Towards a European-wide harmonised transport-specific LCA Approach

TranSensus LCA

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EXECUTIVE SUMMARY

Zero tailpipe emissions vehicles (ZEVs) are a promising option for more sustainable mobility services. Action needs to be taken in Europe and globally to foster more sustainable road transportation prioritizing climate-neutrality targets. To this end, decision-making processes need to be informed via robust methodologies to evaluate and monitor sustainability performance. Life cycle-based methodologies, such as Environmental Life Cycle Assessment (E-LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), are the logical choice as these can provide a holistic sustainability perspective. E-LCA, S-LCA, and LCC are increasingly used within policy making, industry, and science to obtain sustainability information related to products, services, or technologies, as well as systems on a larger scale, including that of ZEVs. However, not all methods are equally mature (e.g. S-LCA being a newer method) and all methods include a number of choices that can be made, which can lead to variations in results. Currently, there is not enough harmonization on these choices, which leads to variations in results, **hinders the comparability of studies, and limits the usefulness of the methods for guiding decision makers.**

A key objective of the TranSensus-LCA project is to develop a consensus methodology for environmental LCA of ZEVs as a first priority, but it also aims to address similar issues in **social LCA**. The consortium includes influential European academic and industrial partners in the mobility field. This report is **Deliverable 2.3** of the TranSensus-LCA project. It delivers a **Final harmonised approach** to enable fair comparison of LCA studies of ZEVs.

The development of this methodology relies on **a scientific and democratic approach within WP2**, divided according to ISO 14040 LCA framework based on intermediate deliverable D2.2 on *Initial description of the building blocks of a recommended approach.* Discussions on practices, scientific alternatives and methodologies enabled to provide requirements or a limited number of alternatives to address each treated topic. Project beneficiaries and associated partners voted to select recommendations or options prepared by the TranSensus-LCA working groups.

The agreed TranSensus-LCA methodology documented in this deliverable concerns E- (environmental) and S- (social) LCAs of existing **product LCA*** as well as **prospective LCA*** and **fleet LCA*.** This methodology includes **143 methodological specific requirements (58 of which being mandatories) for E-LCA.**

The main document describes the different requirements, mandatory to optional, covering all aspects of E-LCA and S-LCA: goal & scope, inventory, impact assessment, interpretation and reporting. The annex document provides complementary information to help LCA practitioners to better apply the TranSensus-LCA methodology and gives more details regarding the way recommendations were built. This methodology is currently being tested to validate its feasibility (T2.6) and success with regards to the project's objectives (T3.3).

EXECUTIVE SUMMARY

Future work will integrate wider consensus with advisory boards, Consensus Liaison Group and plan its implementation into a roadmap. It will also be formatted into a guidance document (D5.2).

(*) Note : for the definitions of 'Product LCA', 'Prospective LCA' and 'Fleet LCA', refer to Subsection I.1.

Important abbreviations

ADP:	Abiotic Resource Depletion
BEV:	Battery Electric Vehicle
BEV-ERS:	Battery Electric Vehicles - Electric Road Systems
BOM:	Bill Of Materials
CED:	Cumulative Energy Demand
CDP:	Carbon Disclosure Project
CFF:	Carbon Footprint Formula
DIN:	Deutsches Institut für Normung
EACs:	Energy Attribute Certificates
EF:	Environmental Footprint
E-LCA:	Environmental Life Cycle Assessment
EoL:	End-Of-Life
ERS:	Electric Road Systems
EU:	European Union
EV:	Electric Vehicles
FCEV:	Fuel Cell Electric Vehicle
FC-REEV:	Fuel Cell Range Extended Electric Vehicle
GHG:	Green House Gas
GVW:	gross vehicle weight
GWP:	Global Warming Potential
H_2 ICEV:	Hydrogen Internal Combustion Engine Vehicle
HDV:	Heavy-Duty Vehicle
HEV:	Hybrid Electric Vehicle
ICE:	Internal Combustion Engine
ICEV:	Internal Combustion Engine Vehicle
IEA:	International Energy Agency's World Energy Outlook (IEA WEO)

ILCD: International Life Cycle Data system

INCOSE: International Council on Systems Engineering

IPCC: Intergovernmental Panel on Climate Change

I-REC: International Renewable Energy Certificates

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

LCC: Life Cycle Costing

LCV: Light Commercial Vehicle

LFP: lithium iron phosphate

MLC: Managed LCA Content (Former GaBi database)

NMC: Nickel Manganese Cobalt (battery)

OEM: Original Equipment Manufacturer

PEF: Product Environmental Footprint

PHEV: Plug-in Hybrid Electric Vehicle

REEV: Range-Extended Electric Vehicle

S-LCA: Social Life Cycle Assessment

SoC: State of Charge

SoH: State of Health

STEPS: Stated Policies Scenario

TTW: Tank To Wheel

WLTP: Worldwide Harmonised Light Vehicles Test Procedure

WP: Work Package

WTT: Well to Tank

ZEV: Zero Emission Vehicle

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Introduction

TranSensus-LCA project

The TranSensus-LCA project (funded by the EU's Horizon Europe programme) aims to develop a baseline for a European-wide **harmonised**, **robust**, **transparent**, **commonly accepted** and applied **single life cycle assessment approach** for **zero emission vehicle**, including **environmental** and **social** aspects. This method should allow **real-data-based LCA**, be **adaptative** (depending on the goal, the practitioner and the level of knowledge), be **comprehensive** including **all life cycle stages** and **relevant impact categories** (not focusing only on GWP), cover a wide range of Zero Emission technologies, allow confidentiality, be standardized, differentiating, auditable.

The project is structured into six work packages (WP). The first WP of TranSensus-LCA (WP1) aims to review existing standard and guidelines, OEMs reports and literature, addressing E-LCA[1] and S-LCA for vehicles and batteries. Based on this review (summarised in deliverables D1.1 & D1.2), surveys and internal expertise, the second WP of TranSensus-LCA (WP2) identified gaps and needs. Two deliverables D2.1 "Ontology & management database" (harmonised proposition for database sharing rules) and D2.2 "Initial description of the building blocks of a recommended approach" have already been delivered earlier in the project. Based on this previous work on building blocks description, the WP2 is proposing now a common Life Cycle Assessment methodology for ZEV in this deliverable. The TranSensus-LCA project has succeeded in initiating a consensus building process to develop a harmonised and commonly accepted methodology (see Figure 1). As part of this approach, D2.1 provides technical aspects on how to define and share datasets and this deliverable (D2.3) provides the technical approach on how to assess the studied system.

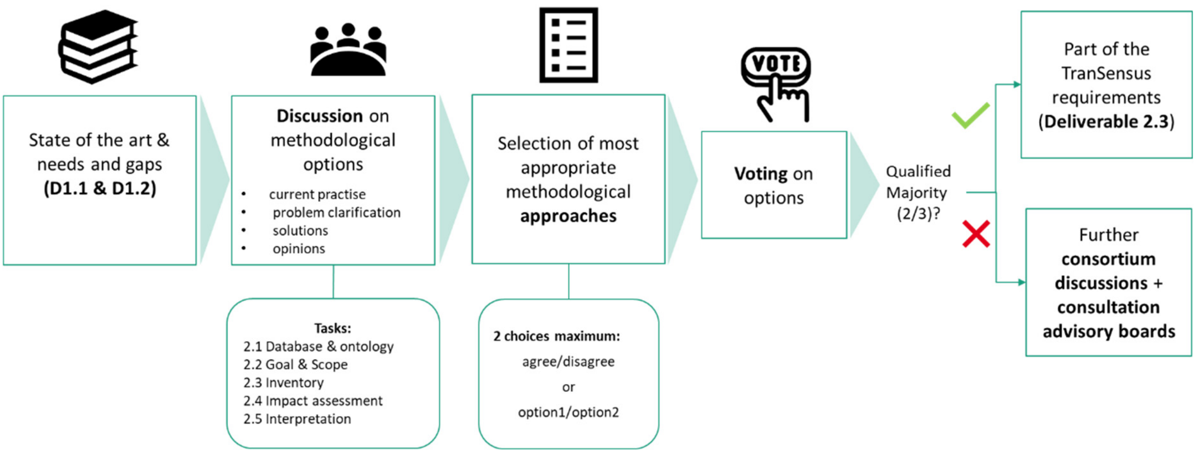


Figure 1: Methodology development with projects beneficiaries supported by associated partners

[1] By default, we will use 'LCA' for 'E-LCA' in this document

The TranSensus-LCA methodology feasibility and workload of each single requirement is being independently evaluated within T2.6 "Feasibility & applicability". At the time of the preparation of this report, two-thirds of the requirements have been tested and upgraded within D2.6, with the last third being currently tested; all test results will be delivered within the final WP2 deliverable, D2.4 "Report on interpretation, decision making and feasibility". The TranSensus-LCA methodology will also be tested and validated as a whole within WP3 "Consensus Building with Advisory Boards", where complete vehicle LCAs will be conducted.

Motivation, objectives and contributions of this deliverable

This report D2.3 "Final harmonised approach" is the result of two years of common work within the WP2 as well as internal votes within TranSensus-LCA project beneficiaries and involved partners on a series of proposed methodological recommendations. This work has been focussing on environmental and social LCA of existing product, prospective, and fleet LCA including all life cycle stages and circularity aspects, focusing not only on GWP but also other pertinent impacts for a wild range of zero emission vehicles technology.

> This report aims to describe the mandatory, recommended and optional requirements which build the harmonised, robust, transparent, commonly accepted and applied single life cycle assessment approach for zero emission road transport system, including environmental and social aspects

The TranSensus-LCA project is one of 26 existing local, regional or international vehicle LCA harmonization activities inventoried by OICA for UNECE A-LCA Informal Working Group (UNECE A-LCA IWG):

- 7 activities with vehicle component focus like Chinese, Japanese[2] Battery Product Category rules (PCR), EU battery regulation Art.7[3], Catena-X rulebook[4]
- 5 regional activities with vehicle focus (non-legislative) in France (PFA[5]), Germany (VDA[6]), Japan, US (GREET[7]) & including this EU project TranSensus LCA[8]
- 6 Customer information-oriented activities like Green NCAP[9] or several EPD PCR.

[2] https://www.meti.go.jp/shingikai/mono_info_service/chikudenchi_sustainability/pdf/004_06_01.pdf
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1542
[4] https://catenax-ev.github.io/docs/next/non-functional/overview
[5] https://pfa-auto.fr/wp-content/uploads/2023/04/DT_Me%CC%81thodologie_2023_V15_ENGLISH.pdf
[6] https://webshop.vda.de/VDA/en/vda-900-100-082022
[7] https://dec-word-edit.officeapps.live.com/we/Argonne GREET Model (anl.gov)
[8] http://www.lca4transport.eu/
[9] https://www.greenncap.com/

- 5 Regional legislative activities with vehicle focus like EU LDV CO2 regulation[10] to be updated in 2025, French Eco Bonus[11], Brazil[12], China or Korean[13] legislative actions.
- 3 Overarching activities: EU[14] & UK[15] Carbon Border Adjustment Mechanism (CBAM) or UNECE[16] A-LCA informal working group

The developed TranSensus LCA methodology contributes to vehicle LCA harmonization and has been built to enable the resulting studies applying this method, to be:

- Understandable, i. e. providing a clear scope and results to the audience (including limitations);
- Harmonized, i. e. being one clear, unique, TranSensus-LCA method fostering the possibility to compare one study results to other ones using it, even when conducted by distinct parties.
- Accurate, i. e. providing indicators close to the actual (true) value of the environmental and social performance of the systems analysed;
- Auditable, i. e. with credible verification process (or audits) overcoming the challenge of confidentiality;
- Accepted by the scientific community and industrials;
- Reliable and trustworthy, i. e. the audience shall have confidence in how far the outcomes of a TranSensus LCA-compliant study correctly represent the environmental and social impacts of a product.

The TranSensus-LCA consortium is now confident that the developed methodology outlined in this report reaches these objectives. Nonetheless, further tests are currently being conducted to verify the methodology feasibility and applicability.

Structure of Deliverable

This deliverable is composed of 2 documents:

- A **main document,** which presents all requirements for all life cycle stages where the reader will find needed information to apply the TranSensus-LCA methodology for ZEV:

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019R0631-20240101
[11] https://www.economie.gouv.fr/particuliers/bonus-ecologique
[12] https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2024/lei/l14902.htm
[13] Korean
[14] https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698889
[15] https://www.gov.uk/government/consultations/consultation-on-the-introduction-of-a-uk-carbon-border-adjustment-mechanism
[16] https://wiki.unece.org/pages/viewpage.action?pageId=172852228

goal & scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), interpretation and reporting. This methodology is applicable also for S-LCA, and across product, prospective, OEM and macro fleet LCA studies. This document outlines the methodological requirements for the four LCA steps of environmental and social LCA:

- **Goal & scope** including definition, technology coverage, functional unit, system boundary for all types of LCA.
- **Life Cycle Inventory** with details for data collection, electricity modelling and multifunctionality.
- **Life Cycle Impact Assessment** giving rules and requirements on mandatory and optional impact categories as well as normalisation.
- **Interpretation & Reporting** of level of exigence (mandatory, recommended, optional) and level of adherence to the TranSensus-LCA methodology.
- **Social LCA (S-LCA)** providing specific considerations structured around the four phases, similarly to environmental LCA.

- An additional "**Annex**" document, which gives complementary information, for example: on the way the outlined recommendations were built, on the selection of options, and on the inclusion or exclusion of certain items. The structure of this document is similar to the main document to help the reader to more easily find relevant information. In this document, the LCA practitioner may also find some further details regarding the consensus building process, where relevant.

How to use the report

This report is an extensive document that has been developed to provide a clear outline of the TranSensus-LCA methodology for environmental and social LCA of ZEVs. LCA practitioner can go through the entire document and find a brief description of any requirement according to the appropriated scope. This document presents also the reporting needs. It has been structured slightly differently from ISO structure for practical reasons but aimed to cover all topics of ISO.

In this document we use the following definitions:

- "**shall**" indicates a **mandatory** requirement ('M')
- "**should**" indicates a **recommended** requirement ('R')
- "**may**" is used to indicate an **optional** requirement ('O')
- For information, we use ('I')

An overview of the methodology structure and main requirements is summarised in a mindmap format on Figure 2. The mindmaps with detailed requirements.will be presented in the dedicated parts of the document. The requirement list can also be found in subsection IV.6.

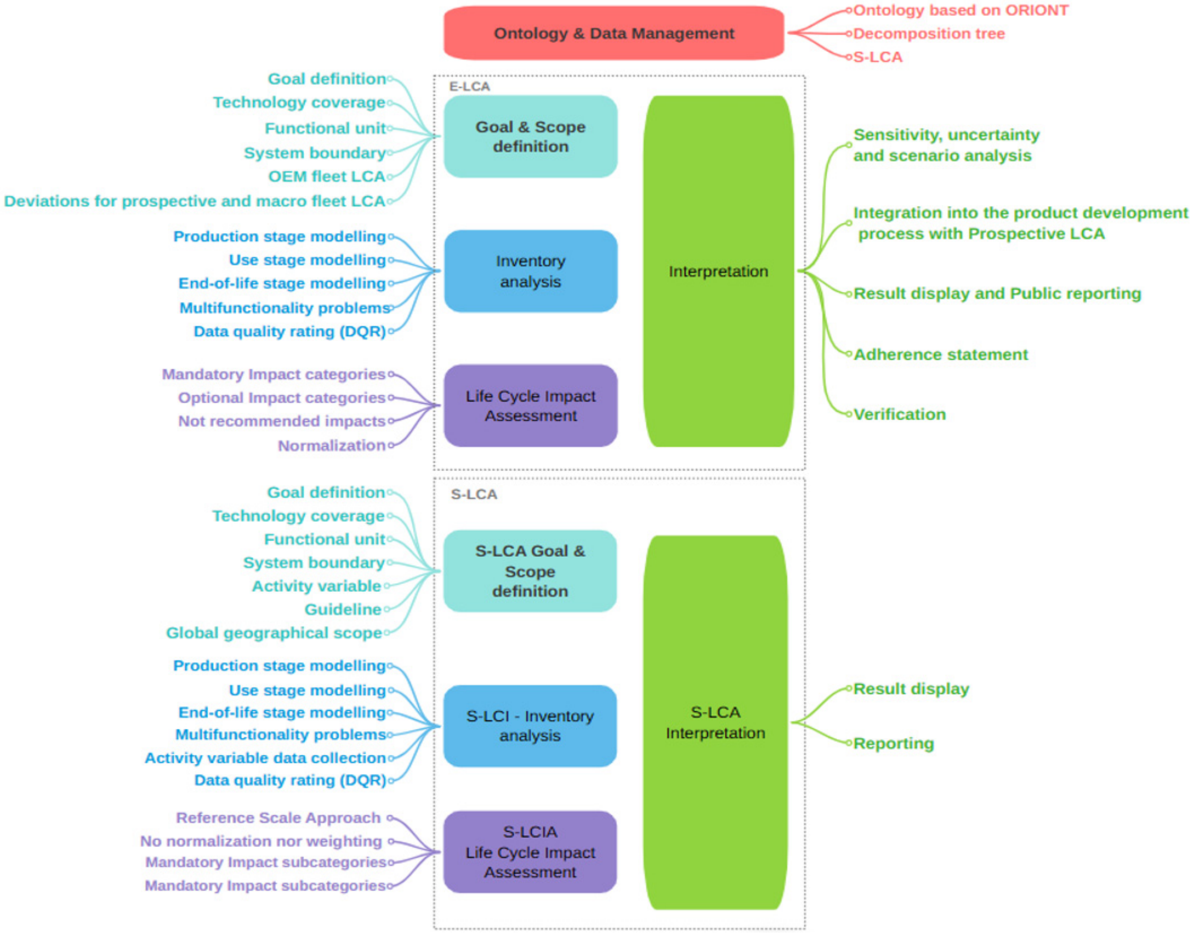


Figure 2 : Requirements of TranSensus-LCA methodology (Summary)

Part A: Environmental LCA

I. Goal and scope

The mindmap below summarizes all TranSensus-LCA requirements for Goal and Scope regarding goal definition, technology coverage, functional unit, system boundary, and OEM fleet LCA.

