Steel | Cast iron, Cast steel, Hot-rolled steel sheet, Cold-rolled steel sheet, Electromagnetic steel sheet, Hot-rolled hot-dip galvanized steel sheet, Hot-rolled electrogalvanized steel sheet, Cold-rolled hot-dip galvanized steel sheet, Cold-rolled electro galvanized 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(plate), Wrought aluminium(extruded) |
| Copper | Tough pitch bare/coated copper wire, Oxgen free bare/coated copper wire , Tough pitch copper strip/bar, Oxgen 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 Sulfide), TPO (Thermoplastic Olefin), TPV (Thermoplastic Vulcanizate) |
| Non-ferrous metals | Magnesium alloy, Zinc alloy, Platinum/Rhodium, Lead, Other metals |
| Other organic materials | SBR (Styrene-Butadiene Rubber), EPDM (Ethylene Propylene Diene Monomer), Other thermoplastic resins, Other thermosetting resins, Natural rubber, Synthetic rubber, CFRP, Anti-rust oil, Wood (apitong wood, lumber), Adhesives, Other organic materials |
| Other materials | Laminated Glass, Paints, Electrodeposition Coating, Electronic Components (Silicon), Engine oil, Brake fluid, Coolant, Refrigerant, Other inorganic materials, Tires, Lead-Acid battery, LiB (Lithium-Ion Battery) |

**4.1.3. System boundaries**

Figure 4.1.3-1 shows a system boundary of the material production stage.

Une image contenant texte, capture d’écran, Police, Rectangle

Description générée automatiquement

[A1] Processes related to material mining, refining, and impurity removal (defined as upstream process)

[A2] Processes related to material production (defined as downstream process)

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’ which has mining, refining, and impurity removal with relatively high CO2 impact.

Then, ‘downstream process’ 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).

After that, it is transferred to the Parts production and vehicle assembly stage.

System boundaries of the main dominant materials (steel, aluminum, copper, plastic) in automotive are shown in Figure 4.1.3‑2, Figure 4.1.3‑3, Figure 4.1.3‑4 and Figure 4.1.3‑5.

グラフィカル ユーザー インターフェイス, アプリケーション

自動的に生成された説明

Figure 4.1.3‑3: A system boundary of aluminium material production stage

グラフィカル ユーザー インターフェイス, アプリケーション

自動的に生成された説明

グラフィカル ユーザー インターフェイス, アプリケーション

自動的に生成された説明

グラフィカル ユーザー インターフェイス, アプリケーション

自動的に生成された説明

Especially, globally regional dependency of electricity and fuel in the material production process, and usage ratio of recycled and bio-derived material greatly affect on PCF.

Burdens related to recycled material to raw material should be evaluated as Material Modular Burdens and Benefits method.

* : it is the proportion of material in the input to the production that has been recycled from a previous system.
* : specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material. [kgCO2e /kg]
* : specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process. [kgCO2e /kg]

**4.1.4. Data collection and data type**

In principle, primary data of activity and emissions shall be collected concerning the material production stage for not only in-house but upper stream suppliers. However, in case it is not practically possible, secondary data should be collected. When collecting primary data from suppliers, the prerequisites should be reported. When collecting secondary data from available databases, data quality should be explained.

Material data is known as follows; material name, material classification (VDA, ISO code, and other standards), the number of materials, material weight, chemical substance composition, recycled material ratio, biomass blended ratio, yield rate, electricity and fuel consumption, etc.

**Primary data collection**

In Purpose 3, the weight of the material used, its yield, and material carbon intensity are collected as much as possible as primary data, and the environmental impact is assessed according to the actual situation.

* PCF dominant impact factor of material production process along system boundary should be considered.
* Unit process data of material production process should be considered
* country or region where material production was conducted
* amount of electricity and fuel used, rate of renewable energy used
* usage rate of recycled material and bio-derived material to total material weight

**Secondary data collection**

When collecting secondary data from available databases, data quality shall be explained as follows.

* PCF dominant impact factor of material production process along system boundary should be considered.
* Unit process data in material production process should be considered as well as primary data as described above.
* It should be utilized as not a consequential data but an attributional data to avoid an assumption.
* Allocation between life cycle generations should not be utilized to assure data transparency.

**4.1.5. Energy modelling [SG6]**

[TBD SG6]

**4.2. Parts production and vehicle assembly stage [SG3]**

**4.2.1. 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 cradle to gate carbon footprint of parts production or vehicle manufacturing can thus reflect:

* an average for a vehicle fleet (various segments, models on global or national level) --> Purpose 1
* 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 --> Purpose 2
* an average for specific vehicle models (with different equipment variants on global, national or local production site level) –> Purpose 3
* a specific vehicle model. --> Purpose 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 this resolution four levels detail are differentiated.

**4.2.1.1. Purpose 1**

As described in 2.2.1 there are multiple approaches possible for Purpose 1, the following section 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 function of net vehicle weight. All specific emission effects due to different materials, gross material input, different production processes or transport of parts or vehicles is included in the carbon emission factor. The calculation of vehicle carbon footprint from production is simply given by:

Where:

CVP carbon emissions due to material production, component and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e)

CEFVP Carbon emission factor of material production, component and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e/kgCW)

MNM Net mass of the vehicle in kilogram (kg), i.e. mass of the vehicle in running order minus the mass of the driver (75kg) minus the mass of any fuels.

The CEF may be determined from literature or OEM publications. The carbon emission factors may reflect geographical differences, if there is evidence that material, component and vehicle production is more CO2e-intense in some parts of the world than in others.

As no details on the production of the vehicle enter into the calculation, also the end of life emissions of a vehicle shall only be captured by the (lump) carbon emission factor.

For transparency all the factors used in calculation shall be reported.

**4.2.1.2. Purpose 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 obvious for the automotive industry because material and mass declaration systems are mandatory for decades. The calculation of the cradle to gate vehicle carbon footprint is given by:

Where:

CVP carbon emissions due to material production processes, component production and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e)

Mi Net mass of the material i in kilogram (kg)

Ui use coefficient of material i in percentage of the gross material input relative to the net material input (%). The value is greater than 100% when offcut or loss is assumed.

CEFi Carbon emission factor of material i reflecting material production processes, component production and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e/kg)

COP Carbon emissions reflecting vehicle manufacturing processes (OEM’s operation of bodyshop, paintshop and general assembly) in kilogram of carbon dioxide equivalent (kgCO2e/vehicle)

Again, all specific emission effects due to different production processes or transport of parts or vehicles is included in the (lump) carbon emission factor. COP may be determined from literature or OEM publications. It may be justified to differentiate virgin or recycled materials. In that case the calculation is given as follows:

Wherein:

Ri share of recycled material i in percentage of the gross material input (%)

CEFi,V Carbon emission factor of virgin material i reflecting material production, component and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e/kg)

CEFi,R Carbon emission factor of recycled material i reflecting material production, component and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e/kg)

For transparency all the factors used in calculation shall be reported.