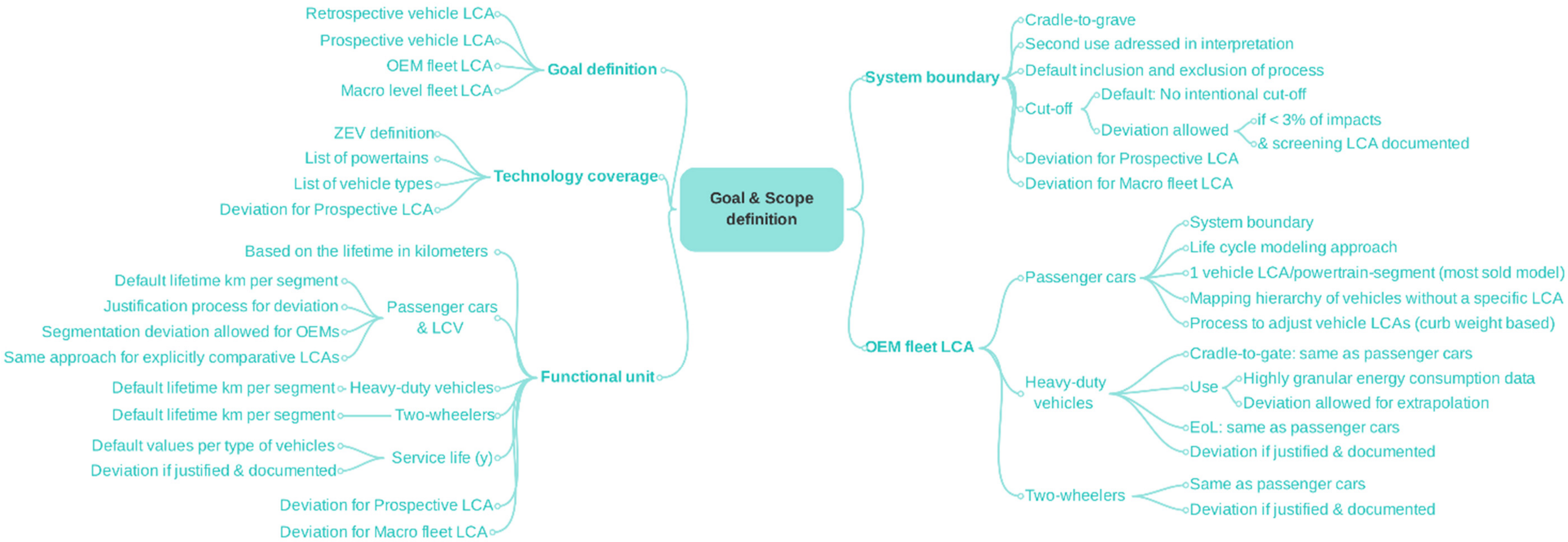


Figure I-1 : Goal and scope requirements of TranSensus-LCA in a form of a mindmap.

I.1 Goal definition

Four LCA types are defined matching different goals in the LCA. The LCA types are characterized with a definition, a reason for carrying out the LCA, the LCA users, as well as the target audience. The base for the LCA type definition is the ILCD decision context. It was extended to two different levels of the fleet LCA.A user of the LCA was also added.

Table I-1 : Four LCA types of TranSensus-LCA with their definition, a reason for carrying out the LCA, the user of the LCA and the targeted audience

LCA type	Definition	Reason	LCA practitioners and users of the results	Target audience
Product LCA	A product LCA is a mostly retrospective vehicle LCA and aims to evaluate environmental impacts slightly before or after the start of production. A nearly finalised bill of materials of all parts is available to the OEM.	Reporting and compliance Calculation base for sustainability report Identification of hot-spots Target setting Comparison between vehicles	LCA experts in the R&D department / product department External consulting firms	Customers Internal stakeholders (decision makers, product developers) Auditors Policy makers
Prospective vehicle LCA	A prospective LCA is conducted in the development phase and aims to estimate environmental impacts before the start of production (several years). The TRL is low (TRL<6) and the BOM is not completely defined.	Research and development (eco-design) Target setting Identification of levers to reach targets Comparison between vehicles	R&D department Purchase department (targeting supply chain) External consulting firms Researchers (universities and RTOs)	Internal stakeholders (decision makers, strategy developers) Policy makers (informative) Scientific community
OEM fleet LCA	A manufacturer fleet LCA, also called OEM fleet LCA, aims to evaluate the weighted environmental impact of a series of different products introduced by a	Corporate reporting of fleet emissions Inform future decarbonisation strategy Fleet portfolio optimisation	Same as retrospective/prospective vehicle LCA	Managers for target tracking and general public (information in Annual and Sustainability report), CDP, sustainability ratings, financial ratings

LCA type	Definition	Reason	LCA practitioners and users of the results	Target audience
	single manufacturer. Typically, it is based on an extrapolation of vehicle product LCAs.			
Macro level fleet LCA	Macro level fleet LCA is conducted at the sub, national or international level to support economy-scale strategies. Fleet is typically generic, i.e. representative of a variety of manufacturers	Inform policy decision making Strategic & sustainability planning Evaluation of consequences of large scale decisions	Research institutes Consultancies Governmental agencies	Policy makers Scientific community General public

A decision tree is defined to help in applying the different LCA types.

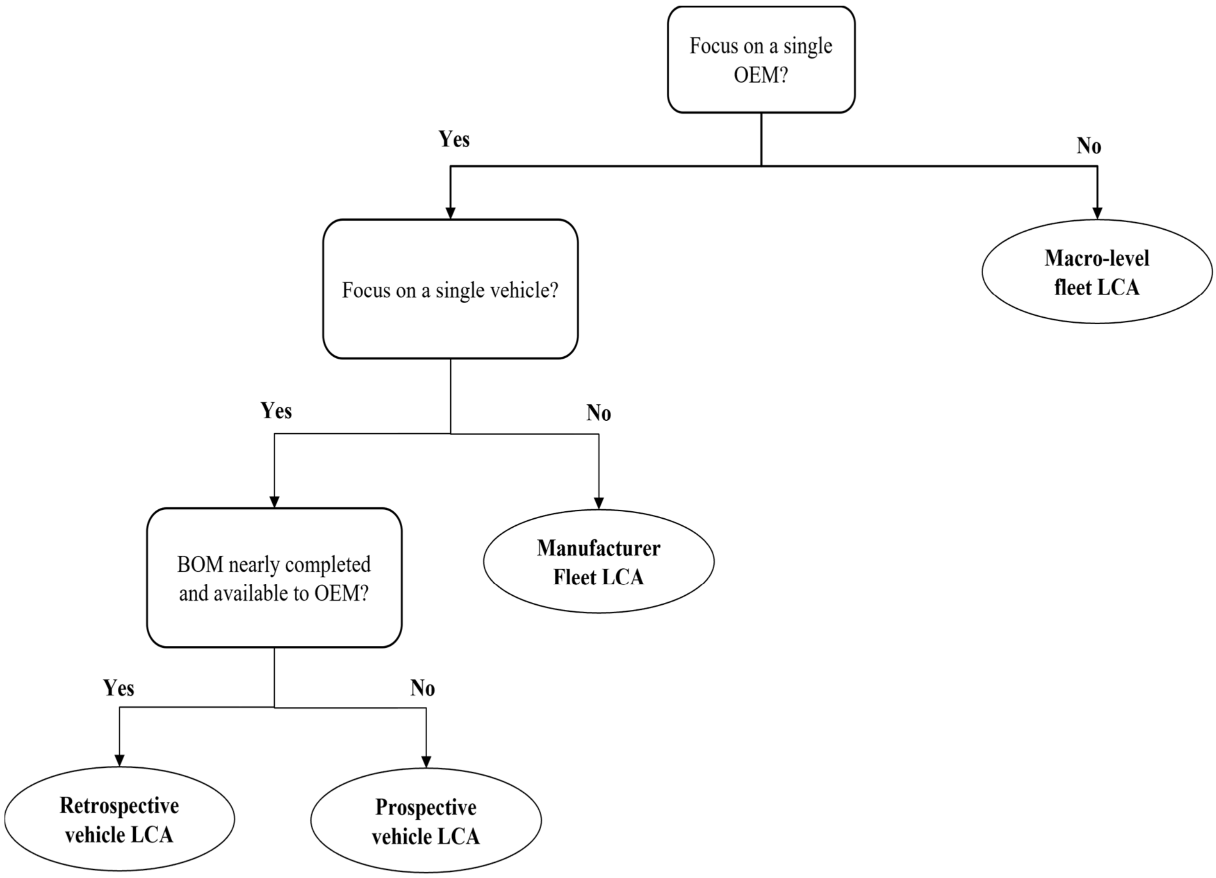


Figure I-2 : Decision tree showing the differentiation between the LCA types

I.2 Technology coverage

A zero-emission vehicle (ZEV) is defined as a vehicle without any significant GHG tailpipe emissions. The following powertrains and vehicle types are covered by TranSensus-LCA:

List of powertrains:

- BEV – Battery electric vehicles
- FCEV – Fuel cell electric vehicles
- FC-REEV – Fuel cell range extended vehicles
- BEV-ERS – Battery electric vehicles with dynamic charging operation on Electric Road Systems (e. g. includes BCEV = battery catenary electric vehicles, as well as vehicles operating on dynamic wireless/inductive charging, or rail conductive charging)
- H_2 ICEV – Hydrogen fuelled internal combustion engine vehicle

List of vehicle types:

- Passenger car
- Light commercial vehicle (LCV)
- Heavy Duty Vehicle (Lorries, Urban busses, Coaches)
- Two-wheeler (Motorcycle, Moped)

Textbox I1: Prospective LCA - Deviation for Technology coverage

The technology coverage in the prospective LCA is open for all new and emerging technologies as long as they meet the definition of the ZEV.

I.3 Functional Unit

The functional unit of different vehicle types for the retrospective vehicle LCA is based on the lifetime of the vehicle stated as kilometres.

The following functional units **shall** be used:

- Tonne-km[17] [18] for lorries
- Passenger-km[17] for busses and coaches. The occupancy rate for busses and coaches (Max capacity, average occupancy, seated) **shall** be documented.

[17] 'tonne-km' is the standard format used by the European Commission (Glossary: Passenger-kilometre - Statistics Explained). It is equivalent to 'tonne*km' or 'tkm' if shortened. Similarly for 'passenger-km' or 'vehicle-km'.
[18] The assumptions on payload must be indicated and aligned with assigned VECTO payload

- Passenger-km for passenger cars with the default assumption of one passenger, which then equals to vehicle-km for passenger cars. If other information on occupancy rates is available, this can be used.

Occupancy rates for the passenger car **should** be addressed as part of a sensitivity analysis.

I.3.1 Lifetime in kilometres

The following default values for the lifetime in kilometres **shall** be used, following the methodology from step 1 to step 4.

I.3.1.1 Passenger cars and LCV

Step 1: Lifetime kilometres **shall** be chosen on a segment basis. Comparisons between vehicles and segments **shall** be made on a km basis (v.km / p.km).

The segment-specific default values **shall** be those given in Table I-2, based on PRIMES-TREMOVE (Ricardo Energy and Environment, '*Assessing the impacts of selected options for regulating CO2 emissions from new passenger cars and vans after 2020*', Final Report for the European Commission, DG Climate Action, 2018).

Table I-2 : Default values for lifetime in kilometres for passenger cars and light commercial vehicles (LCV)

	Passenger car					LCV		
Lifetime activity, km	Small (A/B)	Lower medium (C)	Upper medium (D)	Large (Others	All	Small	Medium	Large
All powertrains	190 000	200 000[19]	210 000	260 000	200 000	240 000		

Source: Estimates based on the PRIMES-TREMOVE model assumptions (2018); Aggregation: Ricardo analysis (2023).

Step 2: Lifetime assumptions may be different from the default values if they are sufficiently justified. Comparisons **shall** be made as described in Step 1. The following process **should** be followed to justify the values:

[19] Basis for generic value for Step 3

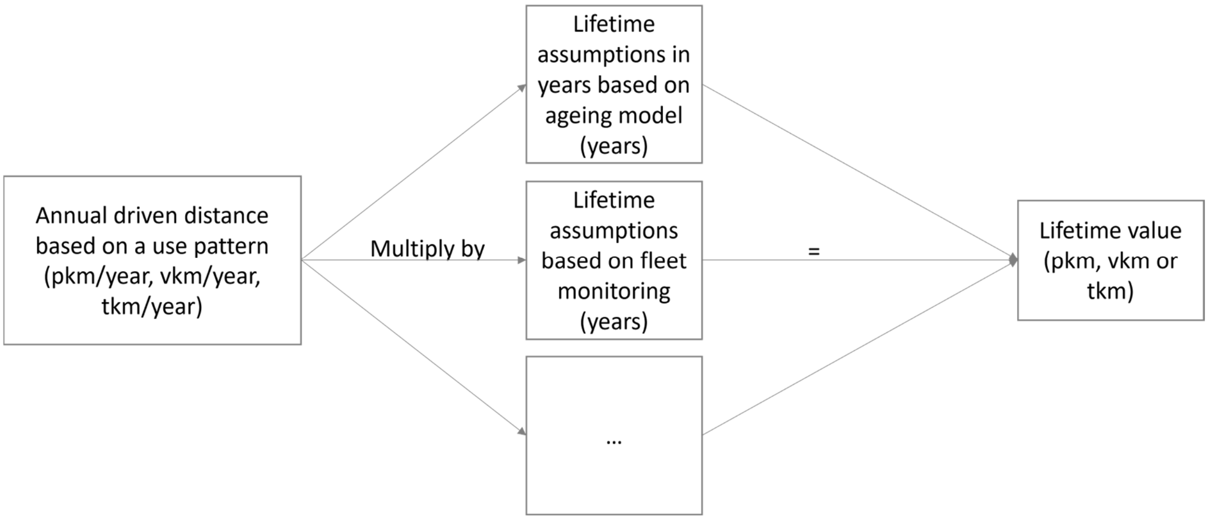


Figure I-3 : Process to define individual lifetime values

First, an annual driven distance should be calculated based on a specific use pattern of this vehicle. This includes the typical trips made, the length of the trips and the frequency. This can also include payload and passengers. The annual driven distance should be multiplied by the lifetimes in years to obtain the full driven distance over the lifetime. There are different ways to justify the lifetime in years, such as for example:

- Based on an ageing model
- Based on fleet monitoring
- Other sufficiently justified lifetime assumptions (in years) are acceptable as well.

A transparent documentation of the assumptions shall be made.

The combination of a use pattern and an ageing model leads to the use of a mission profile. A mission profile is created as follows:

a. List the different typical trips performed by the user (e.g., work commute, weekend excursion, holidays)

Then for each kind of trip:

b. Define its typical length in km
c. Define the number of times this trip is performed per year
d. Define a typical speed profile (might look like a WLTP cycle, but on the full length of the trip)
e. Define the type of charging after the trip (charging power, charged once every *x* trips, state of charge (SoC) limit)
f. For long trips, define the type of charging during the trip (charging power, SoC limits)

g. Consider the climate where the car operates, define the external temperatures at which the trip is performed (e.g., *x* times at 0°C, *y* times at 10°C, *z* times at 20°C,...).

Step 3: TranSensus-LCA acknowledges that OEMs have to steer complex corporate environmental programs including a wide range of vehicle models and regions (and even separate brands) for which vehicle LCAs are a crucial data source. Moreover, OEMs must provide straightforward and legally defensible information regarding the environmental impacts caused over the lifecycle of their vehicles for their customers and other stakeholders. Therefore OEMs **may** opt to use a more generic approach instead, whereby a generic lifetime of 200 000 km is assumed for passenger cars of all segments.

With this approach, comparisons between segments may be performed on a lifecycle basis (i.e. environmental impact/total driven distance) or based on the approach described in Step 1 (environmental impact/1km).

Step 4: Regardless of the selected modelling approach (Steps 1., 2. and 3. above), the same approach **shall** be used in all instances of explicitly comparative LCAs, which are aimed at making "comparative assertions" (i.e. either Step 1, Step 2 or Step 3).

I.3.1.2 Heavy-Duty Vehicles

For HDVs, the segmentation provided by the Commission Regulation (EU) 2017/2400 (The European Parliament and the Council of the European Union, 2017), which is also implemented in VECTO (European Commission, '*Vehicle Energy Consumption calculation TOol - VECTO'*), **shall** be used.

The VECTO tool is prescribed for calculation of HDV energy consumption for each segment and for different mission profiles/cycles as defined in the EU CO_2 and fuel consumption certification legislation for HDVs, and which are also defined in Commission Regulation (EU) 2024/1610 amending Regulation (EU) 2019/1242 on strengthening CO_2 emission standards for heavy-duty vehicles. These regulations also define standardised annual km for new HDVs and weighting factors for different mission profiles/cycles to be used to calculate a weighted average value for the assessment of compliance with CO2 reduction targets for different HDV segments. For the purpose of the TranSensus LCA methodology, these yearly-driven distances are scaled to lifetime driven distances using scaling factors derived from an internal Scania/MAN study based on a real fleet monitoring. Therefore, the following default values for the lifetime assumption **shall** be used:

- For lorries: Yearly distance from VECTO x 12
- For urban buses: Yearly distance from VECTO x 15
- For coaches: Yearly distance from VECTO x 18

I.3.1.3 Two-Wheelers

For two-wheelers, the following default values based on the SIBYL model (Joint Research Center of the European Commission, 2024) by EMISIA **shall** be used:

Table I-3 : Default values for lifetime in kilometres for two-wheelers (motorcycles, mopeds)

	Motorcycles				Mopeds	
	2 stroke > 50cm^3	4 stroke < 250cm^3	4 stroke 250 – 750cm^3	4 stroke > 750cm^3	2 stroke < 50cm^3	4 stroke < 50cm^3
Lifetime in km	75 000				45 000	

Furthermore, default values for the lifetime in years for the different vehicle types are provided.

I.3.2 Lifetime in years

The following default values for lifetime in years **shall** be used:

Table I-4 : Default values for lifetime in years for passenger cars, light commercial vehicles, heavy duty vehicles, motorcycles and mopeds

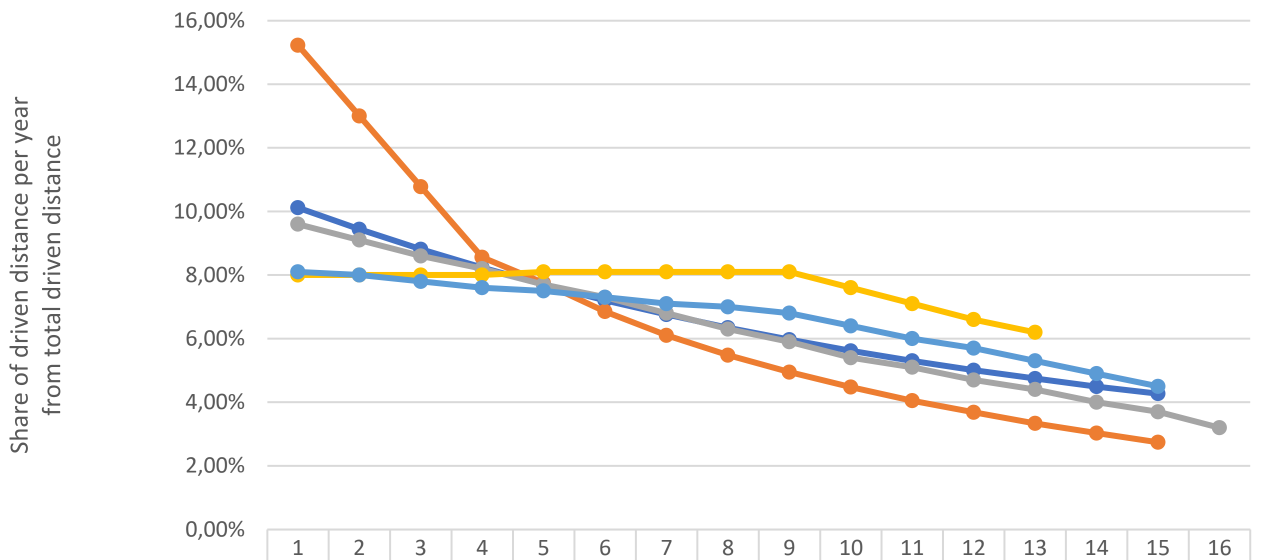
	Passenger cars	Light Commercial Vehicle (LCV)	Heavy Duty Vehicles (HDV)			Motorcycles	Mopeds
			Urban busses	Coaches	Trucks		
Lifetime in years	15	15	13	15	16	25	21

The values are a conservative assumption and shall be updated in the future to reflect the growing service lifetime of vehicles and also when robust data specific to ZEV become available (where this is expected to be meaningfully different for equivalent vehicles). Other values **may** be used if they are documented and justified.

I.3.3 Distribution of driven distance for a dynamic approach in the use stage

If a dynamic[20] approach for emission factors is to be used, a reasonable driven distance distribution (expected driven distance year 1, 2, 3 … X) **should** also be applied. An even distribution assumption will significantly underestimate the GHG footprint for the use stage due to that the effect of high driven distances in later years being multiplied by lower emission factors, especially for lorries. An even distribution of driven distance is not at all supported by real fleet monitoring data.

The default distributions of the driven distance per year for passenger cars, light commercial vehicles and heavy duty vehicles **should** be defined as shown in Figure *I-4*.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Passenger car	10,12	9,44%	8,81%	8,23%	7,70%	7,20%	6,76%	6,34%	5,97%	5,61%	5,30%	5,01%	4,74%	4,49%	4,27%	
Light commercial vehicle	15,22	13,00	10,78	8,56%	7,75%	6,85%	6,10%	5,48%	4,95%	4,48%	4,05%	3,68%	3,33%	3,03%	2,74%	
Truck	9,60%	9,10%	8,60%	8,20%	7,70%	7,30%	6,80%	6,30%	5,90%	5,40%	5,10%	4,70%	4,40%	4,00%	3,70%	3,20%
Urban bus	8,00%	8,00%	8,00%	8,00%	8,10%	8,10%	8,10%	8,10%	8,10%	7,60%	7,10%	6,60%	6,20%			
Coach	8,10%	8,00%	7,80%	7,60%	7,50%	7,30%	7,10%	7,00%	6,80%	6,40%	6,00%	5,70%	5,30%	4,90%	4,50%	

Figure I-4 : Default distribution of driven distance per year

[20] At least driven distance evolution per year and electricity mix change per year are to be considered

I.3.4 Examples for default functional units

The following are examples for default functional units:

- Product LCA on a small passenger car: "190 000 passenger-km driven over 15 years by a small passenger car"
- Product LCA for mopeds: "45 000 vehicle-km driven over 21 years by a moped".

Textbox I-1: Prospective and Macro Fleet LCA - Deviation for Functional Unit

Prospective LCA:

The functional unit should remain the same as for the product LCA. The default values for the reference flow may be adapted following the general process for the product LCA. If additional functions are considered in the system that affect the lifetime of the vehicle (such as the usage of the vehicle to grid), this should be reflected in the reference flow used. [For more information on dealing with multifunctionality, please refer to the section II.5]. The chosen reference flows should be justified and documented.

Macro Fleet LCA:

The functional unit should be adapted to reflect the aim of the study. Macro fleet LCAs may have various options for the potential functional unit. One option is:

Operation of a total fleet of vehicles in a given region over a given time period (i.e. one year or full lifetime of the vehicle)

The functional unit should be clearly explained and documented.

I.4 System boundary

The system boundary modelled **shall** be cradle-to-grave for retrospective vehicle LCA.

As drawn in Figure *I*-5, several system boundaries exist in LCA practices, such as cradle-to-gate, Well-to-tank, Well-to-wheel and Cradle-to-grave.

The system boundary **shall** include the following stages of the life cycle: raw material extraction; material, components (battery and fuel cell included) and energy production; vehicle production; use and end-of-life scenarios. Second use of the battery was excluded from the default system boundary, but it **should** be studied in a scenario analysis in the interpretation phase. Please note that for lorries it is not mandatory to model the production and the End-of-Life of the trailer[21]. The trailer **shall** be included in the use stage for relevant types of lorry, consistent

[21] also applicable to other kind of HDV ZEV specific type of build-on (box, concrete mixer, garbage collector, etc...)

with the European HDV certification regulations (e.g. for articulated lorries, based on simulations including the generic trailer using the VECTO[22] certification model).

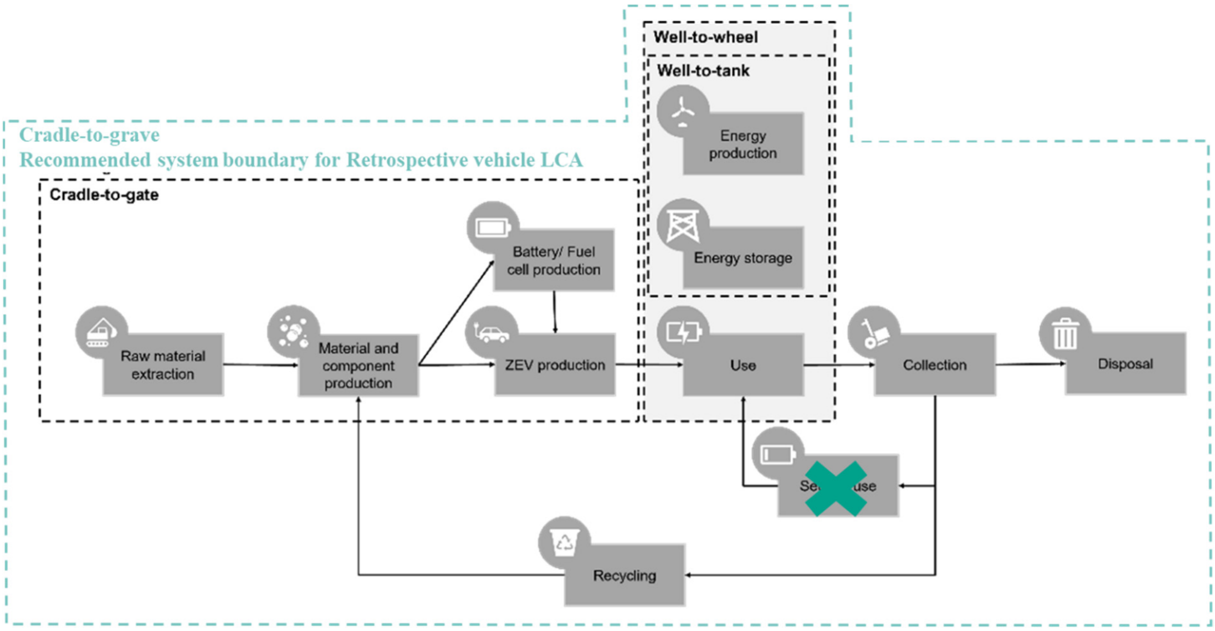


Figure I-5 : Recommended system boundary for retrospective vehicle LCA

The following list of processes to include or exclude from the system boundary addresses frequent discussion points in the LCA and **shall** be followed:

Table I-5: List of processes to include or exclude from the system boundary

Element	Definition	Exclude/ Include
Development, administration, marketing expenses	Refers to inputs to the manufacturing plant that are not directly related to the production process (e.g. heating and lighting of associated office rooms, secondary services, sales processes, administrative and research departments, etc.) (JRC-CBF)	Exclude
Employee commuting	Transport of employees to and from works	Exclude
Capital goods - infrastructure and equipment	Refers to capital goods (e.g., machinery, trucks, and infrastructure) with a lifetime longer than one year. The lifetime is the period between the time of production and the time of initiating waste treatment of the product (ecoinvent, see (Weidema *et al.*, 2013))	Exclude

[22] also applicable to other kind of HDV ZEV specific type of build-on (box, concrete mixer, garbage collector, etc...) if included in VECTO

Element	Definition	Exclude/ Include
Charging station or hydrogen re-fuelling station	This includes depot or public electric vehicle recharging infrastructure or hydrogen refuelling stations/dispensing equipment.	Exclude
Infrastructure for electricity and hydrogen generation	This includes: power plant, transmission (+ losses), transformers	Include
Auxiliary materials for production	Refers to materials needed for production that do not end up in the product (e.g. solvents, cleaning materials). This also includes capital goods with a lifetime shorter than 1 year.	Include
Maintenance: consumables	Refer to Table II-3	Include
Maintenance: wear parts	Refer to Table II-3	Include
Non-exhaust emissions from tyres and brakes	Emissions of particulate matter due to road vehicle tyre and break wear (NFR code 1.A.3.b.vi). (European Environment Agency, 2019)	Include
Charging cable of the vehicle delivered with vehicle	-	Include
Charging and hydrogen refuelling losses	Losses in energy (electrical or hydrogen) between that energy delivered to the electric vehicle charger equipment (or hydrogen dispenser) and the energy stored on-board the vehicle (e.g. in the battery or the hydrogen storage tank).	Include

The cut-off hierarchy following a cut-off allowance by considering thresholds and exceptions from the allowance **shall** be applied.

A hierarchical process **shall** be used to cut off flows:

- No intentional cut-off of flows **shall** be made, where these can be reasonably avoided.
- In case a cut-off is needed, an absolute threshold based on 3% of the environmental impacts (all life cycle stages, company-specific data) **should** be applied.

To use the cut-off allowance, all cut-off flows cumulative **shall** be below 3% of the environmental impacts in all mandatory impact categories in TranSensus-LCA. Which means, if the cut-off flows impact is above 3% in even one of the mandatory impact categories, it cannot be excluded.

To use the cut-off allowance, this minimum 97% coverage (max. 3% cut-off) of environmental impacts **shall** be achieved and documented in a screening analysis, which shall be representative for the vehicle being assessed. The screening analysis is used to determine which processes are relevant and which may fall under the cut-off criterion. If no data is available a conservative estimation shall be made. An initial screening of the LCI of a representative product shall be performed by the company calculating the impacts, referred to as the screening step. The screening pursues the goal of pointing out the need for action in terms of data collection activities or activities to improve data quality. A screening shall include the LCIA of all mandatory impact categories in TranSensus-LCA. Within screening, no exemption is allowed and readily available primary or secondary data may be used, fulfilling the data requirements to the extent possible. Once the screening is performed, the initial scope settings may be refined. The representative product approach and a description of the excluded attributable processes **shall** be documented.

Textbox I-2: Prospective LCA and Macro Fleet LCA - Deviation for System Boundary

Prospective LCA:

The system boundary **shall** remain cradle-to-grave. If deemed relevant for the future market secondary functions such as second use, vehicle to grid or other processes may be included in the system boundary. This **shall** be documented.

Cut-off rules and processes to include and exclude **shall** remain the same. If the system boundary is adapted, the processes to include and excluded **should** be revised. Any changes **shall** be justified and documented.

Macro Fleet LCA:

The system boundaries **shall** remain cradle-to-grave. The cut off rules **shall** remain the same. Processes regarding capital goods and charging stations/hydrogen refuelling stations **should** be included in the macro fleet LCA. The system boundary and all included and excluded processes **shall** be documented.

I.5 OEM fleet LCA

Single product LCAs following the TranSensus-LCA approach **should** be used to calculate an OEM fleet (retrospective, worldwide) LCA following the below-defined process.

Note that the method is explained on the basis of GWP impact as it is the current focus of OEMs. Nevertheless, OEM fleet LCAs **may** be calculated for any impact category.

I.5.1 Passenger cars and light commercial vehicles

The OEM fleet LCA should be used by OEMs to report the lifecycle carbon emissions of their fleet in a specific year and geographical area. It should be tracked and reported in absolute CO_2 equivalent emissions (t CO_2eq) or in t CO_2eq /average vehicle. The OEM fleet LCA includes the production stage, the use stage and the End-of-Life stage. The use stage is modelled based on the fleet reporting to authorities, by using the consumption values for WLTP interpolation families. As soon as the legislation requires reporting including a real-world emission adjustment factor, this input may be adapted. As OEMs need verified values for external publication, the officially requested use stage data is used for the OEM fleet-level LCA. The fleet emissions are based on the sales numbers of the OEM in a specific year and market and include all powertrains in the fleet. The overall fleet emission value of the OEM, i.e. the tank-to-wheel (TTW) emissions, is thus an average of all the sold vehicles: BEVs with 0 g CO_2eq/km, conventional ICEVs with e.g. 103 gCO_2eq/km etc. The OEM fleet modelled is thus based on the sales numbers in a given year and geographic area accounting for the lifecycle emissions/environmental impacts within one reporting year. Thus, the approach described here does not account for a rolling stock. The well-to-tank (WTT) emissions are modelled with the time and market-specific fuel and electricity supply chain emission factors from secondary databases. The overall WTT value in t CO_2eq/average OEM vehicle being a weighted average of the vehicles' consumption values. The production and the EoL stage are modelled based on the available vehicle LCA data of an OEM (minimum criteria are proposed below). A detailed description, numerous modelling possibilities and background for an example of OEM fleet LCA reporting can be looked up in (Neef *et al.*, 2024).

Here, only minimum criteria for the OEM fleet LCA are defined. One refinement possibility is for the OEM to use their time and market specific in-house production emissions from their environmental information systems instead of e.g. outdated energy consumption averages from one single production site that is generically used for all vehicle LCAs included in the vehicle LCAs. OEMs can refine their modelling approach step-by-step with the most reliable data available to them.

Specific vehicle LCAs are not available for all vehicle models in the OEM fleet. Therefore, a minimum criterion to conduct an OEM fleet LCA is to have one vehicle LCA per powertrain-segment combination of the most sold model with respective equipment.

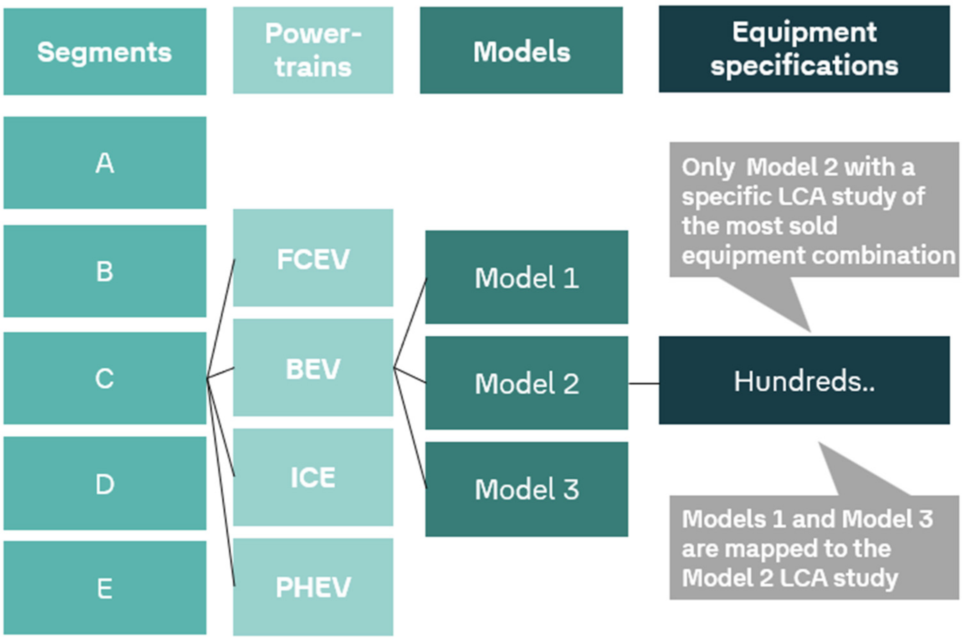


Figure I-6 : Minimum criterion for performed OEM fleet LCAs: one vehicle LCA per powertrain-segment combination of the most sold model with respective equipment.

Vehicles without a specific LCA are mapped to existing ones with the following hierarchy. OEMs should adapt and expand this hierarchy basing on their fleet characteristics. The term "derivative" refers to different car body types produced for one model e.g. a sedan and a coupé version. The term "brand" refers to different car brands owned by one OEM Group, e.g. AUDI and PORSCHE are part of the VW Group and are therefore also part of the VW Group fleet level LCA.

i. Region - segment - powertrain - derivative - brand - model name - generation (model name specification)

ii. Region - segment - powertrain - derivative - brand - model name

iii. Region - segment - powertrain - derivative - brand

iv. Region - segment - powertrain - derivative

v. Region - segment - powertrain

Figure I-7 : Mapping hierarchy of vehicles without specific LCA

The modelling results for the production and EoL stages are then adjusted based on curb weight differences, as shown in an example below:

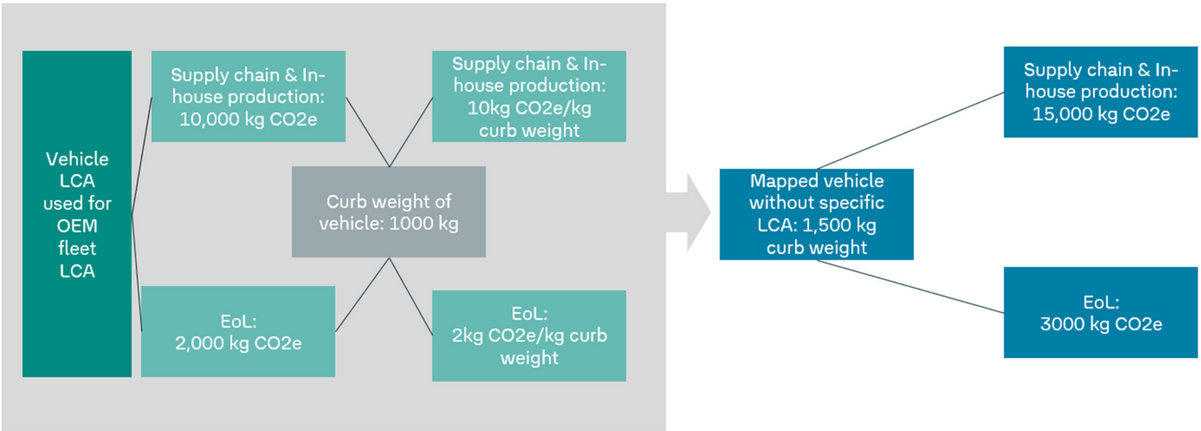


Figure I-8 : Process to adjust vehicle LCAs based on the curb weight

To sum it up, the following process is used to reach the OEM fleet level (example given for GWP):

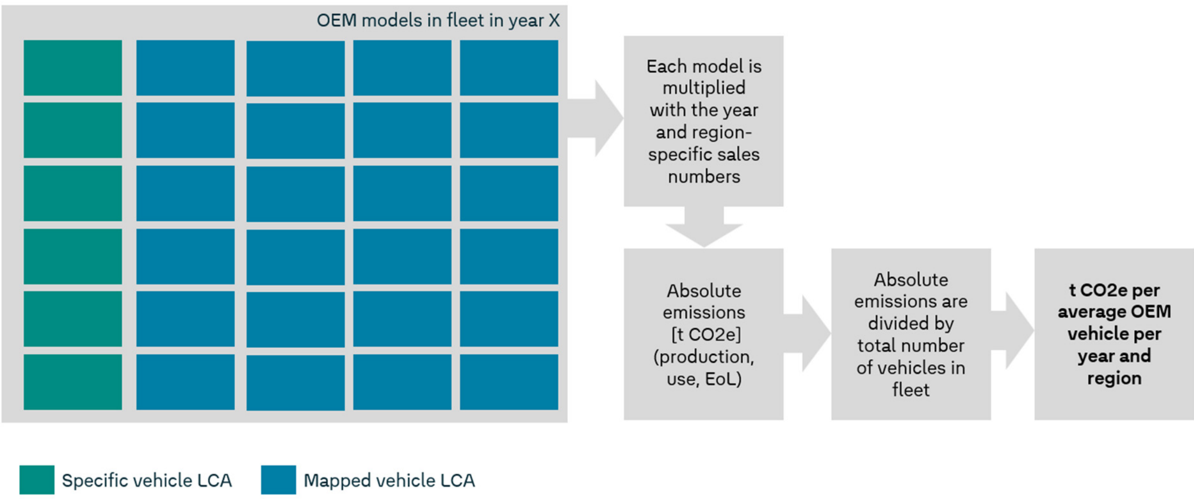


Figure I-9 : Summary of process for the OEM fleet LCA

Data sources and assumptions **should** be sufficiently documented and justified.