**4.2.1.3. Purpose 3**

The contribution of different subsystems of a vehicle to the GHG-emissions of vehicle production is by far not evenly distributed. Accounting these most relevant subsystems in terms of GHG-emissions from vehicle production (so called ‘hotspots’) in a more detailed manner differentiates Purpose 3 from Level2 in the calculation of the cradle to gate vehicle carbon footprint.

[Definition of Hotspots]

For those hotspot or key subsystems 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 released by government authorities.

The calculation of vehicle carbon footprint from production is given by:

Where:

CVP carbon emissions due to material production processes, component production and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e)

CHS carbon emissions due to manufacturing of hotspot subsystems (including material production processes and component production) and their assembly to the vehicle in kilogram of carbon dioxide equivalent (kgCO2e)

CBV carbon emissions due to material production, component and vehicle manufacturing with the exception of hotspot subsystems in kilogram of carbon dioxide equivalent (kgCO2e)

CT carbon emissions due to transport of the fully assembled vehicle to customer show room

CHS is calculated according to Purpose 4 definitions. CBV for the remaining vehicle materials, parts and production processes excluding hotspots follow the calculation defined for Purpose 2. Intermediate transport operations are covered by CHS and CBV.

**4.2.1.4. Purpose 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 section 3.2.12.

The calculation of vehicle carbon footprint from production is given by:

Where:

CVP carbon emissions due to material production, component and vehicle manufacturing in kilogram of carbon dioxide equivalent (kgCO2e)

Cop carbon emissions due to the (vehicle) manufacturer’s own operations in kilogram of carbon dioxide equivalent (kgCO2e)

CT1 carbon emissions reported from the Tier 1 supplier for supplied parts in kilogram of carbon dioxide equivalent (kgCO2e)

CTj carbon emissions reported from the Tier j supplier for the material production processes, component production of supplied parts in kilogram of carbon dioxide equivalent (kgCO2e)

CTrans carbon emissions due to transport of the fully assembled vehicle to customer show room

Intermediate transport operations are covered by CTj.

In case primary data cannot be obtained, secondary data shall be used. Secondary data shall be traceable and based on field survey data and released by government authorities.

[work in progress]

**4.2.1.5 Level overview**

The following Table 4.2.1.5 gives an overview how relevant aspects in vehicle and parts production should/shall be handled in the different levels.

Table 4.2.1.5 : Level overview

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Level1 | Purpose 2 | Purpose 3 | Purpose 4 |
| Waste | Included in CEF | Included in CEF | Hotspot:  Considered explicitly.  Rest of vehicle:  Included in CEF | Considered explicitly |
| Gross vs. net material input (Scrap) | Included in CEF | Included in Ui | Hotspot:  Considered explicitly.  Rest of vehicle:  Included in Ui | Considered explicitly |
| Transport | Included in CEF | Included in CEF | Transport from OEM gate to show room  Reported explicitly  Hotspot:  Considered explicitly.  Rest of vehicle:  Included in CEF | Considered explicitly |
| Primary/secondary material use | Included in CEF | Included in Ri | Hotspot:  Considered explicitly.  Rest of vehicle:  Included in Ri | Considered explicitly |
| Temporal validity | Most recent data | Most recent data | Hotspot:  Annual update  Rest of vehicle:  Most recent data | Annual updates |
| Geographical Representativeness | As specific as possible for research question | As specific as possible for research question | Hotspot:  Plant level  Rest of vehicle:  As specific as possible | Plant level |

**4.2.2. 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 (see 3.2.3).

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 weight and a unique identifier (part number).

For **materials**, i.e., mass products or commodities, the declared unit shall be 1 kg of products, regardless of its state (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 the vehicle manufacturer the declared unit it the fully assembled vehicle delivered to customer at show room.

**4.2.3. System boundaries**

The system boundary of the parts and vehicles production stage is outlined in Figure 4.2.3‑1.

Figure 4.2.3‑1: System boundaries in production.

Une image contenant capture d’écran, texte, Rectangle, carré

Description générée automatiquement

The transport of the final assembled vehicle to the dealer show room is also included in the parts and vehicle production and therefor to be included in the PCF of the vehicle in production.

The cradle-to gate PCF includes all attributable upstream and direct emissions of producing a product, including all upstream transportation activities.

When accounting for emissions, companies shall further define their cradle-to-gate boundary by listing all the attributable processes of their studied product.

The system boundaries are therefore including:

* Production of materials from primary or secondary sources, semi-finished products
* Production of vehicle parts and components
* Auxiliary production processes (e.g., lighting, air conditioning, storage facilities)
* Disposal of production waste
* Packaging of vehicle parts and components,   
  including all operations required for performing packaging
* Disposal of production waste (incl. packaging waste)
* Logistics (including internal logistics and transport packaging)
* Quality control in production
* 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.

~~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:~~

**4.2.4. Data collection and data types**

Emissions shall by default be reported averaged over the period of one year (reporting or calendar year) to avoid seasonal fluctuations and reflect typical production 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 five years. Any averaging period deviating from the default shall be flagged and justified.

Emissions shall by default be reported for the most recent year (reporting or calendar year). An annual check is recommended to ensure data actuality. To perform the annual check, the initial screening analysis should be updated based on data for the most recent year. An update of data is recommended if the reported emission increases 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 (adapted from GHG protocol):

* Structural changes in operation to the product system under study, including significant process change in operation, change in production technologies or technology advancement, raw material or energy changes.
* 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.
* Discovery of significant errors, or a number of cumulative errors that are collectively significant.

Emissions shall by default be reported on the plant level. Averaging over a region, country, continental, or global may be considered but shall be flagged as such. Reason shall be provided if average values over continental or global are used in cases where the use of primary data is recommended.

**4.2.5. Energy modelling [SG6]**

[TBD]

**4.2.6 Logistics**

This section deals with transportation from a supplier to its customer.

Figure 4.2.6-1: Definition of scopes

Une image contenant texte, capture d’écran, conception

Description générée automatiquement

As for the product carbon footprint, the cradle-to-gate boundaries end at the suppliers' outbound gates (cf. Section 3.2.4 System Boundaries). This boundary applies independently from the responsibilities in economic or operative terms for transportation processes.

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 4‑2). Otherwise, the customer shall account for transportation between the supplier’s and its own shipping site (factory gate or distribution center, see Figure 4‑4 and Figure 4‑5).

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

Table 4.2.6: Transportation between supplier and customer.

The responsibility to account for GHG emissions from transport depends on which party is responsible in economic or operative terms.

| **Case** | **Description** | **Economic/operative responsibility for transportation from supplier to customer** | **Accounting for transportation emissions** |
| --- | --- | --- | --- |
| **1** | Multiple shipping sites, and/or multiple unloading sites  Une image contenant capture d’écran, diagramme, cercle, Caractère coloré  Description générée automatiquement | 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  Une image contenant capture d’écran, diagramme, cercle, texte  Description générée automatiquement | 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 products |

Transports from production sites to **suppliers' distribution centers** are deemed as suppliers' in-house logistics, i.e., the distribution center is regarded as the shipping point (see Figure 4‑4).

Une image contenant capture d’écran, cercle, diagramme

Description générée automatiquement

Figure 4.2.6-2: Distribution center on supplier side.