I.5.2 Heavy duty vehicles

For HDVs, the same process as for passenger cars **should** be applied for cradle-to-gate and EoL. The use stage environmental impacts **should** be modelled with highly granular energy consumption data, e.g., fleet monitoring data on chassis number level. As a second option, the energy consumption in the use stage **may** be assessed with extrapolation of a limited set of representative energy consumption values. To justify the representativeness, the practitioner **should** document and justify the chosen assumptions on key input parameters that influence energy consumption. VECTO can be for example used for this second option. Adaptions **may** be made where necessary with sufficient documentation and justification.

I.5.3 Two-wheelers

The same process as for passenger cars **should** be applied to two-wheelers. Adaptions **may** be made where necessary with sufficient documentation and justification.

II. Life Cycle Inventory

The second phase of Life Cycle Assessment is Life Cycle Inventory (LCI). In this chapter the guidelines are grouped according to the life cycle stages of products, namely: production including raw materials acquisition, use, and end-of-life stages. This includes the topics: data choices, electricity and hydrogen modelling, with both the supply and the consumption related to each life cycle stage. In addition, further guidelines on generic topics are provided. These topics are multifunctionality, which provides a full guidance to deal with multifunctionality problems, and data quality assessment represented by a section on Data Quality Assessment (DQR). Lastly, a final section titled "outlook on future work" summarizes what could be improved in the TranSensus-LCA method in the future and suggests specific topics for future research. The mindmap below summarizes all requirements for LCI.

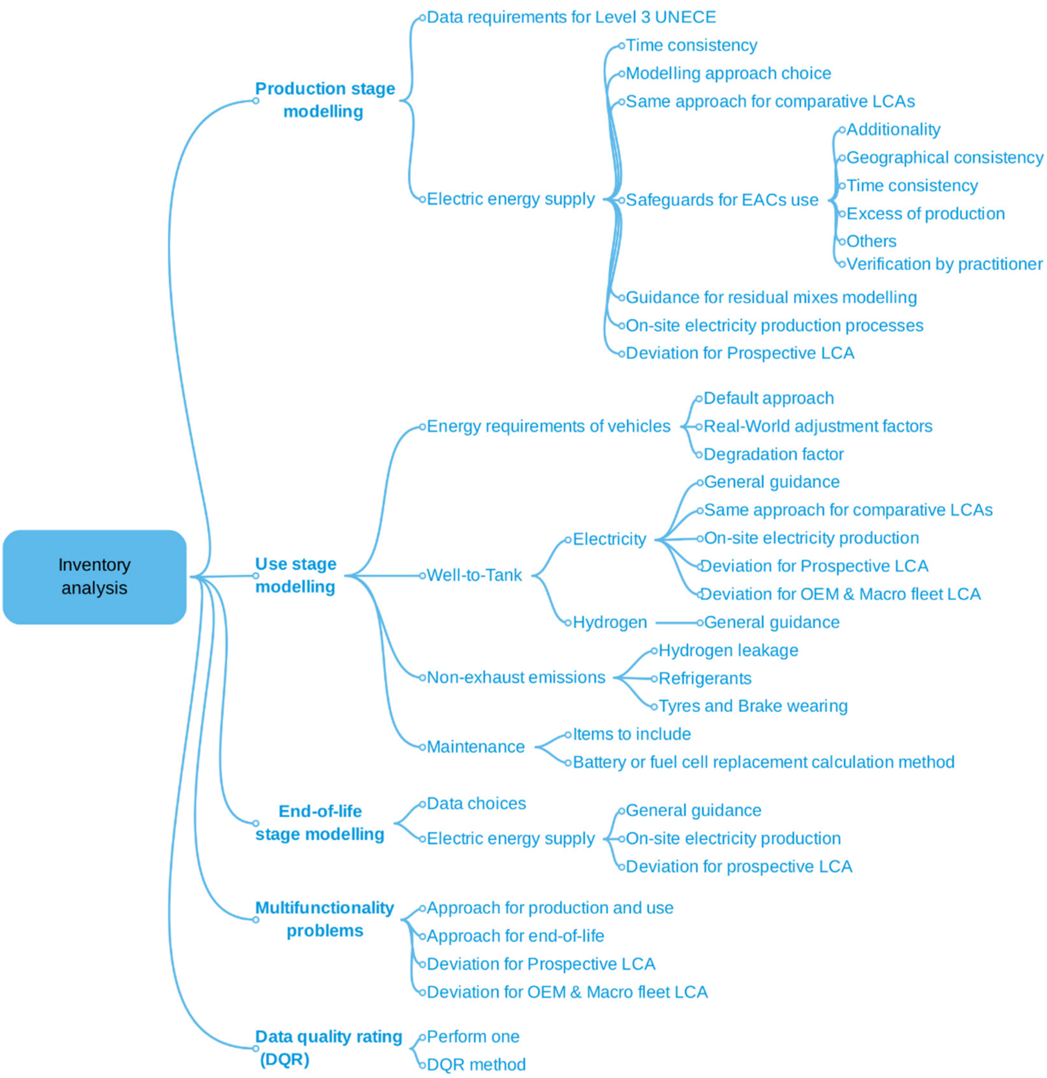


Figure II-1 : LCI requirements of TranSensus-LCA in a form of a mindmap

II.1 Production stage modelling

In this section, we provide guidance on inventory modelling in the production stage of the vehicle. This includes data requirements to reach Level 3[23] LCA (as defined by the UNECE A-LCA IWG[24]), and how to model the electric energy supply (background electricity modelling) to manufacturing activities.

II.1.1 Data requirements for level 3

To reach Level 3 for a BEV Light-Duty Vehicle and Heavy-Duty Vehicle product LCA, following minimum cradle-to-gate data requirements **shall** be applied:

- The practitioner **shall** choose vehicle parts that cause in total a minimum of 20% of the production stage Global Warming Potential (GWP) in addition to the battery system that the EU Battery Regulation Article 7 is covering with data requirements. To reach the 20% threshold, the practitioner **shall** iterate as specified in Figure II-2.
- The chosen parts **shall** be modelled with company-specific data for at least their tier-1 suppliers, while secondary data **may** be used to cover the rest of the parts' supply chain.
- A list of the parts chosen to fulfill these requirements (e.g. car body, rims) **shall** be provided by the practitioner.
- H_2 storage vessel (FCEV, FC-REEV, H_2-ICEV) **may**[25] be treated similarly to batteries which means it is modelled with company-specific data apart from the generic 20%.

[23] Level definition: refer to Annex, subsection 'Data requirements for level 3
[24] UNECE (United Nations Economic Commission for Europe) work on LCA: https://unece.org/transport/documents/2023/01/informal-documents/lca-status-report-iwg-lca
[25] Note that, today, company-specific data collection for the H_2 storage vessel is not required by regulations. However, it may be the case in the future given the significance of the impacts. This point will then have to be revisited in the future.

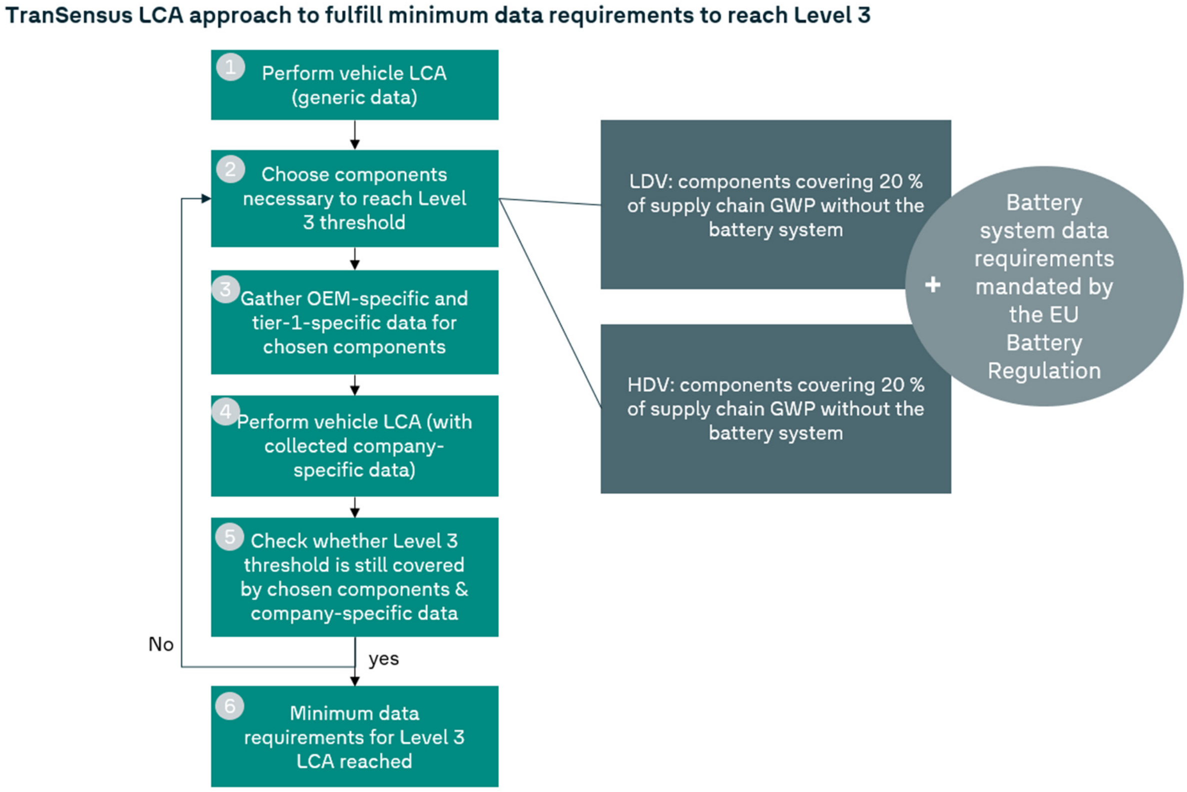


Figure II-2 : Iterative approach to fulfil the TranSensus-LCA Level 3 minimum data requirements.

II.1.2 Electric energy supply in manufacturing stage

II.1.2.1 Overall time consistency

When modelling electricity consumption processes in the manufacturing stage of the subject under study, the electricity consumption processes and datasets that are used **shall** correspond as much as possible to the time period of the manufacturing stage of the subject under study as defined in the goal and scope of the study. It is to be noted that some uncertainty might arise with the selection of the datasets and processes as some databases might not provide the data needed nor be up to date. The choice of the datasets and processes **shall** be justified and documented.

II.1.2.2 General guidelines

In order to satisfy both the entities that would like to use the location-based approach and those that would prefer to use the market-based one, and to propose a solution for companies that have difficulties implementing a 100% market-based approach, the following decision tree was established. A choice **shall** be made between the following 3 options: a location-based approach, a 100% market-based approach, and a mixed-method approach. Therefore, the following modelling approach **shall** be followed for electric energy supply in the vehicle production stage. It starts with location-based approach as a basic choice, but allows for industries to use Energy Attribute Certificates (EACs):

- TranSensus-LCA **shall** use a location-based approach by default (exceptions listed at points below).

  In this approach, every electricity consumption process is modelled using either a sub-national consumption grid mix (i.e. for the USA and China, for more accuracy) or a national consumption grid mix (i.e., country-specific), or, if both national and sub-national consumption grid mixes are not available, a supra-national consumption grid mix (i.e., EU grid mix).

- However, Energy Attribute Certificates (EACs) may be used if desired, in this case industries **should** opt for a 100% market-based approach, in which every electricity consumption process is modelled using either:

  - Processes that reflect the electricity mix purchased via specific contractual instruments related to the considered process and including losses during transmission and distribution of the purchased electricity,

  - Or, if no contract exists for the given process, a residual consumption mix related to it, which can be derived either at a national level (i.e., country-specific residual consumption mix related to the process) or at a sub-national level (i.e. for the USA and China, for more accuracy) or, if both national and sub-national residual consumption mixes are not available, at a supra-national level (i.e. EU residual consumption mix).

To be noted: the contractual instruments that are used **shall** comply with the specific safeguards as stated in the following sections.

To be noted: most of market-based residual consumption mixes and a great majority of general LCA processes using them are not yet available for OEM global supply chains. In practice, for now, it is not feasible (time consuming, data availability) for the OEMs to use market-based residual consumption mixes throughout their entire value chain, which is required by a 100% market-based approach, for electricity consumption that is not covered by an Energy Attribute Certificate (EAC).

To be noted: this approach **should** only be used if the entity has enough data (i.e. secondary databases and datasets using residual consumption mixes for every process in the upstream value chain of the product).

- Lastly, TranSensus-LCA acknowledges that industries, when they do not have either enough adequate data (processes covering needed residual mixes and processes using them) or the time to develop those, **may** use the following mixed-method approach that is currently widely practiced in the OEM industry to model production stage impacts:
  - Use the available location-based electricity mixes consumption processes from the LCA databases as generic default while using specific processes that reflect the electricity mix purchased via specific contractual instruments from suppliers and / or the electricity mix produced within the OEM's factories and including losses during transmission and distribution of the purchased electricity.

To be noted: the contractual instruments that are used **shall** comply with the specific safeguards as stated in the following sections.

Regardless of the chosen modelling approach, in TranSensus-LCA the same approach **shall** be used in all instances of explicitly comparative LCAs, which are aimed at making "comparative assertions", as defined by ISO 14044.

To be noted: the above electricity consumption modelling methodology for the vehicle production stage does not imply dual reporting (i.e. one for location-based and one for 100% market-based/mixed approach). For instance, an industry that wants to use EAC should use a 100% market-based approach, if it has enough data. If not, it can use a mixed approach and still claim level A or B of adherence to the methodology (see subsection IV.3) whatever the choice, as long as the choice is publicly reported and all requested conditions among its choice are respected.

To be noted: TranSensus-LCA acknowledges the high risk of double counting of inventories and impacts that can happen when the mixed approach is applied. Therefore, we strongly encourage working towards a 100% market-based with time, or when possible, location-based.

Whatever the approach chosen for modelling the electricity consumption processes during the production stage, it **shall** be clearly justified and documented (type of approach, electricity mixes used for foreground and background processes). This will allow for comparisons of Product LCA results using the same approach.

Textbox II-1: [Prospective LCA] - Deviation for [Electric energy supply in manufacturing stage – General guidelines]

The [Electric energy supply in manufacturing stage – General guidelines] deviates from the one for the product LCA production stage.

Indeed, prospective LCA will have production occurring in the future. The exact time frame of this stage **should** be specified within the goal and scope of the study.

The hypotheses that are used **should** also be specified within the goal and scope of the study. The use of Power Purchase Agreements (PPAs) is one of them.

Since the production stage of Prospective LCA occurs in the future, it is impossible to use the usual Energy Attribute Certificate (EAC), since such contractual instruments are dedicated to past electricity production.

Nevertheless, it is possible to assume that some PPA can be secured. A PPA is a combination of electricity and EACs. It is often a long-term agreement between a seller of renewable electricity and a buyer of that renewable electricity. Within that a PPA both electricity and EACs are purchased.

Guidance for electricity modelling in prospective LCA for the production stage.

When performing a Prospective LCA, the following decision tree for the production stage electricity modelling approach, **should** be used:

- ➢ Is there a hypothesis concerning the use of PPAs for a Prospective LCA electricity production modelling?
  - ☐ If No, then use the specific average grid mix of the country or region where the vehicle is expected to be produced, used and decommissioned, estimated for the considered time frame, as defined in the goal and scope of the study, on the basis of the use stage electricity modelling approach for Product LCA (dynamic future electricity grid mix or static current mix).
  - ☐ If Yes, then use the following hierarchy:
    - if specific contracts (like PPA) are expected to be used for the same time representativeness as the study, use these specific contracts mixes,
    - For whatever electricity that is not expected to be covered by a PPA contract, use a <u>prospective</u> residual grid mix with the same time representativeness as the study,
    - For whatever electricity that is not expected to be covered by a PPA contract, use a <u>current</u> residual grid mix.

To model future electricity mixes, LCA practitioners **may** use the results of the PREMISE (PRospective EnvironMental Impact asSEment) project (Sacchi *et al.*, 2022), which offers a streamlined approach to producing databases for prospective Life Cycle Assessment using Integrated Assessment Models.

Whatever the approach chosen for modelling the electricity consumption processes during the manufacturing stage of a prospective LCA, it **should** be clearly justified and documented (type of approach, electricity mixes used for foreground and background processes). This will allow for comparisons of Prospective LCA results using the same approach. Furthermore, Prospective LCA results using countries or regions where double counting of renewable power plant emissions occurs (i.e. in locations where no residual consumption mixes are used) **should** be justified and documented.

II.1.2.3 Safeguards for the use of EACs in TranSensus-LCAs

Most market-based methods rely on classic EACs, which remain unrestrictive in terms of activation time (one year) or compatibility with the physical transmission and distribution of electricity associated with these contracts. As such, they could open the way to all the "generic arguments against the unbundled contractual instruments" (potential accusations of greenwashing).

The environmental integrity of the use of EACs depends on ensuring that these contractual instruments respect the following additional guidelines and safeguards on additionality, bundling with production, synchronicity, negative emissions and other classical characteristics. Therefore, in case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, all following safeguards **shall** be followed.

II.1.2.3.1 Safeguard on additionality[26]

If no additivity constraint is imposed, a large part of EACs can be generated by power plants that have already made a profit. They are only a windfall effect, contribute to low prices, and do not encourage the development of new renewable power plants. To be completely efficient, any safeguard proposed on additionality should be supported by law and with harmonization within the electricity market.

Therefore, in case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, all the EAC used **shall** be issued for installations that have been recently built, and that started to produce electricity and were connected to the grid less than 15 years ago.

The person performing the study **should** make sure that such safeguard is respected while conducting the study.

The additivity characteristics of the EAC used for the TranSensus-LCAs **shall** be clearly justified and documented.

[26] Additionality definition: the installation would not have existed without the financial intervention.

II.1.2.3.2 Safeguard on geographical consistency

Some EACs rely on electricity producing assets that may not belong to the same bidding zone[27] as where the sold electricity is consumed. Some may not even be connected physically to the processes that consume electricity within the product upstream value chain. This is for instance the case of Iceland electricity that cannot be physically consumed anywhere else than in Iceland. Taking advantage of Iceland electricity production emissions for production stage processes that occur in Europe is therefore highly questionable.

In case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, the attribute tracking instrument **shall** refer to an electricity production asset located in the same bidding zone (within which a physical synchronous interconnection can be proven) in which the product production stage electricity-consuming operations are located.

In cases for which it is difficult to prove that the electricity producing asset related to the used EAC belongs to the same bidding zone as the value chain site where the electricity is consumed, a simple distance checking can be used: the asset may not be further than 500 km in a straight line from the value chain site consuming the electricity.

The person performing the study **should** make sure that such safeguard is respected while conducting the study.

The geographical characteristics of the EAC used for the TranSensus-LCAs **shall** be clearly justified and documented.

II.1.2.3.3 Safeguard on time consistency

Some EAC rely on electricity producing assets that may produce electricity that cannot be consumed during the production stage under study, because their time of production does not match their time of consumption. This may be the case for renewable energy plants (like wind for instance and solar, that cannot be consumed at night) which times of production are determined by natural conditions and not by manufacturing schedules.

The best way to show that the electricity produced is in reality consumed during the production stage would be to have an hourly synchronization between the two. Nevertheless, at the moment, most EAC have either monthly or yearly timesteps.

[27] A bidding zone is the largest geographical area in which bids and offers from market participants can be matched without the need to attribute cross-zonal capacity. Currently, bidding zones in Europe are mostly defined by national borders. https://www.acer.europa.eu/electricity/market-rules/capacity-allocation-and-congestion-management/bidding-zone-review

In case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, the following hierarchy related to a production/consumption time synchronization **shall** be used for all used EAC:

1. Hourly production/consumption time synchronization,
2. Monthly production/consumption time synchronization,
3. Yearly production/consumption time synchronization.

The hourly / monthly / yearly matching of electricity production and consumption can be checked through metering, both on the electricity production side, and on the electricity consumption side, which can be done in accordance to the vehicle production timeline (no need to have meters for every machine in the production line, general meters dedicated to entire production lines or facilities complemented with justified and documented allocation procedure can be used).

The current OEM practice, which depends on the market data availability, is a monthly or yearly time synchronization meaning that it is made sure that the overall amount of electricity used during that period is covered with EACs.

The person performing the study **should** make sure that such safeguard is respected while conducting the study.

The production/consumption time synchronization characteristics (hourly / monthly / yearly) of the EAC used for the TranSensus-LCAs **shall** be clearly justified and documented.

II.1.2.3.4 Safeguard on the excess of production that is not consumed during the product LCA production stage

Some EAC rely on electricity producing assets that may produce more electricity than what is consumed during the production stage under study. This may be the case for renewable energy plants (like wind and solar) which times and quantities of production are determined by natural conditions and not by manufacturing schedules.

In case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, every excess of electricity production related to an EAC that is used for the LCA and that is not consumed during the production stage of the vehicle **shall** not be counted as negative emissions nor impacts. This is in line with the current OEM practice.

II.1.2.3.5 Other safeguards

In case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen for the production stage, the following minimum criteria **shall** be used for all used EAC:

- They **shall** convey the information associated with the unit of electricity delivered together with the characteristics of the generator.
- They **shall** be assured with a unique claim and therefore be the only instruments that carry the environmental attribute claim associated with that quantity of electricity generated.
- They **shall** be tracked and redeemed, retired or cancelled by or on behalf of the company (e.g., by an audit of contracts, third-party certification, or may be handled automatically through other disclosure registries, systems, or mechanisms).

The person performing the study **should** make sure that such safeguard is respected while conducting the study.

It **shall** be clearly justified and documented, for each EAC that is used, if it complies with the 3 criteria above.

II.1.2.4 Guidance for residual mixes modelling

In case a **100% market-based** approach for electricity modelling is chosen, to ensure a sound and robust market-based approach, and depending on resources available to the LCA practitioner, the residual mixes that are used within the 100% market-based approach **shall** be modelled according to the following hierarchy:

1. Use the residual mixes characteristics prescribed by coordinating entities that disclose annually all the residual mixes related to their bidding zone, each coordinating entity covering all EAC issued in the corresponding bidding zone and following equivalent rules (as does the AIB in Europe),
2. Use national mixes from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the actual and future development of EAC).

In case a **mixed approach** for electricity modelling is chosen for the production stage, to ensure a sound and robust market-based approach, and depending on resources available to the LCA practitioner, the residual mixes that are used within the mixed approach **should** be modelled according to the following hierarchy: (same hierarchy as for 100% market based approach but here the requirement is ‘should’ instead of ‘shall’)

1. Use the residual mixes characteristics prescribed by coordinating entities that disclose annually all the residual mixes related to their bidding zone, each coordinating entity covering all EAC issued in the corresponding bidding zone and following equivalent rules (as does the AIB in Europe),
2. Use national mixes from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the actual and future development of EAC).

Acknowledging the time-consuming aspect of these guidelines for some locations, in case a market-based electricity modelling option is adopted (for both the 100% market based and the mixed approach), the modelling of residual mixes **should** be carried in the best possible manner according to available resources (available time, data and software).

Additionally, in case either a 100% market-based electricity modelling approach or a mixed modelling approach is chosen, the modelling of residual mixes, if any be used, **shall** be clearly justified and documented, and if no residual mixes are modelled, this **shall** also be clearly justified and documented.

Textbox II-2: [Prospective LCA] - Deviation for [Electric energy supply in manufacturing stage – Guidance for residual mixes modelling]

The [Electric energy supply in manufacturing stage – Guidance for residual mixes modelling] from the one for the product LCA production stage.

The residual mixes used for Prospective LCA **should** be modelled as national mixes (whether dynamic future electricity national grid mixes or static current national mixes) from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the future development of Energy Attribute Certificate (EAC)).

The modelling of residual mixes, if any be used, **should** be clearly justified and documented, and if no residual mixes are modelled, this **should** also be clearly justified and documented.

II.1.2.5 On-site electricity production processes

There may be some electricity production systems (e.g., solar panels, wind turbines) within the boundaries of the LCA. This would be the case for instance for an electricity production system that is located within the premises of the vehicle manufacturing plant considered and, or directly connected to the plant but not connected to the grid. When such electricity production systems are owned by the entity owning and operating the vehicle manufacturing facilities, it is called an on-site electricity production system. For such systems, part of the produced electricity can be consumed by the facility it is related to and part of it can be fed into the grid (in case of some hourly excess electricity production as compared to the hourly manufacturing facility electricity consumption for instance).

In the case of on-site produced electricity, with no contractual instruments sold to a third party, that is partly or entirely consumed during the production stage, the following points **shall** be respected:

- The energy producing system be within the boundaries of the studied system,
- The inventory of the on-site production system be included in the LCA inventory,
- The inventory of the on-site production system be prorated to the time and quantity of the electricity production that is really consumed during the production stage (on an hourly basis for instance),

For the electricity produced that is consumed during the production stage, this **shall** be proved using the following hierarchy:

1. Proof must be given that the electricity produced is used during the production stage on an hourly basis (taking into account electricity storage devices),
2. Proof must be given that the electricity produced is used during the production stage on a yearly basis as a minimum.

The electricity produced that is not consumed during the production stage is either wasted or fed to the grid as grey electricity (no EACs associated with it) and **no** negative emissions nor impacts **shall** be associated with the excess of electricity produced on site.

In the case of on-site produced electricity, with related contractual instruments sold to a third party, the on-site electricity production system **shall** be out of the boundaries of the studied system and not considered for the LCA (no negative emissions nor impacts shall be associated with such on-site electricity production system). This is in line with the current OEM practice.

The use and characteristics of on-site electricity production for the production stage **shall** be clearly justified and documented.

Textbox II-3: [Prospective LCA type] - Deviation for [Electric energy supply in manufacturing stage – On-site electricity production processes]

The [Electric energy supply in manufacturing stage – On-site electricity production processes] deviates from the one for the product LCA production stage.

Prospective LCA can use many different hypotheses. Among them would be the presence of on-site electricity production systems. If electricity production systems that are located on the life cycle processes premises and/or directly connected to them and not connected to the grid are owned by the entity owning and operating the related facilities, then these electricity production systems can be considered as on-site electricity production systems. For such systems, it can be assumed that part of the produced electricity is consumed by the facility it is related to and part of it is fed into the grid (excess of electricity production).

When performing a Prospective LCA, in the case of a hypothesis that there is some on-site produced electricity, with no contractual instruments sold to a third party, for the production stage the followings guidelines **should** be considered:

- The energy producing system **should** be within the boundaries of the studied system,
- The inventory of the energy producing system **should** be included in the LCA inventory,
- The inventory of the energy producing system **should** be prorated to the time and quantity of the electricity production that is really consumed during the production stage,
- The electricity produced that is not consumed during the production stage is either wasted or fed to the grid as grey electricity (no EACs associated with it) and **no** negative emissions nor impacts **should** be associated with the excess of electricity produced on site.

In the case of a hypothesis that there is some on-site produced electricity, with related contractual instruments sold to a third party, the on-site electricity production system **should** be out of the boundaries of the studied system and not considered for the LCA (no negative emissions nor impacts be associated with such on-site electricity production system).

The use and characteristics of on-site electricity production for the production stage **should** be clearly justified and documented.

II.2 Use stage modelling

In this subsection we provide guidance on the inventory modelling of the use stage in a vehicle life cycle. The topics discussed here are: how to estimate the energy requirements of vehicles in their use stage, the Well-to-Tank (WTT) modelling of both electricity and hydrogen, non-exhaust emissions from ZEVs, and finally vehicle maintenance considerations.

II.2.1 Estimating the energy requirements of vehicles

For both light duty vehicles (LDVs) and heavy-duty vehicles (HDVs) the starting point basis for defining the energy consumption **shall** be the EU regulatory type-approval / certification values. For LDVs, this **shall** be values based on WLTP (Worldwide Light-duty Harmonised Testing Protocol). The estimation of the energy requirements of HDVs **shall** be based upon certified energy consumption values according to the Vehicle Energy Consumption calculation Tool (VECTO) developed for the European Commission (European Commission, 2023), and used in whole-vehicle certification in the EU. By default for HDVs, the weighted average values (according to the cycle weighting defined in vehicle certification and the CO_2 regulations for HDVs for different vehicle groups) **shall** be used. Values for other cycles **may** be provided as additional sensitivity analyses results.

The following overall methodological approach **shall** be used when accounting for adjustments for LDV and HDV type-approval (i.e. WLTP or VECTO certified values respectively) energy consumption data (i.e. for BEV, FCEV, other ZEV powertrains):

$$\text{Lifetime energy consumption} = \text{EU type-approval certified energy consumption} \times \text{RW Adjustment Factor}^{(i)} \times \text{Degradation Factor}^{(ii)}$$

Notes: (i) Where this is to be applied, either as a default or sensitivity scenario; (ii) where applicable for defined powertrains and vehicle types.

Equation 1 : Calculating use stage vehicle energy consumption

II.2.1.1 Real-World Adjustment Factors

For LDVs, both the regulatory protocol (WLTP for LDVs) and a factor for accounting, real-world (RW) emissions/energy consumption **shall** be included in an LCA study. As the default a RW Adjustment factor shall be used (also in accordance with the methodology developed under the UNECE A-LCA IWG); a sensitivity analysis on the energy consumption **shall** also be included.

For LDVs, the following prioritisation **should** be followed for the real-world adjustment factor to apply to WLTP-based energy consumption (in cases where this is relevant), called WLTP-RW. The different options are listed in order of accuracy and preference, with the choice of which option is most appropriate or feasible left to the practitioner (i.e. depending on the availability of data / objective of the study). The right column shows which level of LCA (according to UNECE standards) can be achieved with each choice.

The first approach **shall** be the preferred one. The second approach **should** be considered as the minimum default approach to follow. Approach 3 **may** be considered as a mitigation approach to Approach 2 in case values are not yet available at the time of the study. All three approaches successfully satisfy the TranSensus-LCA methodology as long as all asked conditions within each are met.

Proposed prioritisation in order of accuracy and specificity (highest to lowest)	UNECE Level
1. OEM-specific average data based on analysis of data from their vehicles operating in the real-world for similar powertrains (i.e. for ZEV/electric powertrains = BEVs, FCEVs, etc.), matched to the region of operation (i.e. European region for TranSensus-LCA)[28]	Level 4 (Optional, depending on availability)
2. Default values provided for European application as part of (i) the LCA methodology for the LDV CO_2 regulations, or (ii) the UNECE A-LCA methodology (priority in this order, depending on availability).	Level 3 and below.
3. If the previous options are not available, use default values based on EC JRC's 2018 analysis, as used in impact assessments of the car and van CO_2 regulations before 2024 (see Table II-1 below).	Level 3 and below.

[28] For example based on OBFCM or similar data provided by operators with a suitably wide/significant sample size across the European region, or alternatively data based on RDE testing for the specific model.

Table II-1: Summary of the default WLTP-RW conversion factors proposed to be used for prioritisation approach 3, in the absence of other datasets

Mode	Segment	Powertrain	WLTP-RW
Cars	Small (A, B)	BEV	115%
Cars	Medium (C, D)	BEV	113%
Cars	Large (Other segments)	BEV	112%
Cars	Small (A, B)	FCEV	115%
Cars	Medium (C, D)	FCEV	113%
Cars	Large (Other segments)	FCEV	112%
LCVs	All	BEV	120%
LCVs	All	FCEV	120%

Source: (Ricardo et al., 2018), Assessing the impacts of selected options for regulating CO_2 emissions from new passenger cars and vans after 2020 (europa.eu)

For HDVs, The Real-World Adjustment Factor **shall** be set to 1 for all HDVs (i.e. there will be no adjustment).

II.2.1.2 Degradation factor (only applies to Fuel Cells)

For all vehicle type (i.e. LDVs and HDVs), a degradation factor **shall** be considered for operation on hydrogen in FCEV, to account for fuel cell degradation and the resulting reduction in efficiency over the operational life of the vehicle. The maximum efficiency loss **shall** be set 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. The following formula **shall** be used to calculate the average efficiency reduction in the intermediate cases up to this point:

$$\boldsymbol{EnCon}\ [\boldsymbol{AvLife}] = \frac{EnCon[Start]}{1 - (10\% \times \frac{FCEV\ [lifetime\ energy]}{\frac{\mathrm{FC}[\max energy]}{2}})}$$

Equation 2 : Calculating the degradation factor of fuel cells

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) whether from WLTP for LDVs or from VECTO for HDVs

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 (%) Formula given below (Equation 3).

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) Formula given below (Equation 4)

To be noted: Fuel cell durability or 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, equal to an average reduction in overall efficiency of 10% divided by 2.)

***FCEV[lifetime energy]* shall** be calculated as follows:

$$\boldsymbol{FCEV[lifetime\ energy](kWh)} = EnCons\ [\,Start]\left(\frac{MJ}{km}\right) \times fuel\ cell\ average\ efficiency\ (\%) \times EnConCoversion\ \left(\frac{kWh}{MJ}\right) \times Lifetime\ activity\ (km)$$

Equation 3 : Calculating the "FCEV[lifetime energy]" in equation 2

Where:

EnCons [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) whether from WLTP for LDVs or from VECTO for HDVs

EnConConversion = conversion factor for converting MJ to kWh

***FC[max energy])* shall** be calculated as follows:

$$\boldsymbol{FC[max\ energy](kWh)} = Fuel\ cell\ durability\ (hrs) \times Fuel\ cell\ average\ running\ power\ (kW)$$

Equation 4 : Calculating the "FC[max energy]" in equation 2

Where:

Fuel cell average running power (kW) = maximum rated fuel cell power (kW) * average operation % of rated fuel cell power. See paragraph underneath to define assumptions and values.

Prioritisation for fuel cell durability assumptions in equation 4 above:

The following prioritisation **shall** be followed for the underlying assumptions of fuel cell life and average operational efficiency. The right column shows which level of LCA (according to UNECE standards) can be achieved with each choice

The different approaches are listed in order of accuracy and preference. The third approach is proposed as a mandatory minimum default approach, where sufficient information is not available for the other options. All options successfully satisfy the TranSensus-LCA methodology as long as all asked conditions within each are met.

Proposed prioritisation in order of accuracy and specificity (highest to lowest)	UNECE Level
1. OEM / supplier specific methodological approach to define operational fuel cell efficiency loss (with end of life defined by reaching 10% loss in efficiency), if validated by an independent third party.	Level 4 (Optional, depending on availability)
2. 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)	Level 4 (Optional, depending on availability)
3. If OEM/ supplier-specific data is not available, assume an operational life of 6000/24000 hours (for LDVs/HDVs)[29], an efficiency of 55%/52% (at the start of the fuel cell life for LDVs/HDVs)[30], with efficiency loss of 10% over the life of the fuel cell, and running at an average of 25%[31]/25%[32] (for LDVs/HDVs) of the peak power rating.	Level 3 and below.

II.2.2 The Well to Tank (WTT) modelling

II.2.2.1 Electricity

II.2.2.1.1 General Guidance

Given the significance of the vehicle use stage, it is of utmost importance that modelling approaches reflect the most representative assumptions and input data. Therefore, the electricity consumption modelling methodology for the vehicle use stage **shall** comply with the following three points:

- TranSensus-LCA **shall** use a "dynamic" modelling approach, informed by a reputable energy futures scenario in order to model the electricity input to the use stage of ZEVs –

[29] Based on 2025 targets from FCH2JU KPIs FCH 2 JU - MAWP Key Performance Indicators (KPIs) - European Commission (europa.eu)
[30] Based on Ricardo review of typical fuel cell efficiency for LDV and HDV applications
[31] Based on Fuel Cell Electric Vehicle Durability and Fuel Cell Performance (nrel.gov)
[32] Average approximation based on Ricardo analysis of VECTO simulation results for different HDVs and cycles.

more details are given below. This modelling approach is deemed to be the most realistic and most likely to approximate the actual environmental emissions and impacts accruing over the full-service life of the vehicle.

- However, TranSensus-LCA acknowledges that OEMs are legally responsible for all published values and claims regarding their vehicles, and that therefore OEMs **may** opt to use a more conservative "static" modelling approach instead, whereby the market- and year-specific electricity mix at date of production is used to model the electricity input throughout the entire use stage of ZEVs.
- Regardless of the chosen modelling approach (points 1. and 2. above), in TranSensus-LCA the same approach **shall** be used in all instances of explicitly comparative LCAs, which are aimed at making "comparative assertions", as defined by ISO 14044.

To be noted: the above electricity consumption modelling methodology for the vehicle use stage does not imply dual reporting. For instance, an OEM wanting to use a conservative "static" modelling approach may not additionally use a "dynamic" modelling approach. OEM will still be able to legitimately claim level A or B of adherence to the methodology (see subsection IV.3) whatever its choice, as long as the choice is publicly reported and all requested conditions among its choice are respected.

The following step-by-step methodological approach **shall** be used for the **"dynamic" modelling approach** (a worked example of applying this approach is provided in the Annex)**:**

1. A scenario for the expected default conservative future evolution of the electricity grid mix in the geographical region of interest **shall** be selected, according to the following order of preference:
    a. The official published scenario specifically for electricity supply mix for the country or geographical region of interest. For TranSensus-LCA, this is expected to be for the EU by default. Additional alternative official scenarios **may** also be used in the sensitivity analysis, where available.
    b. 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)[33]. For TranSensus-LCA, this is expected to be for the EU by default. Additional alternative official scenarios **may** also be used in the sensitivity analysis, where available.

[33] For the EU, the most recent official reference scenario for current policy is EU Reference Scenario 2020. However, this scenario is now out of date compared to recent policies implemented as part of the Green Deal. The European Commission is currently working on an updated reference scenario, which will be available later in 2024. Ideally an official electricity mix projection would be provided and updated at a higher frequency than this, which may be the case in the future.

c. Stated Policies Scenario (STEPS) from the most recent International Energy Agency's World Energy Outlook (IEA WEO) report, for the geographical region of interest[34]. For TranSensus-LCA, this is expected to be for the EU by default. (The Sustainable Development Scenario (SDS) or other alternative official IEA scenarios **may** also be used in the sensitivity analysis, where available).