Transports from **customers'** distribution **centers** to production sites are deemed as customers' in-house logistics, i.e., the distribution center is regarded as the unloading point (see Figure 4‑5).

Une image contenant capture d’écran, cercle, diagramme

Description générée automatiquement

Figure 4.2.6-3: Distribution center on customer side.

Regardless of whether transportation emissions are quantified by a supplier or a customer, they shall be consolidated within the customers' PCFs.

**4.3. Use stage [SG4]**

**4.3.1. Service life and functional unit**

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. Both are relevant for the purpose of the methodology. Vehicle lifetime mileage is required to translate vehicle production emissions (in tonnes of CO2e) into the functional unit (gCO2e per km driven over the lifetime). 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 intensity 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. In principle, this would include the continued operation in a country or region outside the country or region where the vehicle is first registered.

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, this document presents standardized values of the lifetime of vehicles at the point of recycling, as examples and guidelines. It acknowledges that reaching a consensus on such figures can be challenging. Additionally, 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 average lifetime of passenger vehicles varies between regions:

1) Europe: 18-25 years, depending on source

a) Average lifetime in the EU's SIBYL model: 25 years

b) Average age of vehicles when reaching end of life, based on recycling statistics:

Germany (in 2014-2016): 17–18 years (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2020)

France (in 2018): 19 years (Ministère de la transition écologique et solidaire, 2019)

Portugal (in 2015): 20 years (Öko-Institute, 2018)

Poland (in 2015): 20 years (Öko-Institute, 2018)

UK (in 2022): 18 years (LSE, 2024)[[3]](#footnote-4)

2) Unites States: estimated to be at least 18 years

Latest data on average age of vehicles when de-registered in the U.S. is from 2003, showing 15-16 years for vehicles produced before/around 1990 (U.S. Department of Transportation, 2006).

Average age of LDVs in the U.S. increased from 8.4 years in 1995 to 12.5 years in 2023 (U.S. Department of Transportation, 2024).

Latest U.S. survival curve data is from 2003, for vehicles produced before/around 1990. Applying the increase in average age of about 4 years between 1995 and 2023 to the avg. vehicle lifetime, yields in 19-20 years. 18 years is thus considered a conservative estimate.

3) Brazil: national statistics show that 50% of vehicles of an age of 22–23 years are still in use in Brazil (Ministry of Science, Technology and Innovations of Brazil, 2020).

Important: 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. Here, the average age when being de-registered (e.g., 13 years in Germany) is lower than the average age when being recycled (e.g., 18 years in Germany).]

[There are pros and cons of providing differentiation by segments, (1) differentiation provides a better representation of the typical use expected (also partly reflecting greater potential utility larger vehicles can provide), (2) particularly around the boundaries between segments it might artificially bias consumer choices (e.g. a particular user is unlikely to drive a vehicle more just because it is in a different segment - it is purchased for a specific use).]

**4.3.2. 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. Therefore, in an intermediate step this requires the calculation of energy consumption as activity data for electrified vehicles such as HEV, PHEV, FCHV and PEV. 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, hence:

* Electric energy: from vehicle charging port to the wheels
* Fuel: 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 Energy modelling [SG6], hence:

Electric energy: GHG emissions related to[ electricity generation infrastructure[[4]](#footnote-5)[[5]](#footnote-6), ] production and distribution of the fuels used in electricity generation, direct impacts from electricity generation, and transmission and distribution loss from the electricity grid to the charging system[[6]](#footnote-7).

Fuel: GHG emissions linked to extraction/production of feedstock’s’ refining/processing of feedstocks into fuels, storage and transportation of these to the market, and dispensing to the vehicle.

These latter WTT GHG emissions shall be covered in the conversion factor of each energy type according to Energy modelling [SG6].

Use stage boundaries are depicted in the figure below.

Figure 4.3.2‑1: Life-cycle flow schematic

**(1) Material (2) Parts production and (3) Use stage (4) End of life stage**

Material parts production

Material transport

Material production

Material

Fuel production/ energy generation

Maintenance parts

Disposal/

Recycle

Fuel/ electricity

Material parts transport

Fluorocarbon emissions

Fluorocarbons

Driving

Waste transport

Waste

**Production Vehicle assembly stage**

**stage**

Recycling

Material for recycling

Material transport

Disposal/ recycle

Waste

Parts production

Waste transport

Material

Parts transport

Vehicle assembly

Parts

ASR

Dismantled ELV

ELV

Finished vehicle

Finished vehicle transport

ASR transport

Dismantled ELV transport

Shredding

ELV transport

Waste transport

Material production

Waste

Disposal/ recycle

ASR landfill

ASR recycle

Dismantling

Residue

Recovered parts

Residue transport

Recovered parts transport

Landfill

Disposal/ recycle

Inputs, outputs etc.

Key:

Process to be calculated

Figure 4.3.2-2 : 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 4.3.2‑2: SG4 system boundaries

Une image contenant capture d’écran, ligne

Description générée automatiquement

The hand over point with “Parts production and vehicle assembly” stage is set at the “showroom level, when the vehicle is passed on from the OEM to the final customer”. On the disposal and recycling side, GHG emissions after 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:



Where,

is the CO2 equivalent for the whole use stage, kg CO2e;

is the CO2 equivalent due to the in-use vehicle operation, kg CO2e;

is the CO2 equivalent due to maintenance and consumables, kg CO2e;

is the CO2 equivalent due to leakages and fluorocarbons emissions, kg CO2e;

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

**4.3.3. Use phase consumption**

Contrary to upstream activities where carbon footprint is unique for a vehicle, downstream activities are different for different region for the same vehicle. The LCA vehicle's GHG emissions are declared at the point of sale, but it is difficult to measure energy consumption after sale. Instead, for Purpose 1 and Purpose 2 analysis, projections or estimations can be made based on available information such as certification values.

Usage of Category 1 vehicles (passenger cars) depends on regional customer behaviour. To provide a standard approach that ensures repeatability, comparability and varifiability by authorities, each region has defined homologation driving cycles and test conditions (Table 4.3.3 1 shows an overview of the main certification protocols across the world) that are regularly reviewed to reflect real-life operation. 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, compared to using globally standardized values.

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. This gap is particularly pronounced for plug-in hybrid electric vehicles, as evidenced by numerous scientific studies. 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, 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" if data are available for the region in question. If the factor is not available for a specific region, then the factor should be calculated based on best available data and expert qualified assumptions with a minimum value of ‘1’. For vehicles that have more than one mode of operation (e.g. PHEVs), the discrepancy factors should account for these different operational modes.

For example, considering a ‘Purpose 4’ calculation (see Level Concept [SG1]), it would also be permissible to use OEM-specific average data to determine the “discrepancy factor” based on analysis of data from their vehicles operating in the real-world for similar powertrains (e.g. for ICEVs, or ZEV/electric powertrains = PEVs, FCEVs, etc.), matched to the defined region of operation (i.e. sale). “Discrepancy factor” can only be quantified at the first time of vehicle registration (0 km). these factors should be defined and updated on a regular basis by the authorities.