If none of the previous sources (a to c) are available for the geographical region of interest, then the most recent "static" grid mix composition shall be used. Additionally for comparison, an alternative mix using 100% renewable energy **should** also be provided. The latter is intended as a hypothetical scenario corresponding to an optimistic assumption (to provide counterpoint to the otherwise likely pessimistic assumption of the current static grid mix); it is acknowledged that in some countries, the 100% renewable energy scenario may be unrealistic. See examples of the different scenarios in Figure II-3.

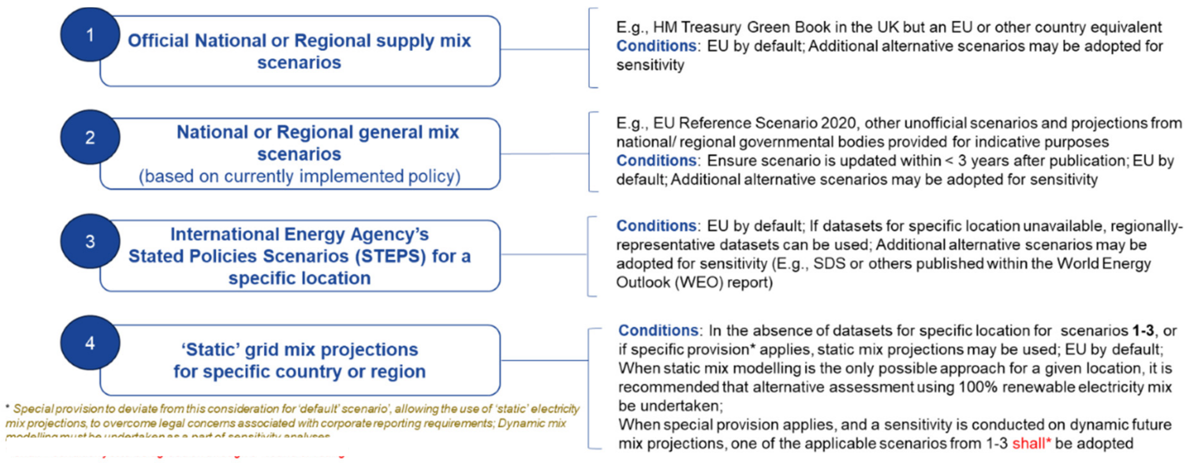


Figure II-3 : Mandatory hierarchy for the selection of appropriate datasets for use-stage dynamic mix electricity modelling

2. The grid mix composition for each year of vehicle operation **shall** be estimated (i.e., the shares $S_{i,n}$ 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 predefined time horizons in the scenario selected at point 1 above.

3. The average representative grid mix composition over the full-service life of the vehicle **shall** be calculated as follows:

[34] IEA WEO region-specific datasets for STEPS are available for purchase for the following regions: North America, USA, Central&South America, Brazil, Europe, EU-27, Africa, Middle East, Eurasia, Russia, Asia Pacific, China, India, Japan, Southeast Asia, OECD, non-OECD, Emerging and developing economies.

a. **By default**, use 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).

b. Alternatively, if there is reason to expect that the vehicle's use intensity will change over time, and if year-specific activities may be estimated with sufficient confidence, then a more refined (and accurate) modelling approach **may** be adopted, employing a weighted average (as opposed to a simple arithmetic average) of the individual shares $S_{i,n}$ of electricity supplied by each technology ***i*** in the year ***n***, i.e.:

$$\sum_N W_N S_{i,N}$$

Where $W_n = A_n/L$ (A_n = vehicle activity in year ***n***, ***L*** = total lifetime activity).

4. A bespoke grid mix model **shall** finally be built in the LCA software package of choice (e.g., "LCA for Experts", or "SimaPro"), 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[35][36].

To ease verification work, all steps of electricity modelling **shall** be documented and justified.

[35] For Variable Renewable Energy (VRE) generators like solar photovoltaics (PV) and Wind, increased accuracy may be attained by using the database processes per unit of installed power [kW_P], and then multiplying the associated LCIs by the appropriate region-specific Capacity Factors (CF), which are defined as the ratio of the electricity delivered in a year [kWh] to the product of the nameplate installed power [kW_P] times the number of hours in a year. CFs for Wind and PV for all World locations are freely available at, respectively: https://globalwindatlas.info/ and https://globalsolaratlas.info/.

[36] An additional element of complexity is represented by the fact that some technologies (among which primarily PV and Wind) may also be expected to continue evolving and improving over time, leading to reduced average impact per unit of electricity generated as newer generations of these technologies come on-line and start contributing to the grid mix. However, addressing this aspect in the modelling may be deemed outside of scope for conventional product LCAs, and may instead form part of a dedicated Sensitivity Analysis, especially in prospective and fleet-level LCAs.

Textbox II-4: [Prospective LCA type] - Deviation for [Electric energy supply in use stage – General Guidance]

The [Electric energy supply in use stage – General Guidance] deviates from the one for the product LCA use stage.

When performing a **Prospective LCA**, the following decision tree for the **use stage** electricity modelling approach, **should** be used:

- Is there a hypothesis concerning the use of PPAs for a Prospective LCA electricity production modelling?
  - ☐ If No, then use the specific average grid mix of the country or region where the vehicle is expected to be produced, used and decommissioned, estimated for the considered time frame, as defined in the goal and scope of the study, on the basis of the use stage electricity modelling approach for Product LCA (dynamic future electricity grid mix or static current mix).
  - ☐ If Yes, then use the following hierarchy:
    - If specific contracts (like PPA) are expected to be used for the same time representativeness as the study, use these specific contracts mixes,
    - For whatever electricity that is not expected to be covered by a PPA contract, use a prospective residual grid mix with the same time representativeness as the study,
    - For whatever electricity that is not expected to be covered by a PPA contract, use a current residual grid mix.

The residual mixes used for Prospective LCA **should** be modelled as national mixes (whether dynamic future electricity national grid mixes or static current national mixes) from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the future development of Energy Attribute Certificate (EAC)).

To model future electricity mixes, LCA practitioners **may** use the results of the PREMISE (PRospective EnvironMental Impact asSEment) project, which offers a streamlined approach to producing databases for prospective Life Cycle Assessment using Integrated Assessment Models.

The electricity modelling chosen for the use stage in prospective LCA **should** be clearly justified and documented.

II.2.2.1.2 On-site Electricity production processes

For harmony and comparability, and to comply with the system boundaries as defined in the goal and scope process of the LCA (which excluded charging stations from the boundaries of the study), on-site electricity production (e.g. charging station on-site electricity production) **should** not be considered for the use stage.

Textbox II-5: [Both Fleet Level LCA types] - Deviation for [Electric energy supply in use stage – On-site electricity production processes]

The [Electric energy supply in use stage – On-site electricity production processes] deviates from the one for the product LCA use stage.

When performing a Fleet level LCA, in the case of on-site produced electricity, with no contractual instruments sold to a third party, that is partly or entirely consumed during the use stage, the following guidelines **should** be considered:

- The energy producing system **should** be within the boundaries of the studied system,
- The inventory of the energy producing system **should** be included in the LCA inventory,
- The inventory of the energy producing system **should** be prorated to the time and quantity of the electricity production that is really consumed during the use stage,
- For the electricity produced that is consumed during the use stage the following hierarchy **should** apply:
  - Proof **should** be given that the electricity produced is used during the use stage on an hourly basis (taking into account electricity storage devices),
  - Proof **should** be given that the electricity produced is used during the use stage on a yearly basis.
- The electricity produced that is not consumed during the use stage is either wasted or fed to the grid as grey electricity (no EACs associated with it) and no negative emissions nor impacts **should** be associated with the excess of electricity produced on site.

In the case of on-site produced electricity, with related contractual instruments sold to a third party, the on-site electricity production system **should** be out of the boundaries of the studied system and not considered for the LCA (no negative emissions nor impacts should be associated with such on-site electricity production system).

The use and characteristics of on-site electricity production for Fleet level LCA use stage **should** be clearly justified and documented.

Textbox II-6: [Prospective LCA type] - Deviation for [Electric energy supply in use stage – On-site electricity production processes]

The [Electric energy supply in use stage – On-site electricity production processes] deviates from the one for the product LCA use stage.

When performing a Prospective LCA, in the case of a hypothesis that there is some on-site produced electricity, with no contractual instruments sold to a third party, for the use stage the followings guidelines **should** be considered:

- The energy producing system **should** be within the boundaries of the studied system,
- The inventory of the energy producing system **should** be included in the LCA inventory,
- The inventory of the energy producing system **should** be prorated to the time and quantity of the electricity production that is really consumed during the use stage,
- The electricity produced that is not consumed during the use stage is either wasted or fed to the grid as grey electricity (no EACs associated with it) and no negative emissions nor impacts **should** be associated with the excess of electricity produced on site.

In the case of a hypothesis that there is some on-site produced electricity, with related contractual instruments sold to a third party, the on-site electricity production system **should** be out of the boundaries of the studied system and not considered for the LCA (no negative emissions nor impacts be associated with such on-site electricity production system).

The use and characteristics of on-site electricity production for Prospective LCA use stage **should** be clearly justified and documented.

II.2.2.2 Hydrogen

The following step-by-step methodological approach **shall** be followed for the modelling of hydrogen supply mixes feeding into the use stage of xEVs, which is analogous to that used for electricity. Since there are currently no official projections for future hydrogen supply mix, in practice it is anticipated that 1(c) or 1(d) will be the de facto default approach in near term:

1) A scenario for the expected default conservative future evolution of the hydrogen supply mix in the geographical region of interest **shall** be selected, according to the following order of preference – i.e. also limited by whether this is explicitly available for hydrogen:
   a) The official published scenario specifically for hydrogen supply mix for the country or geographical region of interest. For TranSensus-LCA, it is expected to be for the EU by default. Additional alternative official scenarios **may** also be used in the sensitivity analysis, where available.

b) The official general scenario based on currently implemented policy for the country or geographical region of interest (providing this has been updated within less than 3 years). For TranSensus-LCA, this is expected to be for the EU by default. Additional alternative official scenarios **may** also be used in the sensitivity analysis, where available.

c) Hydrogen produced by electrolysis using a conservative future grid electricity mix scenario that **shall** be consistent also with the scenario being used for ZEVs using electricity in comparative studies also including these:

i) The official published scenario specifically for electricity supply mix for the country or geographical region of interest.

ii) The official general scenario based on currently implemented policy for the country or geographical region of interest (providing this has been updated within less than 3 years)[37].

iii) Stated Policies Scenario (STEPS) from the most recent International Energy Agency's World Energy Outlook (IEA WEO) report, for the geographical region of interest[38]. For TranSensus-LCA, it is expected to be for the EU by default. The Sustainable Development Scenario (SDS) or other alternative official IEA scenarios **may** also be used in the sensitivity analysis, where available.

d) If none of the previous options (a to c) is available for the geographical region of interest, or legal responsibilities may prevent OEMs from adopting a dynamic electricity mix modelling, then hydrogen produced by electrolysis using the most recent "static" grid mix composition **shall** be modelled instead.

In case either option 1(c) or 1(d) is applied, then an alternative assessment using (i) hydrogen production from steam reforming of natural gas, and (ii) a 100% renewable electricity (RE) mix for comparison **should** be provided. The latter is considered as a hypothetical scenario corresponding to an optimistic assumption to provide counterpoint to the otherwise likely pessimistic assumption of the current static grid mix or production from natural gas. It is acknowledged that in some countries, the 100% RE scenario may be unrealistic.

[37] For the EU, the most recent official reference scenario for current policy is EU Reference Scenario 2020. However, this scenario is now out of date compared to recent policies implemented as part of the Green Deal. The European Commission is currently working on an updated reference scenario, which will be available later in 2024. Ideally an official electricity mix projection would be provided and updated at a higher frequency than this, which may be the case in the future.

[38] IEA WEO region-specific datasets for STEPS are available for purchase for the following regions: North America, USA, Central & South America, Brazil, Europe, EU-27, Africa, Middle East, Eurasia, Russia, Asia Pacific, China, India, Japan, Southeast Asia, OECD, non-OECD, Emerging and developing economies.

2) The electricity grid mix composition for each year of vehicle operation **shall** be estimated based on the methodology outlined for this (see separate section I.2.2.1.1 on Vehicle Use Stage Electricity Supply Mix). The hydrogen supply mix composition for each year of vehicle operation **shall** then be estimated (i.e., the shares $\mathbf{S_{i,n}}$ of hydrogen supplied by each technology **i** in the year **n**), in a similar way to the electricity mix, by applying linear interpolation between the respective hydrogen supply shares reported for the nearest pre-defined time horizons in the scenario selected at point 1 above. To clarify, for each year of operation **n**, both the share $\mathbf{S_{i,n}}$ of hydrogen supplied by each technology **i** (where **i** = steam reforming, or electrolysis) and the specific electricity grid mix used to power the electrolysis process in the same year **shall** be calculated. However, if option 1(c) or 1(d) is applied, then **i** = electrolysis only, and only the grid mix calculations apply.

3) The average representative hydrogen supply mix composition over the full-service life of the vehicle **shall** be calculated as follows (i.e. similarly to electricity use):

By default, as the arithmetic average of the individual hydrogen 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 modelling approach **may** be adopted, employing a weighted average (as opposed to a simple arithmetic average) of the individual shares $\mathbf{S_{i,n}}$ of hydrogen supplied by each technology **i** in the year **n**, i.e.:

Where $\mathbf{W_n = A_n/L}$ ($\mathbf{A_n}$ = vehicle activity in year **n**, **L** = total lifetime activity).

4) A bespoke hydrogen mix model **shall** finally be built. This can be done in the LCA software package of choice (e.g., "LCA for Experts", or "SimaPro"), using the hydrogen mix composition calculated at point 3 above, and leveraging the most up-to-date database processes available for the individual hydrogen production and electricity generation technologies[39,40].

[39] For Variable Renewable Energy (VRE) generators like solar photovoltaics (PV) and Wind, increased accuracy may be attained by using the database processes per unit of installed power [kW_P], and then multiplying the associated LCIs by the appropriate region-specific Capacity Factors (CF), which are defined as the ratio of the electricity delivered in a year [kWh] to the product of the nameplate installed power [kW_P] times the number of hours in a year. CFs for Wind and PV for all World locations are freely available at, respectively: https://globalwindatlas.info/ and https://globalsolaratlas.info/

[40] An additional element of complexity is represented by the fact that some technologies (among which primarily PV and Wind) may also be expected to continue evolving and improving over time, leading to reduced average impact per unit of electricity generated as newer generations of these technologies come on-line and start contributing to the grid mix. However, addressing this aspect in the modelling may be deemed outside of scope for conventional product LCAs, and may instead form part of a dedicated Sensitivity Analysis, especially in prospective and fleet-level LCAs.

II.2.3 Non-exhaust emissions

II.2.3.1 Hydrogen leakage

The following hierarchy **shall** be applied by the practitioner to account for typical fugitive hydrogen emissions from the supply chain and from vehicle use:

1) Where available, use official governmental estimates (or supplier-specific information) on typical fugitive hydrogen emissions for different hydrogen production options, local production versus imported hydrogen, and for different hydrogen vehicle types.

2) In the absence of official governmental estimates (or supplier-specific information) on fugitive hydrogen emissions, include estimated H_2 supply chain emission rates based on Table *II-2*, derived and simplified from (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022).

Table II-2 : Proposed default H2 supply chain emission rates for hydrogen produced from (i) steam reforming of natural gas, (ii) electrolysis of water

	Production and proces-sing	Com-pres-sion	Storage and transport	Lique-faction	Ship-ping	Regasi-fi-cation	Trans-mission and storage	Distri-bution	Use in H2 ICEV, FCEV and FC-REEV*	Total
H_2 from natural gas (pro-duction in same region as use)	0.55%	0.17%	0.31%				0.05%	0.02%	0.50%	1.61%
H_2 from natural gas (im-ported to region of use - as LH2)	0.55%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	2.05%
H_2 from electrolysis (pro-duction in same region as use)	2.05%	0.17%	0.31%				0.05%	0.02%	0.50%	3.13%
H_2 from electrolysis (im-ported to region of use - as LH2)	2.05%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	3.57%

Notes: Hydrogen has a high tendency to leak, which makes it difficult to be contained; primarily due to safety concerns, many studies have assessed the potential for hydrogen leakage from fuel cell electric vehicles, both in stationary conditions and from operation. However, such studies generally do not contextualise hydrogen leakage rates in terms of the overall supply of hydrogen to the vehicle. Engine slip of H_2 in ICEVs fuelled by hydrogen is reported to range from 0 to 12%, and a value of 0.5% is assumed by (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022) (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022). In the absence of other information, a similar rate is assumed also for hydrogen vehicles using fuel cells.

II.2.3.2 Refrigerants

Refrigerant emissions **shall** be included in the inventory as elementary flows (for vehicle mobile air conditioners (MAC) systems, or in temperature-controlled commercial freight vehicles as non-exhaust emission if the GWP100 of the used refrigerant is equal to or greater than 150 $kgCO_2eq/kg$. Refrigerant with GWP less than 150 $kgCO_2eq/kg$ **may** be included as non-exhaust emissions. TSLCA does not mandate a specific method to estimate the amount of leaked refrigerants to the environment. It is left to the LCA practitioner under the condition of transparency and documentation of how it was estimated. See annex for more information.

II.2.3.3 Tyres and Brake wearing

Non-exhaust emissions from tyre and brakes wear **shall** be included in the inventory as elementary flows. Current[41] official data are available from EMEP guidebook: [EMEP/EEA air pollutant emission inventory guidebook 2023](). Chapter *NFR code 1.A.3.b.vi* from *EMEP/EEA emission inventory guidebook 2013* provides the methodology, emission factors and relevant activity data to enable non-exhaust tyre and brake wear emissions to be calculated for passenger cars, light commercial vehicles, heavy-duty vehicles and buses, moped & motorcycles. TranSensus-LCA also acknowledge that found references to estimate these emissions are relatively old. Unless the practitioner has better data that can be justified and documented, the EMEP **shall** be consulted to estimate the amounts of these flows. (See annex for more information)

Further research is urgently needed in this area (See section I.6 for more information)

II.2.4 Maintenance

Table II-3 lists all relevant types and items for maintenance in the first two columns. Following points are to be followed regarding maintenance considerations in the model:

Third column of the table indicates with a “yes” items responsible for the most significant potential impacts that **shall** be included if a replacement is needed (to be justified) in the considered lifetime of the vehicle.

All maintenance, wear and consumable items listed in Table II-3 **should** be considered in all studies.

For consumables and maintenance items, the assessment of requirements **should** be based on the vehicle/model’s maintenance schedule, with the number of replacements required based on the relevant replacement/maintenance interval in mileage or time – whichever comes first – and

[41] When EuroVII requirements will be decided, data will have to be reviewed

the corresponding lifetime activity (in km) and operational lifetime (in years) defined in the study's Goal & Scope (i.e. according to TranSensus-LCA guidance on these).

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

Due to the low impact of some maintenance items, emission factors and processes **may** be taken from secondary data sources.

The practitioner **shall** be transparent about the maintenance parts, wear and consumables considered in the model, and their amounts (OEM and car model specific).

Table II-3 : Proposed list of maintenance and wear parts and consumables to consider in LCA studies – items marked as mandatory shall be included in all studies (values can be zero if no replacements are required). Inspired by UNECE A-LCA IWG: SG4 - 7th meeting - Transport - Vehicle Regulations - UNECE Wiki

Type	Item	Mandatory, if replacement is needed	H2 ICEV	BEV	BEV-ERS	FCEV	FC-REEV
Consumables	Engine lubricant		✓	N/A	N/A	N/A	N/A
	Engine/oil filters		✓	N/A	N/A	N/A	N/A
	AdBlue/Urea	**Yes**	(✓)	N/A	N/A	N/A	N/A
	Coolants		✓	✓	✓	✓	✓
	Screen wash		✓	✓	✓	✓	✓
	Electric drive unit / transmission fluid		✓	✓	✓	✓	✓
	Brake fluids		✓	✓	✓	✓	✓
	Refrigerants for Heating, Ventilation and Air conditioning (HVAC)	**Yes**	✓	✓	✓	✓	✓
	Other fluids or filters		✓	✓	✓	✓	✓
Maintenance and wear parts	Passenger air filter		✓	✓	✓	✓	✓
	Windscreen wiper blades		✓	✓	✓	✓	✓
	Tyres	**Yes**	✓	✓	✓	✓	✓
	Starter battery (i.e. 12V)	**Yes**	✓	✓	✓	✓	✓
	Brake pads	**Yes**	✓	✓	✓	✓	✓
	Brake discs		✓	✓	✓	✓	✓
	Steering joint		✓	✓	✓	✓	✓
	Link arm		✓	✓	✓	✓	✓

Type	Item	Mandatory, if replacement is needed	H2 ICEV	BEV	BEV-ERS	FCEV	FC-REEV
	Traction/storage battery (See below)	**Yes**	N/A	✓	✓	✓	✓
	Fuel cell stack (See below)	**Yes**	N/A	N/A	N/A	✓	✓
	Other auxiliary batteries[42]	**Yes**	(✓)	(✓)	(✓)	(✓)	(✓)

Notes: Items marked (□) may only be relevant for certain vehicle types or configurations. N/A means not applicable

Traction batteries and fuel cell replacement:

Traction batteries and fuel cells systems are generally designed so that no replacement should be needed during the vehicle lifetime in most vehicle types (except for some heavy-duty vehicles with higher lifetime activity or some specific intensive usages such as car sharing, taxis, delivery). However, due to the major impact of battery and fuel cell on the vehicle LCA, the need for replacement or not of these systems in the context of the LCA study **shall**-be checked and justified.

Battery and fuel cells durability assumptions:

For battery or fuel cell replacement, the following hierarchy **shall** be applied:

1. Determine the frequency of replacement using the ageing model specific to the system and its mission profile (justification **should** be documented to explain that the ageing model is consistent with the study, i.e. in terms of service life, lifetime km and resulting delivered energy for the vehicle, etc.; the conditions to decide that the battery has reached its end of life, typically state of health <80%, should also be documented).
2. Only if the previous option is not available then a simplified methodology outlined below should be used. This simplified methodology below does not include the calendar ageing of the battery system. In that case, a sensitivity analysis **should** be applied.

   Simplified methodology to decide the need for **traction battery replacement(s)** if no specific data is available (2. step of the hierarchy)

   The following approach is based on a combination of parameters including the anticipated battery cycle life (i.e. number full charge/discharge cycles). This methodology also provides

[42] For commercial vehicles, these may have additional systems or equipment that could be powered separately to the main traction battery and the starter 12V battery (where can be a lot of variations in this for different vocational applications or setups). For example, it is conceivable that a separate battery system could power refrigeration equipment, also more likely where there is a separate trailer, or otherwise, etc.

a dynamic link to the vehicle battery capacity and the lifetime activity (as defined in the Goal & Scope of the study).

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):

$$\boldsymbol{N} = \frac{E[Average] \times A[Lifetime]}{(C[Battery\ usable] \times CL[Battery]}$$

Equation5 : Simplified method to calculate the number of traction battery replacements

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, excluding losses from charger, in kWh per km

* As a sensitivity analysis, the potential number of replacements needed based on the warrantied number of km for the battery (where this is present) may be explored.

Simplified methodology to decide the need for **fuel cell system replacement(s)** if no specific data is available (2. step of the proposed hierarchy)

Refer to subsection II.2.1 in which the methodology to calculate fuel cell degradation and durability is described.

3. In the absence of manufacturer-specific data on the battery cycle life (parameter ‘CL’ in Equation5 above), then default values below **should** be used:
   - **2000** charge/discharge cycles, for light duty vehicles (i.e. passenger cars and light commercial vehicles)
   - **3000** charges/discharge cycles, for heavy duty vehicles (i.e. lorries, busses and coaches)

In that case, a sensitivity analysis **should** also be applied.

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.

II.3 End of life stage modelling

II.3.1 Data Choices

EoL processes are usually outside the control of an OEM (or generally the entity that carries out the study) and lie in the future. For this reason, the use of company-specific data seems currently unrealistic. Therefore, the entity that carries out the study **shall** use company-specific data only if it already possesses partnerships, owns facilities in that field, or is certain about the fate of the End-of-life vehicle (ELV) in the future (e.g., one central treatment facility in the geographical scope of the study where all the ELVs treatment occur). If not, the LCA practitioner **may** use secondary generic data.

II.3.2 Electric energy supply in the End of Life stage

II.3.2.1 General guidance

As the end of Life (EoL) of the vehicles will occur after their use stage, to be consistent, the same electricity modelling approach **shall** be used for the EoL stage as for the use stage. This means that future projection of the electricity mix at the point of time where the vehicle is expected to reach the EoL **shall** be used to model the energy supply to ELVs processing.

To ease verification work, all steps of electricity modelling shall be documented and justified.

Textbox II-7: [Prospective LCA type] - Deviation for [Electric energy supply in the End-of-life stage]

The [Electric energy supply in the End-of-life stage] general guidance deviates from the one for the product LCA EoL stage.

When performing a Prospective LCA, the following decision tree for the EoL stages electricity modelling approach, should be used:

- ➢ Is there a hypothesis concerning the use of PPAs for a Prospective LCA electricity production modelling?
  - ☐ If No, then use the specific average grid mix of the country or region where the vehicle is expected to be produced, used and decommissioned, estimated for the considered time frame, as defined in the goal and scope of the study, on the basis of the use stage electricity modelling approach for Product LCA (dynamic future electricity grid mix or static current mix).
  - ☐ If Yes, then use the following hierarchy:
    - If specific contracts (like PPA) are expected to be used for the same time representativeness as the study, use these specific contracts mixes,

- For whatever electricity that is not expected to be covered by a PPA contract, use a prospective residual grid mix with the same time representativeness as the study,
- For whatever electricity that is not expected to be covered by a PPA contract, use a current residual grid mix.

The residual mixes used for Prospective LCA **should** be modelled as national mixes (whether dynamic future electricity national grid mixes or static current national mixes) from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the future development of Energy Attribute Certificate (EAC)).

To model future electricity mixes, LCA practitioners **may** use the results of the PREMISE (PRospective EnvironMental Impact asSEment) project, which offers a streamlined approach to producing databases for prospective Life Cycle Assessment using Integrated Assessment Models.

The electricity modelling chosen for the EoL stage in prospective LCA **should** be clearly justified and documented.

II.3.2.2 Guidance for on-site electricity production

For simplicity, on-site electricity production **shall** not be considered for the EoL stage.

II.4 Summary of electricity modelling rules for product, prospective, OEM & macro fleet LCA

The rules for prospective LCA and Fleet level LCA in general should be the same rules followed in Product LCA (see chapter II).

Some discrepancies exist between the three types of LCA, which are summarized in the following tables.

Table II-4. Discrepancies in electricity consumption modelling for the different LCA (Product LCA, Fleet LCA and Prospective LCA)

	Production stage	**Use stage**	**EoL stage**
Product LCA	Location based / 100% market based / mixed approach	"dynamic" modelling approach / "static" modelling approach	"dynamic" modelling approach / "static" modelling approach
Fleet LCA	Location based / 100% market based / mixed approach	"dynamic" modelling approach / "static" modelling approach	"dynamic" modelling approach / "static" modelling approach
Prospective LCA	"dynamic" modelling approach or "static" modelling approach / hierarchy with: PPA, prospective residual grid mix, actual residual grid mix	"dynamic" modelling approach or "static" modelling approach / hierarchy with: PPA, prospective residual grid mix, actual residual grid mix	"dynamic" modelling approach or "static" modelling approach / hierarchy with: PPA, prospective residual grid mix, actual residual grid mix

Table II-5. Discrepancies in electricity on-site production modelling for the different LCA (Product LCA, Fleet LCA and Prospective LCA)

	Production stage	**Use stage**	**EoL stage**
Product LCA	Can be considered (with guidelines)	Not considered	Not considered
Fleet LCA	Can be considered (with guidelines)	Can be considered (with guidelines)	Not considered
Prospective LCA	Can be considered (with guidelines)	Can be considered (with guidelines)	Not considered

II.5 Multifunctionality problems

Following subsection first defines important concepts to understand TranSensus-LCA methodological requirement to address multifunctionality. Then, three steps are advised to identify multifunctionality problems in the conducted LCA. Finally, TranSensus-LCA requirements are detailed.

II.5.1 Important definitions

The definition of what a multifunctionality problem exactly comprises of is crucial for any scientific approach trying to deal with it, which is often lacking in many approaches to multifunctionality today. The first definition to be introduced is that of 'economic flow' *(Guinée et al.*, 2002).

- **Economic flow**: a flow of goods, materials, services, energy or waste from one unit process[43] to another, with either a positive (e.g. steel, transportation) or zero or negative (e.g. waste) economic value.

In follow-up work, (Guinée *et al.*, 2004), building on previous work by Huppes (1992, 1993, 1994), introduced the concept of functional flow to define the problem of multifunctionality in an encompassing way, including co-production, combined waste processing, recycling as well as any combination of these three typologies of multifunctional processes. They introduced several other basic definitions:

- **Functional flow**: any of the (economic) flows of a unit process that constitute its goal (or part of its goal), which is the product outflows (including services) of a production process and the waste inflows of a waste treatment process.
- **Non-functional flow:** any of the flows of a unit process that are not a functional flow. These include product inflows and waste outflows, as well as elementary inflows and outflows (natural resources and pollutants).

What is important to note is that a flow is not intrinsically a functional flow, but only with respect to a certain unit process. An outflow that is a functional flow for one unit process is a non-functional inflow for one or more other unit processes, and an inflow that is a functional flow for a specific unit process is a non-functional outflow for one or more other unit processes.

[43] Smallest element considered in the LCI for which input and output data are quantified. (ISO, 2020)

Since the TranSensus-LCA method is meant for process-based LCA[44], the multifunctionality issue should be dealt with on the unit process level where every unit process in the LCA model needs to be investigated for potential multifunctionality.

- **Multifunctional process**: a unit process yielding more than one functional flow.

II.5.2 Step-by-step approach to identify multifunctionality problems

Bearing the aforementioned definitions in mind, multi-functionality problems **should** be identified for each LCA study in practice by going through the following three steps:

1. **The identification of each flow between two processes as either a product or a waste.**

A product is a flow between two processes with an economic value higher than or equal to zero, whereas a waste is a flow between two processes with an economic value smaller than zero. Note that any other criterion to distinguish between products and wastes may be applied as long as it can be consistently applied over different product systems.

2. **The identification of a process' functional flow(s).**

Having identified product and waste flows, the functional flow(s) of each process can now be identified: these are either products that are produced by a process or wastes that are treated by a process. Note that every process needs at least one functional flow.

3. **The identification of multi-functional processes.**

Having identified the functional flows of all processes, multifunctional processes can now be identified: they are unit processes yielding more than one functional flow.

There can be different typologies of multi-functional problems. Depending on the number of functional flows and the combination of functional flows, co-production, combined waste processing, recycling and all sorts of combinations of these three typologies can be distinguished. Table II-9 in the Annex summarizes these typologies.

II.5.3 Approach to solve multifunctionality problems in all life cycle stages prior to EoL

The following hierarchy **shall** be used to solve any multifunctionality problem encountered in the model except for the multifunctionality that might arise in the end-of-life of the product. Further information and specific rules on this is provided in subsection II.5.4.

[44] Process-based LCA (with unit processes as building blocks) as conceived by the Society of Environmental Toxicology and Chemistry (SETAC) and ISO which is different from input/output-based LCAs.

Allocation **shall** be avoided whenever possible by:

1-Subdivision of the multifunctional process into mono-functional processes

Subdivision refers to physical disaggregation of multifunctional processes or facilities to isolate the input flows directly associated with each process or facility output. The goal is to end up with two or more unit processes with single functional flows. This can be achieved by better data collection (see **Figure *II-4***).

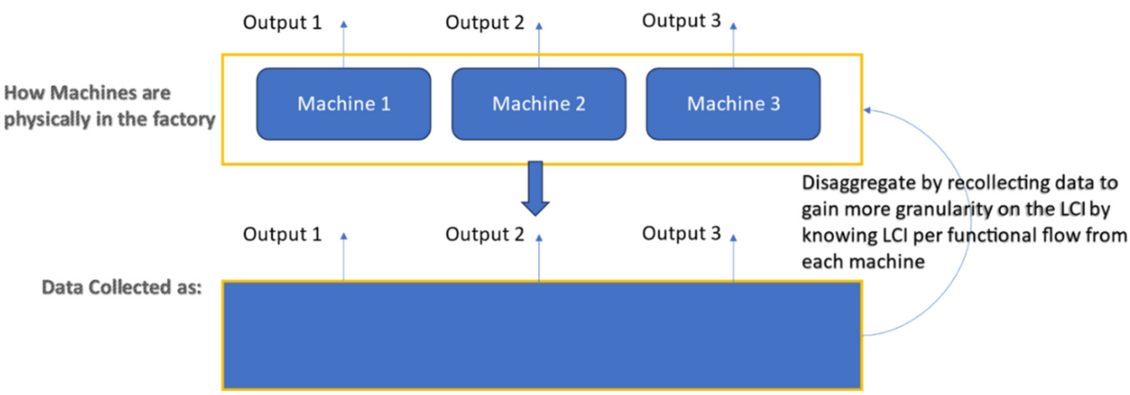


Figure II-4 : Illustrative example on subdivision

If subdivision is physically not possible or better data collection practice cannot solve the issue, the practitioner **shall** proceed to the next step.

2-System expansion

System expansion refers to expanding the product system to include the additional functions provided by its functional flows or in business terms: co-products[45] in case of co-production process.

One could also say that system expansion, therefore, models a product system as it exists in reality, i.e. including the multifunctional processes and their co-products as they are. While this approach does not suffer from the limits of the next steps in this hierarchy (substitution and allocation) as it accounts for the system as a whole, it cannot answer the question of the environmental impacts related to just one of the functional flows (Figure II-5). Thus, if the aim of the study is to assess the environmental impacts related to just one of the functional flows, system expansion is not the right approach, and the practitioner **shall** proceed to the next step in the hierarchy.

[45] In industrial processes there may be a wide variety of different types of materials produced in conjunction with the intended product. In business vocabulary, these may be identified as by-products, co-products, intermediate products, non-core products or sub-products. Here, these terms are considered as equivalent.

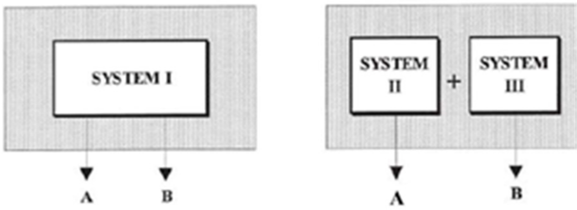


Figure II-5 : Illustration of system expansion. The LCA results of system 1 are the combined impacts of product A + B. In a comparative LCA, system 1 needs to be compared to another (set of) system(s) that provides the same basket of products as system 1

3-Substitution (avoided burdens)[46]

When a functional flow of a multi-functional process leads to the reduced production of another product from another system, this is called substitution. The substitution approach thus accounts for the replacement of other products by the co-products of the multifunctional process. In this way, the multiple functions of the overall system are reduced to a single function, thereby solving the multi-functionality problem. This is also known as the avoided burdens approach as it consists of accounting for the entire burdens of the multifunctional process and then subtracting the burdens of the substituted processes (Figure II-6). While some scholars argue that substitution concept in general is only suitable for consequential modelling (Schrijvers et al., 2016), other references allow it in attributional modelling under certain conditions (EC-JRC, 2010; Koffler and Finkbeiner, 2018). In practice, it is widely used in attributional modelling (Provost-Savard and Majeau-Bettez, 2024). Therefore, we allow it here but under some conditions and safeguards.

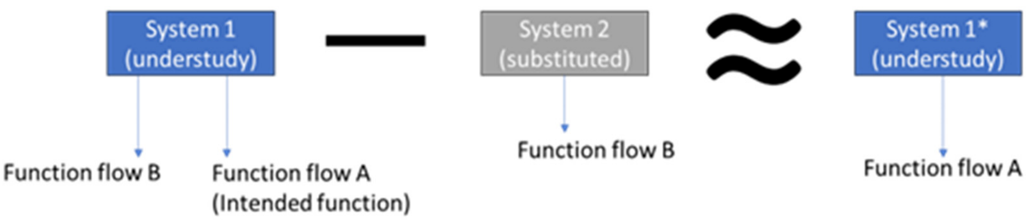


Figure II-6 : Illustration of substitution (avoided burdens approach)

Substitution **shall** only be used if all the following conditions are met:

[46] Practically can also be called "system reduction" as stated by ILCD since something is "subtracted from" and not "added to" the studied system.

1) There is a real, measurable substitution effect[47]: for each co-product (functional flow B in Figure II-6 example), there is an identifiable product that is directly replaced. The utilization of the co-product in another product system **shall** be proved, for example via contractual ties[48] or receipts. **No** market-mediated effects **shall** be considered, i.e. the assumption that a co-product will automatically avoid a specific or the average product from the market is not enough. Instead, the substitution of a specific product **shall** ensure that the need for the primary product has decreased. This is to avoid claims of substitution that in the end are not real substitutions, but market extensions (simply more of the same product is produced).

2) Functional equivalence: each co-product (functional flow B in Figure II-6 example) **shall** deliver the exact same function as the substituted product. It **shall** also be available at the same geographical location and time as the substituted product.

3) Data is available: The LCI or emission factors for TranSensus-LCA mandatory impact categories of the substituted system are available. Market average **shall** always be used. This is to prevent any attempts to substitute the worst technology. Also following ILCD handbook "C1" decision making situation (EC-JRC, 2010).

4) Cascaded multifunctionality is avoided: there **shall** be an identifiable primary monofunctional production path that produces the co-product (functional flow B in Figure II-6 example) as single product. This is to avoid the need to solve the multifunctionality in a loop of systems which might lead to error propagation and can be out of scope of TranSensus-LCA

Any assumptions related to substitution **shall** be clearly documented. Any credits obtained from substitution **shall** be documented so that it is transparent to which degree substitution affects the overall LCA results.

[47] It is not the job of attributional modelling to quantify the impact of substitution on societal level (Koffler and Finkbeiner, 2018). Therefore here we follow the concept of (Zink et al., 2018, 2016; Zink and Geyer, 2017) which argue that unless a true displacement of primary material in the market takes place, the environmental benefit is diminished or relinquished entirely

[48] Any means of demonstrable proof is acceptable. In case of substitution within the same facility, no contractual ties or hard proofs are needed since the substitution effect is self-evident. In fact, this is the ideal case of a substitution.