The efficiency of certain powertrains, such as fuel cell and plug-in hybrids, may deteriorate over time because of fuel cell and battery degradation. If "deterioration factors" for the total vehicle efficiency or the specific modules are available for a particular region, they should be used to account for this issue. If the factor is not available for a region, then the factor should be calculated based on best available data and expert qualified assumptions with a minimum value of ‘1’. 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, ECin-use shall be calculated as follows:



Where,

is the energy consumption or fuel consumption, MJ/km or Wh/km;

is the discrepancy factor (if not available for a region, then 1 should be used)

is the deterioration factor (if not available for a region, then 1 should be used)

[Table 4.3.3‑1 : *certification protocols for main regions (draft to be completed)]*

|  |  |  |  |
| --- | --- | --- | --- |
| Region | Powertrain | Protocol | Unit |
| Europe | ICE | WLTP (4 phases) | MJ/km |
|  | HEV, PHEV, FCHV, PEV | WLTP (4 phases) | Wh/km |
| Japan | ICE | WLTP (3 phases) |  |
|  | EV |  |  |
| China |  | CLTC-P |  |
|  |  |  |  |
| Korea |  |  |  |
|  |  |  |  |
| US | ICE | FTP-75 |  |
|  | HEV, PHEV, FCHV, PEV |  |  |
| Canada |  |  |  |
|  |  |  |  |

**4.3.3.1. Calculation of ‘Discrepancy Factor’**

[A significant gap remains between certification values and real-world energy or fuel consumption across all powertrains. To address this, guidelines suggest applying a "discrepancy factor" where regional data exists. If unavailable, the factor should be estimated using the best available data and expert assumptions, with a minimum value of 1. For vehicles with multiple modes, such as PHEVs, discrepancy factors should reflect each mode of operation.]

[methodology to derive Discrepancy factor]

**4.3.3.2. Calculation of ‘Deterioration Factor’**

[Fuel Cell Electric Vehicles]

[Given the loss in (charge/discharge) efficiency of batteries over the lifetime of the vehicle is reportedly relatively low, and no approaches have been identified to quantify this objectively, it is not proposed to include this aspect for PEVs. However, the situation for fuel cells is different, where efficiency degradation is expected to be significant, particularly for HDVs. Therefore, the following overall methodological approach is proposed for determining fuel cell efficiency degradation over lifetime of the vehicle.

For fuel cells, efficiency losses occur over the operational life of the vehicle. It is proposed to calculate the average loss of efficiency (used to calculate an amended lifetime average energy consumption in MJ/km) based on the fuel cell durability assumptions and operational lifetime km, as outlined below. Fuel cell durability is defined as the number operational hours to reach 10% degradation of the original fuel cell rated power (in kW). The following general methodological approach is therefore proposed to determine the average loss in efficiency over the service lifetime of a vehicle using fuel cell based powertrain (i.e. an FCEV or FC-REEV powertrain).

Potential for further development of knowledge in this area is expected. To adjust to this perspective, TSLCA allows OEM or suppliers to propose an alternative owned methodology to define operational fuel cell efficiency loss, as long as it is validated by an independent third party expert on fuel cells.

For operation on hydrogen for FCEV – amended to account for fuel cell degradation, the maximum efficiency loss should be to a maximum of 5% degradation over the life of the vehicle, i.e. in the case where FC [lifetime energy] >FC [max energy], where a fuel cell replacement will be required in any case:



Where:

EnCon [AvLife] = average input hydrogen energy consumption in MJ/km over the entire lifetime of the vehicle.

EnCon [Start] = input hydrogen energy consumption in MJ/km at the start of the vehicle life (i.e. before any FC degradation), as defined in vehicle certification (i.e. before any real-world adjustments being applied).

FCEV [lifetime energy] = Lifetime vehicle operational electrical energy requirement (i.e. fuel cell output, kWh) based on the input hydrogen energy consumption (in kWh/km), the lifetime activity (in km) and the average fuel cell efficiency (%).

FC [max energy] = maximum energy delivered by the fuel cell (in kWh) over the defined service life (in hours) at the average fuel cell running power (in kW).

NB: Fuel cell durability/service life is defined as based on the number of operational hours to 90% of original peak power rating, hence an efficiency loss of 10% over the life of the fuel cell = an average reduction in overall efficiency of 10%/2.

The (i) maximum lifetime energy that can be delivered by the fuel cell before reaching 10% degradation (FC [max energy]), and (ii) fuel cell electric vehicle lifetime energy requirements (FCEV [lifetime energy]) are calculated as follows:

(i) Fuel cell lifetime maximum electrical energy output (= FC [max energy]):



Where:

Fuel cell average running power (kW) = maximum rated fuel cell power (kW) \* average operation % of rated fuel cell power.

(ii) Fuel cell electric vehicle lifetime electrical energy requirement (i.e. energy output from fuel cell)

(= FCEV [lifetime energy]):

Where:

EnCon [Start] = input hydrogen energy consumption in MJ/km at the start of the vehicle life (i.e. before any FC degradation), as defined in vehicle certification (i.e. before any real-world adjustments being applied).

EnConConversion = conversion factor for converting MJ to kWh = 3,6 MJ/kWh

*Prioritisation for fuel cell durability assumptions:*

The following recommended prioritisation is proposed for the underlying assumptions of fuel cell life and average operational efficiency, with the choice of which option is most appropriate or feasible left to the practitioner (i.e. depending on the availability of data and objective of the study).

The different options are listed in order of accuracy and preference. The third option is proposed as a mandatory minimum default approach, where sufficient information is not available for the other options.

Table 4.3.3.2‑1*: Prioritisation for fuel cell durability assumptions*

| Proposed prioritisation in order of accuracy and specificity (highest to lowest) | UNECE Level |
| --- | --- |
| OEM / supplier specific methodological approach to define operational fuel cell efficiency loss, if validated by an independent third party expert on fuel cells. | Purpose 4  (Optional, depending on availability) |
| OEM / supplier specific data on fuel cell life (to 10% loss in power) and average operational power level (as % of the peak power of the fuel cell, according to regulatory testing cycles) | Purpose 4  (Optional, depending on availability) |
| If OEM/ supplier-specific data is not available, assume an operational life of 6000/24000 hours (for LDVs/HDVs)(a), an efficiency of 55%/52% (at the start of the fuel cell life for LDVs/HDVs)(b), with efficiency loss of 10% over the life of the fuel cell, and running at an average of 25%(c)/25%(d) (for LDVs/HDVs) of the peak power rating. | Purpose 3 and below. |

*Notes: (a) based on 2025 targets from FCH2JU KPIs FCH 2 JU - MAWP Key Performance Indicators (KPIs) - European Commission (europa.eu); (b) based on Ricardo review of typical fuel cell efficiency for LDV and HDV applications; (c) based on Fuel Cell Electric Vehicle Durability and Fuel Cell Performance (nrel.gov), (d) average approximation based on Ricardo analysis of VECTO simulation results for different HDVs and cycles.]*

Plug-in Hybrid Electric Vehicles

[The proposed methodology should account for the effect of the change in the battery capacity (i.e. State of Health) over the lifetime of the vehicle and its impact on electric range and via the Utility Factor UF on the share of operation in charge sustaining and charge depleting modes.]

**4.3.3.3. Quantification of Leakages**

Methodology for EVAP, Hydrogen, LNG/CNG emissions

**4.3.3.4. Quantification of fluorocarbons emissions**

[List HFCs and address impact]

From last version IPCC AR6: hydrofluorocarbons (HFCs), perfluorinated compounds, perfluorocarbons (PFCs), chlorofluorocarbon (CFCs) and hydrochlorofluoro¬carbon (HCFCs).

emission factors: GWP100

Table 7.15 (<https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf>)

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - <https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_7_Ch7_ODS_Substitutes.pdf>

**4.3.3.5. 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 should 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 country 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) should 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 should align with the average age of vehicles at the time of recycling, considering only those registered and recycled within the same country. Studies considering split use among different regions/countries in a more detailed way could be performed for scenario analysis.

**4.3.4. Data Collection and data type**

Data shall be collected for the item outlined below. Activity data shall be collected as primary data. In case of the difficulty, secondary data may be applied to activity data. GHG emission intensity data shall be collected as secondary data. Scenarios for secondary data and secondary data source shall be reported. The following data shall be collected:

Process of driving

* Certified fuel or electricity consumption
* Discrepancy factor
* Degradation factor
* Utility Factor/share of modes of operation for dual-fuel/operation vehicles (e.g. PHEVs, REEVs, etc.)
* GHG emission factor for fuel and energy [SG6]
* Electric charging efficiency if not included in the certification values [SG6]
* Vehicle service life (in years)
* Vehicle lifetime activity (in km)
* Leakages (evaporative emissions, hydrogen, LPG/CNG, etc…)
* Boundary conditions:
  + - average ambient temperature
    - vehicle occupancy rates for scenario analysis

Process of emitting fluorocarbons

* Fluorocarbon emissions
* GHG emission factor for emitting fluorocarbons

Process of producing maintenance parts and consumables

* List of maintenance parts and consumables
* Frequency for the maintenance parts
* Frequency for consumables
* GHG emission factor for producing maintenance parts and consumables

Process of transporting maintenance parts and consumables

* List of maintenance parts and consumables
* Frequency for the maintenance parts
* Frequency for consumables
* Distance
* GHG emission factor for producing maintenance parts and consumable

Vehicle activity out of region of sales

Service life should be based upon the average lifetime up to the point of scrappage for a country/region, i.e. excluding de-registrations for exports for further use in other regions.

**4.3.4.1. Primary data collection items**

The following data shall be collected as primary data:

Process of driving

* Certified fuel or electricity consumption
* Discrepancy factor
* Degradation factor
* Utility Factor/share of modes of operation for dual-fuel/operation vehicles (e.g. PHEVs, REEVs, etc.)
* Electric charging if not included in the certification values [SG6]
* Leakages (evaporative emissions, hydrogen, LPG/CNG, etc…)
* Vehicle service life (in years)
* Vehicle lifetime activity (in km)

Fluorocarbons emissions

* List of main Fluorocarbons to be included

Process of producing maintenance parts

* List of maintenance parts and consumables
* Maintenance frequency of the maintenance parts and consumables

Process of transporting maintenance parts

* List of maintenance parts and consumables
* Maintenance frequency of the maintenance parts and consumables

Vehicle activity out of region of sales

[Out of scope – all vehicles will be characterized with data from region of sales up to the point of scrappage]

**4.3.4.2. Secondary data collection items**

The following data shall be collected as secondary data, provided and regularly updated by the authorities and contracting parties. The default values in Appendix Figure X may be adopted, or data collected independently by the party performing the calculation may be used. In this case, the validity of their own data is subject to verification.

Process of driving

* GHG emission factor for burning fuel
* Leakages
* boundary conditions:
  + - average ambient temperature
    - vehicle occupancy rates for scenario analysis

Fluorocarbons emissions

* GHG emission factor for emitting fluorocarbons

Process of producing maintenance parts

* GHG emission factor for producing maintenance parts

Process of transporting maintenance parts

* GHG emission factor for transporting maintenance parts

Vehicle activity out of region of sales

[Out of scope – all vehicles will be characterized with data from region of sales up to the point of scrappage]

Table 4.3.3‑2*: Processes and Data to be included in Use stage*

| **Processes** | **Activity data** | **GHG emissions Intensity Data** |
| --- | --- | --- |
| (Primary data) | (Secondary Data) |
| **Driving** | Certified Fuel consumption [l/100km] and/or electricity consumption [kWh/100km] |  |
| Discrepancy factor RW data |  |
| Degradation factor |  |
| xEV charging efficiency if not embedded in Certification values | Average xEV charging efficiency if not included in TA value |
| Vehicle lifetime (years), and reference flow (km) | Vehicle recycling statistics/ Nationally authorized statistics/OEM's average vehicle life |
|  | GHG emission factor for burning fuel |
| **Emitting Fluorocarbons** | Fluorocarbon emissions | GHG emission factor for emitting fluorocarbons |
| **Maintenance and Consumables Production** | List of maintenance parts and consumables | Fixed percentage of upstream emission attributed to maintenance processes depending upon powertrain, service life, vehicle segment and region of use. |
| Frequency of replacement |  |
|  | GHG emission factor for producing maintenance parts |
| **Maintenance and Consumables Transportation** | List of maintenance parts and consumables |  |
| Frequency of replacement |  |
| Transport Weight [kg] Transport Distance [km] | GHG emission factor for transporting maintenance parts |
| **Driving in secondary countries** | To be evaluated in line with End of Life [SG5] | To be evaluated in line with End of Life [SG5] |
| **Second life of components** | Out of scope | Out of scope |

**4.3.5. Application of the Energy modelling schemes [SG6]**

General rules must be referred to the section 3.2.8.

**Future Changes in Energy Mix:**

Practitioners should also account for any potential changes in the fuel or electricity production pathways during the lifetime of the vehicle. (detailed methodology shall be considered)

Specifically, the following recommendations are made on how to model electricity inputs to the use phase:

**Use phase electricity:**

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

* The official published scenario specifically for electricity supply mix for the country or geographical region of interest.
* The official general scenario based on currently implemented policy for the country or geographical region of interest (providing this has been updated within < 3 years).
* Stated Policies Scenario (STEPS) from the most recent International Energy Agency’s World Energy Outlook (IEA WEO) report, for the geographical region of interest.
* If none of the previous options (a to c) are available for the geographical region of interest, then the most recent “static” grid mix composition shall be used instead.

1. The grid mix composition for each year of vehicle operation shall be estimated (i.e., the shares Si,n of electricity supplied by each technology i in the year n), by applying linear interpolation between the respective electricity supply shares reported for the nearest pre-defined time horizons in the scenario selected at point 1 above.
2. The average representative grid mix composition over the full service life of the vehicle shall be calculated as follows:

* By default, 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 homogenously over its full service life (i.e., L/N km are driven each of the N years of operation, where L = total lifetime activity).
* 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 ***Si,n*** of electricity supplied by each technology ***i*** in the year ***n***, i.e.: , where ***Wn = An/L*** (***An*** = vehicle activity in year ***n***, ***L*** = total lifetime activity).

1. A bespoke grid mix model shall finally be built using the grid mix composition calculated at point 3 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 phase of the vehicle.

**4.3.6. Maintenance**

Vehicle maintenance refers to the recommended regular inspection defined by the vehicle manufacturer in order to ensure its optimal performance, longevity, and safety by preventing issues from arising and preserving its overall condition. Maintenance in the use stage of a vehicle's life cycle can have a none-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 range from 2%- 5% of total vehicle carbon footprint, depending on the powertrain type and vehicle segment.

**4.3.6.1. Maintenance scope**

Two types of maintenance are included in the guideline:

* *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, filter, brake pads and discs, etc… For these items recycling is not required, and hence only carbon footprint related to material and production should be considered.
* *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, tires, 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 behavior, 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 should 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 guideline are:

* *Unexpected repairs (i.e., accident):* Looking at the challenge of estimating the consequences of road accidents and premature fails (for components expected to last for service life), the guideline does not address such cases. Furthermore, impact of such cases is not very significant compared to overall carbon footprint of a car.
* *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 guideline does not address cleaning operations.

**4.3.6.2. GHG emission estimation**

Since the carbon footprint related to maintenance occurs after the vehicle is placed on the market, it can only be estimated based on statistical data.

There are two possibilities (considered in a hierarchical order):

(a) List of maintenance parts/consumable and associated frequency provided by the manufacturer.

(b) List of maintenance parts/consumable not available

**4.3.6.3. Maintenance Data Availability**

If list of maintenance parts/consumable and associated frequency is provided by the OEM then the following estimation should be used.

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



Where,

i: Consumable/ maintenance parts

: Maintenance frequency of the consumable/maintenance parts defined

: Carbon emission factor of the consumable/maintenance parts as used for calculation of upstream emissions

Determination of list of consumables and parts

Following table provide 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.

Table 4.3.6‑1 : List of consumables and maintenance parts

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Petrol | Diesel | CNG | NOVC-HEV | OVC-HEV | Pure EV | FCHV | OVC-FCHV | H2-ICE | . . . |
| Consumables | Engine coolant | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | - | ✓ |  |
| Engine lubricant | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | - | ✓ |  |
| Screen wash | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Brake fluids | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Electric drive unit fluids | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | - |  |
| Transmission fluid | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Refrigerant | ✓ | ✓ | ✓ | ✓  Under discussion | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| AdBlue/Urea/Reagent | - | ✓ | - | - | - | - | - | - | - |  |
| Maintenance parts | Passenger air filter | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Engine filter | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | - | ✓ |  |
| Spark plug | ✓ | - | ✓ | ✓ | ✓ | - | - | - | - |  |
| Windshield wiper blades | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Tyres | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Brake linings | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| SLI battery (12V) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |
| Aftertreatment | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | - | ✓ |  |
| Traction battery | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | - |  |
| Fuel cell | - | - | - | - | - | - | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |  |  |

Une image contenant texte, capture d’écran, nombre, Parallèle

Description générée automatiquement

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: Tires, starter battery (i.e. 12V), brake pads, brake discs, traction/storage battery (i.e. for electric powertrain vehicles), fuel cell stack (for fuel cell electric vehicles), additional auxiliary batteries (if relevant for commercial vehicles – e.g. for temperature controlled payload areas).

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

Determination of Frequency

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

Frequency by distance

Frequency by duration

In case the OEM recommends frequency by both distance and duration, both calculations should be performed, and most conservative frequency should be considered for the carbon footprint estimation.

A more sophisticated approach is appropriate for traction batteries and fuel cells systems: these systems are generally designed so that no replacement should be needed during the vehicle lifetime in most vehicle types (except perhaps for some heavy duty vehicles with higher lifetime activity). However, due to the major impact of battery and fuel cell on the vehicle lifecycle impacts, the need for replacement or not of these systems in the context of the study should be checked and justified.

The following approaches are adopted to provide a structured hierarchy for determining the need for replacements of traction batteries and fuel cells, which could be applied across all types of LCA study (i.e. for general analyses and scientific studies, as well as product LCA or prospective LCA).

*[Methodology for calculating the need for traction battery replacement(s)]*

The following recommended prioritization is proposed for the underlying assumptions of traction battery replacement, with the choice of which option is most appropriate or feasible left to the practitioner (i.e. depending on the availability of data and objective of the study). The different options are listed in order of accuracy and preference. It is recognized that OEMs and battery suppliers will likely have more sophisticated battery performance modelling supporting their product development and specification. The most important point is that in all cases the study should clearly indicate whether a battery replacement is included or not, and the basis/explanation for this assumption.

Table 4.3.6‑2 : *: Prioritisation for traction battery replacement*

| Proposed prioritization in order of accuracy and specificity (highest to lowest) | UNECE Level |
| --- | --- |
| OEM / supplier specific methodological/modelling approach to define the need for a battery replacement (or not) over the operational life of the vehicle. An explanation/justification for the result should be provided. | Purpose 3/4  (Optional, depending on availability) |
| Standardized methodology based on battery cycle life and lifetime operational activity (below). An explanation/justification for the result should be provided. | Purpose 3/4 or below |
| Simple assumption on whether battery replacement is needed or not, including explanation for this. | Purpose 2 and below. |

For vehicle traction batteries, the following approach for accounting for the frequency of energy storage replacement for Option 2, which is based on a combination of parameters including the anticipated battery cycle life (i.e. number full charge/discharge cycles)[[7]](#footnote-8). This methodology also provides a dynamic link to the vehicle battery capacity and the lifetime activity/service life (as defined in the study Goal & Scope), which can be used in product LCA, prospective LCA or other more generic studies.

The methodology for determining the number of traction battery replacements is as follows (i.e. where a value of N > 1 means at least one replacement is likely to be needed):



Where:

**N** = Total number of traction batteries needed over the vehicle lifetime

**C** [Battery usable] = usable (i.e. ‘net’) traction battery capacity in kWh

**CL** [Battery] = average battery cycle life – number of full charge/discharge cycles (within the usable capacity)

**A** [Lifetime] = vehicle lifetime activity (in km) \*

**E** [Average] = vehicle average electrical energy consumption, in kWh per km

*\*As a sensitivity it is recommended to also explore the potential number of replacements needed based on the warrantied number of km for the battery (where this is present).*

In the absence of manufacturer-specific data on the battery cycle life (parameter ‘CL’ above), then it is proposed to use a value of 2000 charge/discharge cycles, which is representative of a typical value for current technology. Should the battery come with an expected calendar lifetime lower than the defined vehicle lifetime in the Goal & Scope of the LCA study, then a replacement will also be required.

*[Methodology for calculating the need for fuel cell system replacement(s)]*

Fuel cell durability(/life) is defined as the number operational hours to reach 10% degradation of the original fuel cell rated power (in kW)[[8]](#footnote-9). The following general methodological approach is therefore proposed to determine the need for one or more fuel cell replacements over the service lifetime of a vehicle using fuel cell based powertrain (i.e. an FCEV or FC-REEV powertrain), consistent with the similar methodology proposed for fuel cell efficiency degradation (see earlier Section 4.3.3.2).

(Recognising the potential for further development of knowledge in this area, it is also proposed to that should an OEM / supplier specific methodological approach be subsequently developed to define operational fuel cell efficiency loss and/or replacements, this would also be acceptable, if validated by an independent third party expert on fuel cells.)

*Fuel cell lifetime max energy output (= FC [max energy]):*



Where:

Fuel cell average running power (kW) = rated fuel cell power (kW) \* average operation % of rated fuel cell power

*Fuel cell vehicle lifetime energy requirement (energy output from fuel cell) (= FC [lifetime energy]):*



Where:

MJ/km = hydrogen energy input to the vehicle, i.e. hydrogen energy consumption.

The number of fuel cells needed (and therefore the number replacements) is defined by the ratio of the vehicle’s lifetime energy requirements and the maximum fuel cell lifetime energy delivered:



**4.3.6.4. Maintenance Data not available**

The maintenance parts/consumable are already included in the upstream emission as they are part of the vehicle before placing the vehicle on the market. Hence, if list of maintenance parts/consumable not available then a fixed percentage of upstream emission can be attributed to maintenance depending upon powertrain, service life, vehicle segment and region of use.

These factors can be defined by each region through statistical analysis. For all category 1 vehicle it can be assumed that there is no variation within segments.

Where,

: Maintenance frequency as defined in table 2.2

: Carbon footprint of material acquisition stage

Carbon footprint of production stage

: Carbon footprint of recycling stage for maintenance parts, to be evaluated in line with End of Life [SG5].

Table 4.3.6‑2 : Default maintenance frequency as a function of powertrain

Under discussion

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Powertrain | Petrol | Diesel | CNG | NOVC-HEV | OVC-HEV | Pure EV | FCHV | OVC-FCHV | H2-ICE | . . . |
| fmaintenance | YY % | ZZ % |  |  |  |  |  |  |  |  |

**4.4. End of Life [SG5]**

**4.4.1. Levels in disposal and recycling stage**

As introduced in section 3.2.1, 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.

Table 4.4.1‑1 : Level concept of disposal and recycling stages



**4.4.2. System boundaries**

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

Figure 4.4.2‑1 : System boundaries of Disposal and Recycling stages

**Une image contenant texte, capture d’écran, Police, nombre

Description générée automatiquement**

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

**4.4.3. Data collection and data types**

Data shall be collected for the item outlined below. Activity data shall be collected as primary data in Purpose 3 or 4. In case of the difficulty, secondary data may be applied to activity data. GHG emission intensity data shall be collected as secondary data in Purpose 1 or 2. Scenarios for secondary data and secondary data source shall be reported. Secondary data may be referred, among others, to the following data set.

* EF compliant data sets
* IDEA
* JAMA CFP guideline

Table 4.4.3‑1 : Data types for disposal and recycling stages



**4.4.4. Scenario**

**4.4.4.1. Second life parts**

The second life parts for Remanufacturing, Reuse or Repurposing shall be evaluated based on regulation or market observation. In any case the second life parts traceability shall be confirmed with following recommendation of recycling modelling.

　Table 4.4.4‑1 : recycling modelling recommendations for second life

Une image contenant texte, capture d’écran, Police, nombre

Description générée automatiquement

**4.4.4.2. EVL management out of sale region**

The EoL GHG emission of vehicles exported from the country where they were sold/used shall be evaluated by the EoL process of the country where they were exported, used and disposed/recycled. However, if the country to which they were exported cannot be tracked or it is difficult to grasp the EoL process of the country where they were exported, used and disposed/recycled, second Use and EoL phase of exported used car to out of sales region or country may be excluded and evaluated by the EoL process of the country where they were sold/used originally instead.

**4.4.4.3. Recycling process and technology**

GHG emissions intensity for each disposal and recycling process and CFF parameters shall be set in view of the process and recycling technology about 13-17 years later in the future. When a specific recycling process is not existing yet, for which assumptions can be made if they can be appropriately justified. However, if it is difficult to make the dataset based on appropriate future scenario, a scenario based on the current process and recycling technology may be applied.

**4.4.5. Energy modelling [SG6]**

General rules must be referred to the section 3.2.8.

**Future Changes in Energy Mix:**

Practitioners should also account for any potential changes in the fuel or electricity production pathways during the lifetime of the vehicle. (detailed methodology shall be considered)

Specifically, the following recommendations are made on how to model electricity inputs to the EoL phase:

**EoL phase electricity:**

1. The same scenario for the expected future evolution of the electricity grid mix in the geographical region of interest shall be adopted, as previously selected for the dynamic modelling of the use phase electricity input.
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 Si,N of electricity supplied by each technology i in the year N), by applying linear interpolation between the respective electricity supply shares reported for the two nearest pre-defined time horizons in the scenario selected at point 1 above
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 electricity generation technologies. The resulting grid mix thus modelled shall be used to estimate the Emission Factor of the electricity input to the EoL phase of the vehicle.

For dynamically evolving fuel mixes (e.g., “green”/”grey” hydrogen; bio/fossil diesel blends; etc.), a similar approach to the one described above for electricity should be employed, whereby the respective fuel mix models for the use phase and EoL phase are arrived at by considering the existing future scenarios. "

**4.4.6. GHG calculation for each process**

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

GHG emissions in ELV dismantling and shredding/sorting process [kgCO2e] = ELV weight [kg] × GHG emissions intensity for ELV dismantling and shredding/sorting [kg CO2e/kg]

E2; Recovered parts disposal and recycling process

(a) Tyre

(a-1) Disposal

GHG emissions in tyre disposal [kgCO2e] = Tyre weight [kg] x (1-Wear ratio [%]) x GHG emissions for tyre disposal [kgCO2e /kg], which may include the incineration with thermal and electricity recovery which is Energy Modular Burdens and Benefits method and transport.

Energy Modular Burdens and Benefits method shall be evaluated following 2.2.10.2 Incineration with energy recovery

(a-2) Recycle

GHG emissions in materials recycling= Σ (each material weight to which CFF is applied[kg] ×Material Modular Burdens and Benefits method of each material [kgCO2e /kg])

Material Modular Burdens and Benefits methodshall be evaluated following 2.2.10.1. Material and parts recycling modeling.

b) Lead battery

(a-1) Disposal

GHG emissions in lead battery disposal [kgCO2e] =Lead battery weight [kg] x GHG emissions intensity for lead battery disposal [kgCO2e /kg], which may include plastic parts incineration, lead scrap treatment, electrolyte neutralization treatment and transport.

(a-2) Recycle

GHG emissions in materials recycling= Σ (each material weight to which CFF is applied[kg] ×Material Modular Burdens and Benefits method of each material [kgCO2e /kg])

Material Modular Burdens and Benefits methodshall be evaluated following 1.1.5.1 Material and parts recycling modeling.

(c) Airbag

GHG emissions in Airbag disposal [kgCO2e] =Air bag weight [kg] x GHG emissions intensity of airbag proper disposal [kgCO2e/kg]

(d) Air conditioner (AC) refrigerant

GHG emissions in AC refrigerant disposal [kgCO2e] =AC weight [kg] x GHG emissions intensity for AC refrigerant (fluorocarbons) disposal [kg CO2e/kg], which may include fluorocarbons destruction, CO2 from destruction and transport.

(e) Waste Oil

GHG emissions in waste oil disposal [kgCO2e] =Waste oil weight [kg] x GHG emission intensity for oil disposal [kgCO2e /kg], which may include the incineration with thermal / electricity recovery which is Energy Modular Burdens and Benefits method and transport.

Energy Modular Burdens and Benefits method shall be evaluated following 2.2.10.2 Incineration with energy recovery

(f) Drive battery

(f-1) Disposal

GHG emissions in drive battery disposal [kgCO2e] =Used battery pack weight[kg] x GHG emissions intensity for used battery pack proper treatment [kgCO2e /kg] +Σ (carbon ratio of each combustible material [%] × 44/12 × each combustible material weight in used battery packs [kg])

In case that the used battery is repurposed, it is multiplied by (1-repurposing ratio [%]).

The materials to which CFF is applied, e.g. steel, aluminum and copper materials, in the battery pack shall be evaluated as materials recycling by CFF in accordance with E4; Material recycling process.

(f-2) Secondary use (Repurposing)

CFF shall be applied to evaluate the repurposing of the drive battery from ELV to other industries in case of the traceability confirmed in accordance with 1.1.5.3. Second life parts.

In case of CFF application, 1) Production burden shall be evaluated in the battery production stage. Both 2) Burdens and benefits related to secondary parts input and 3) Burdens and benefits related to secondary battery output shall be evaluated and merged in the disposal/recycling stage as Repurposing Modular Burdens and Benefits method*.* Modular Burdens and Benefits method shall be separately reported and included into total vehicle CFP .

Repurposing Modular Burdens and Benefits method formular for battery repurposing

-; Allocation factor of burdens and credits between supplier and user of reused battery.

-; Proportion of the battery that will be reused in a subsequent system. [%]

- ; Quality of outgoing secondary battery / quality of virgin battery

-; Specific emissions and resources consumed (per unit of analysis) arising from the production of virgin battery. [kgCO2e /kg]

-; Specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process. [kgCO2e/kg]

Datasets () to be used in CFF may be collected as primary data. CFF parameters () may be defined as default values in reference documents.

f-3) Material recycle

GHG emissions in materials recycling= Σ (each material weight to which CFF is applied[kg] ×Material Modular Burdens and Benefits method of each single material [kg CO2eq/kgmaterial] recovered from the battery disassembly process) + Σ (battery cell weight to which CFF is applied [kg] × Material Modular Burdens and Benefits method of battery cells specific recycling process [kg CO2e/kgbattery\_cells], if applicable according to regional regulations)

Material Modular Burdens and Benefits methodshall be evaluated following 1.1.5.1 Material and parts recycling modeling.

g) Catalytic converters

g-1) Disposal

GHG emissions in Catalytic converters disposal [kgCO2e] = Catalytic converters weight [kg] x GHG emissions intensity for Catalytic converters disposal [kgCO2e /kg], which may include residue landfill after recycling process.

g-2) Recycle

GHG emissions in materials recycling= Σ (each material weight to which CFF is applied[kg] × Material Modular Burdens and Benefits method of each material [kgCO2e /kg])

Material Modular Burdens and Benefits method shall be evaluated following 1.1.5.1 Material and parts recycling modeling.

E3; Automobile shredder residue (ASR) disposal and recycling process

GHG emissions in ASR disposal [kgCO2e] = ASR thermal recovery material weight [kg] x GHG emissions intensity for ASR disposal [kgCO2e /kg], which may include the incineration with thermal and electricity recovery by CFF and residue landfill, excluding wood.

GHG emissions in wood disposal [kgCO2e] = Wood material weight [kg] x GHG emissions intensity for wood disposal [kg CO2e/kg], which may include the incineration with thermal and electricity recovery by CFF, not including CO2 absorption effect.

E4; Materials recycling processes

GHG emissions in materials recycling= Σ (each material weight to which CFF is applied[kg] ×Material Modular Burdens and Benefits method of each material [kgCO2e /kg])

Material Modular Burdens and Benefits methodshall be evaluated following 1.1.5.1 Material and parts recycling modeling.

E5; Transport processes (transfer to SG1; t,b,c )

GHG emissions in transport = Σ (transport weight [t] ×transport distance [km]×transport ton-km GHG intensity [kgCO2e /t/km])

Tranport processes in disposal and recycling stage shall cover following transport processes.

-Dealer→Dismantler

-Dismantler→Shredder

-Shredder→ASR recycler

-ASR recycler→Landfill

**4.5. Interpretation [?]**

**4.6. Sensitivity Analysis [?]**

**4.7. Reporting [?]**

Concerning reporting, the LCA results according to this Resolution shall be treated without bias to the intended audience. The A-LCA report shall include results, data, methods, assumptions and limitations, which shall be presented transparently and in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also describe its goals of the study clearly so that the results and interpretation to be used in a manner consistent with the goals.

In the case that the study results are intended to be used in comparative assertions to be disclosed to the public, it is strongly recommended to include other requirements given in chapter 5 of ISO 14044.

**4.8. Verification process [?]**

1. ILCD handbook [↑](#footnote-ref-2)
2. Source: https//ellenmacarthurfoundation.org/white-papers-and-articles [↑](#footnote-ref-3)
3. [Estimating the longevity of electric vehicles: What do 300 million MOT test results tell us?](https://cep.lse.ac.uk/_NEW/publications/abstract.asp?index=10626) [↑](#footnote-ref-4)
4. Infrastructure/capital goods for production of fuel or electricity may be excluded/cut-off if the resulting impacts are less than 3.0% (cumulatively) share of the total impacts (including use) for the fuel or electricity supplied. In this case an appropriate scoping assessment should be provided as evidence/justification for the cut-off. [↑](#footnote-ref-5)
5. Electricity transmission and distribution and energy storage infrastructure are excluded from the scope/boundaries for the assessment. [↑](#footnote-ref-6)
6. UNECE report on LCA electricity: [Carbon neutrality in the UNECE region: integrated life-cycle assessment of electricity sources](https://digitallibrary.un.org/record/4020227?v=pdf), and at least for renewable and nuclear-derived electricity. These impacts should also be factored into the production of any RFNBO (renewable fuels of non-biological origin) produced from electricity, such as hydrogen and other gaseous or liquid e-fuels. [↑](#footnote-ref-7)
7. As also previously implemented in (Ricardo et al., 2020) based on consultation with stakeholders. [↑](#footnote-ref-8)
8. [FCH 2 JU - MAWP Key Performance Indicators (KPIs) - European Commission (europa.eu)](https://www.clean-hydrogen.europa.eu/knowledge-management/strategy-map-and-key-performance-indicators/fch-2-ju-mawp-key-performance-indicators-kpis_en) [↑](#footnote-ref-9)