Illustrative example on the conditions for substitution:

"Factory X produces sulfuric acid as a co-product of a certain unit process which has Product X as the main product intended from this unit process." In order to use substitution:

Condition 1: factory X has to prove that this sulfuric acid is purchased and consumed in another factory Y hence reduced the need from primary sulfuric acid in factory Y.

Condition 2: "if factory X produces a sulfuric acid of low quality and **NOT** sulfuric acid that is readily available for factory Y. Then, factory Y has yet to apply additional process(s) to obtain high quality sulfuric acid. In this case, factory X cannot claim benefits for avoiding primary sulfuric acid."

Condition 3: "Data in LCI or emission factor form for average sulfuric acid market should be available.

Condition 4: "There must be a way in the real world to obtain sulfuric acid as a primary product"

If these conditions cannot be fulfilled, allocation **shall** be applied.

4-Allocation

When allocation cannot be avoided, the LCA practitioner **shall** calculate the economic value of each functional flow. The economic value is calculated as:

Economic Value (€) = economic factor (€/piece or kg, m^3 ..etc)* flow quantity (e.g., in pieces, kg, m^3)

Equation6 : Calculating economic value

For the calculation of economic values, the following hierarchy **shall** be followed to determine the "economic factor" in Equation6:

1. Global market price[49]
2. Regional market price
3. Processing cost[50]
4. Other factors (e.g. Sales price)

This hierarchy is meant to strike a balance between transparency, level of uncertainty and accessibility beyond industry. The first two options are openly available to everyone, and process

[49] Note that global market prices are usually only available for commodities.
[50] Unlike price, this refers to expenditure rather than proceeds. It comprises 1) the real costs of processing the input material in this unit process until and including the production of output 2) to treat waste and residues and 3) all potential losses.

cost comes before sales price because it is less volatile and more transparent. Only if the respective prioritized factor is not available, the next factor in the hierarchy **shall** be chosen. The chosen factor **shall** always be averaged over the last 5 years to smoothen fluctuations.

If the calculated economic value ratio between any of the functional flows is higher than four[51], economic allocation **shall** be applied consistently on the entire unit process using economic value as a criterion to partition the inventory between the functional flows following the equation:

$$Allocation\ factor\ (functional\ flow\ n) = \frac{Economic\ value\ of\ function\ flow\ (n)}{\sum_{1}^{n} Economic\ values}$$

Equation7 : Calculating economic allocation factor

If the calculated economic value ratio is **equal to or lower than four** between all functional flows, allocation **shall** be applied using a physical relationship to partition inputs and outputs between the functional flows. The relationships to choose from are based on what is most suitable to the specific case, for example:

- Produced pieces
- Produced masses
- Contained exergy
- Contained energy

Table ***II-6*** provides a list of which physical relationship **shall** be followed in some of the typical situations. If the case under study does not fit in any situation in the table, the LCA practitioner **may** choose the most suitable physical relationship.

Illustrative example on choosing the best physical relationship :

Example 1: "If the sulfuric acid from factory X is coproduced with another product that is inherently defined by its mass (e.g. metal), then mass-based allocation can be applied. Contained energy is not a good choice since it is not an inherent property of either product.

This shall be done only after ensuring economic value ratio ≤ 4 between the sulfuric acid and the metal."

[51] The factor 4 is the dominant value in most of guidelines reviewed. This is can be brought back to the consideration of 25% as a threshold for significant economic difference found in literature (European Union, 2021; Santero and Hendry, 2016).

More examples on choosing the best physical relationship (from other fields):

Example 1: "In a combined heat and power plant (CHP), contained exergy is perhaps the best choice that accounts for the different nature of electricity and heat although both are forms for energy"

Example 2: "In case of an oil refinery where multiple types of fuels are produced, contained energy might be the reasonable solution that reflects the inherent/most important property of the products"

Table II-6 : Cases where some physical relationships for allocation shall be followed

Case	Mandatory physical relationship
Energy Provision	Contained exergy
Metals and alloys coproduction	Mass
Co production of Components	Units/Pieces, mass, other relationship based on engineering judgement
Coating	Coated surface area
Cutting/stamping (e.g. steel sheets)	Final piece area OR Piece perimeter
Vehicle Assembly	Pieces Time Or Mass
Welding	Welding length
Quality checks	Time Or Pieces
Storage	Volume Or Square footage

Finally, if no underlying physical relationship between the functional flows can be identified, economic allocation **shall** still be used as the last option following equations 1 and 2 to calculate allocation factors.

The allocation approach and the allocation factors **shall** be documented transparently. This includes the prices or the other economic property (e.g. process cost) used and their sources, in addition to the chosen physical relationship in case of physical allocation.

Textbox II-8: [prospective and both Fleet-level LCA types] - Deviation for [Multifunctionality]

The rules for prospective LCA and Fleet level LCA in general **should** be the same rules followed in Product LCA (II.4). The exception regarding the main hierarchy is that in prospective and Macro-Fleet level LCA, the strict first substitution condition (i.e. "There is a real, measurable substitution effect ") **may** be overlooked if justified and clearly stated.

Textbox II-9: [prospective LCA type] - Deviation for [Multifunctionality]

Additionally for prospective LCA, additional considerations that LCA practitioners **may** heed to are provided (Table II-7). These considerations can be translated into parameters and combined into scenarios to be explored within a prospective LCA.

Table II-7 : Prospective LCA Multifunctionality additional considerations

Multifunctionality solution	**Questions to be considered (for system understudy)**	**Questions to be considered (for reference system in case of comparison)**
System expansion	Would the multiple functions provided by the system change in the future?	Will there be clear mono-functional reference systems in the future to compare with?

Substitution	• Which reference products might change due to quality changes of the output product?
	• Does the substitution ratio might change due to:
	  ○ Quality changes of the output product?
	  ○ Up-scaling of the process under research?
	  ○ Changes of the input(s) in future?
		• Does the process efficiency of the reference process(es) might change in a future scenario?
		• Do the environmental burdens of the reference process might change in a future scenario?

Economic allocation	• Would the product price change due to:
	  ○ New applications of secondary by-products (circular economy)?
	  ○ Technology diffusion?
	  ○ Changing consumer preferences?
	  ○ Process improvements?
		N.A.

Physical allocation	• Does the future technology setup change the physical flows? • Does upscaling change the physical flows?	N.A.

II.5.4 Multifunctionality in the end of life

Multifunctionality in the end of life (EoL) of a vehicle or battery **shall** be dealt with using the cut-off approach which is also referred to as “recycled content” or “100:0” approach. Future updates of the TranSensus-LCA method can consider shifting to the Circular Footprint Formula (CFF) if its applicability is improved in the future. The cut-off point **shall** come at least after sufficient separation and sorting including all transportation until this point. In practice, this means the processes of collection, pretreatment, dismantling and shredding. After this, the exact position **shall** be based on the market value of each individual waste stream resulting from previous processes. This is the point where the waste stream goes from a "waste" with negative market value to a "good" with positive market value (see annex for more information). This applies to open-loop reuse, recycling and energy recovery systems. Co-products of waste treatment that can clearly be identified as sellable products (i.e. with a positive market value) **shall** be cut-off (i.e. they will come burden-free for the subsequent product system that uses them). In the case of energy recovery, such sellable products are heat and/or electricity. In case the market value of a waste or product flow cannot easily be determined, and as a last resort, the LCA practitioner **shall** refer to the general vehicle EoL management scheme provided in **Figure *II-7*** with preset cut-off points for typical waste streams.

The step-by-step guide is:

1. Model EoL until sufficient sorting leads to distinct waste streams (incl. all transportation). Namely: collection, pretreatment, dismantling and shredding.
2. After having clear waste streams, follow the market value of each waste stream until it turns positive. This is where the point of cut-off **shall** be placed. Market values **shall** be based on market investigation of each waste stream (knowing who pays to whom).
3. If the point of cut-off cannot be determined via this procedure, e.g. because it proves difficult to determine the market value, use the general reference model provided in **Figure *II-7*** to determine the cut-off point for typical streams.
4. If a recycled content exists in the production/manufacturing stage, the LCA practitioner **shall** account for any additionally needed upgrading/processing of the burden-free input until the intended component of the new vehicle is obtained. Datasets documentation **should** be read carefully to reduce omission or double counting risks.

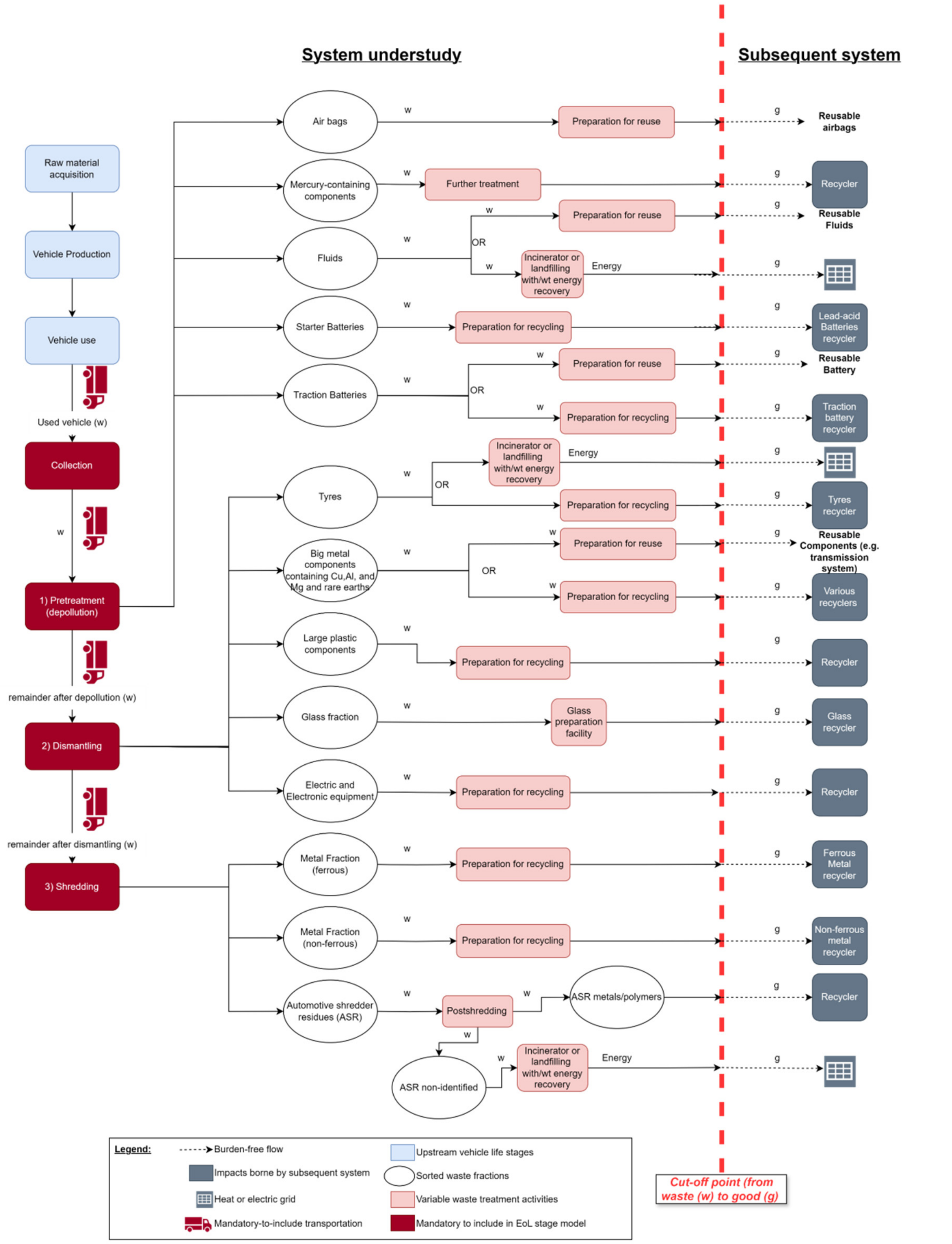


Figure II-7 : A reference vehicle EoL model (a guide for waste streams whose market values are untraceable)

It is important to note that we do not mandate Figure II-7 as a strict EoL model to follow. The EoL model in regards of granularity and fate of waste streams can vary between companies and is subject to regulations in place (e.g. (The European Parliament, 2000). For instance, it is indicated that plastic/polymer fraction of Automotive shredder residues (ASR) go to recycling, this does not mean that the LCA practitioner shall model it this way. He/she can assume that all ASR go to landfilling (the common practice until 2015) (Accardo *et al.*, 2023).

The purpose of this reference EoL model is to offer guidance on determining cut-off points for typical waste streams. It strives to serve as a comprehensive catalogue for this purpose. This reference is intended solely for waste streams whose market value trends cannot be tracked.

Furthermore, the activities in Figure II-7 should not be perceived as "unit processes". Instead, they represent different stakeholders in the value chain in an economic sense. For example, the "glass preparation facility" can be represented by many unit processes in the LCA model.

All transportation (with reasonable assumptions) between facilities **shall** be included until the cut-off point of the specific stream.

Second life of traction batteries

The two typical modes of giving a battery a second life are: remanufacturing (reusing it again as traction battery) or repurposing (using it for stationary energy storage applications) (DeRousseau *et al.*, 2017). Both possibilities are represented by the term "reuse" in Figure II-7. Following the cut-off method and the system boundary in TranSensus-LCA (Task 2.2), these applications are excluded (no negative emissions credit is given to the first life cycle) in Product LCA type. Nonetheless, according to the cut-off method, the reusable battery comes burden-free for the next application. In case of remanufacturing this is simple to model by replacing a brand-new battery. However, for repurposing it is complex to model because it feeds into the background electricity provision systems which means that systematic modification of electricity background systems is needed. This is not practical and complex to model, therefore for product LCA, this is to be omitted for simplification. However, this can be explored in scenario analysis, or in the other LCA types (i.e. prospective or fleet level LCA).

Textbox II-10: [prospective LCA type] - Deviation for [Multifunctionality in the EoL]

Regarding the EoL in prospective LCA, the cut-off method **should** be used as indicated in subsection II.5.4, however as for the hierarchy above, further considerations are pointed out which **may** be considered in pLCA scenarios:

- Change in recycling technologies in the future
- Change in incineration technologies (e.g. lower emissions)
- Battery second life (repurposing) **may** be considered by integrating it in future background electricity provision system as a burden-free input (Figure II-8)

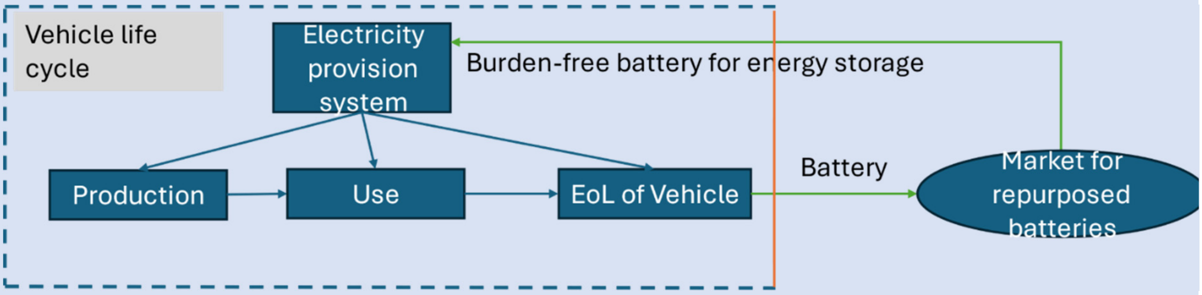


Figure II-8 : A way to consider the benefits of traction battery repurposing (for stationary applications) in the vehicle prospective life cycle assessment (pLCA for a vehicle)

Textbox II-11: [both Fleet-level LCA types] - Deviation for [Multifunctionality in the EoL]

A possible novel multifunctionality situation (can particularly be relevant in Fleet-level LCA) is vehicle to grid services (V2G) or more generally to (V2X) where "X" can be home, office, etc. This is expected to be a wide-spread technology in the future hence can be tested in scenarios in future fleet-level studies. The general hierarchy in subsection II.4 **should** be sufficient to deal with the situation.

The rules to deal with end of life (cut-off method) still apply to fleet-level LCA. If the second life of batteries are part of the main system or tested in a scenario, it **may** be handled the same way as mentioned in Figure II-8 but on a fleet scale.

II.6 Data quality rating (DQR)

ISO is clear in its recommendation on carrying out a data quality assessment and compare it with data quality requirements decided in the scope definition. Therefore, some sort of data quality assessment **shall** take place to be ISO compliant especially when the study is communicated to a third party for verification. However, since moving from qualitative evaluation of data to numbers is not entirely objective in the typically used methods (See annex for more information), we do not mandate a specific way to assess the data quality or to calculate DQRs, especially given that some of these methods are time and resource demanding.

However, the LCA practitioners **should** apply the same method used in the background database (e.g, ecoinvent, MLC Sphera). This will probably save resources, foster the consistency and will facilitate calculating global DQR of the study if needed (i.e. the aggregations of the DQRs per exchange from all unit processes (background and foreground)).

Note: Besides the data rating that comes with databases, the foreground system data **should** be evaluated by the LCA practitioner. Normally, this data is expected to score high in quality. For example, if an OEM models the manufacturing stage of an in-house product with directly collected data from its own facilities, the OEM might end up with a score "1" for all or most flows.

An example of data quality assessment activity done by Volvo Cars in a vehicle LCA can be found in Appendix 6 in Volvo Cars, (2024).

II.7 An outlook on future work

Here we discuss briefly what can be improved/researched more in the future when it comes to the topics discussed under LCI phase. This is presented in Table II-8 with each column representing each the three different main topics of the LCI task in TranSensus-LCA.

Table II-8 : topics for future work and improvement in Task 2.3 grouped per each working subtask

Data	Electricity modelling	Multifunctionality
Estimating the particulate matter emissions of tyres and brakes require more research in general. TranSensus-LCA recommendations regarding this should be reviewed in the future to keep up with the foreseen research in this area. Current data are not based on last technologies of brakes and tyres. Emissions factors will be updated in the near future. The brake pad wear results depend on technology definition, customer profiles (which depends on OEM strategy), etc. Some recent publications may help to update brake particle emission factors [Hicks *et al.* 2023; Giechaskiel *et al.* 2024a] Regarding tyre wear emissions update, studies are performed by tyre suppliers directly. For the moment it is limited to tyre wear only (not yet particles emissions) in order to fulfill future regulation. Recent publications present updated information which may be useful for tyre wear emission factors update [Beddows *et al.* 2023; Charbouillot *et al.* 2023; Giechaskiel *et al.* 2024b]	It is to be noted that evolution will probably occur both in terms of better traceability of electricity and modelling and use of residual grid mixes, which could bring a solution for most cons listed for the three methods in the decision tree. Once these evolutions are achieved and commonly accepted, TranSensus-LCA rules for electricity modelling regarding the market-based approach should be re-evaluated. For either a 100% market-based electricity modelling approach or a mixed modelling approach the EAC characteristics must be improved as data availability improves: the additionality criteria related to the age of the electricity producing assets should decrease from 15 years to 10 or 5 years and the EAC production/consumption time synchronization should be on an hourly timestep. Future work can provide LCA databases with residual mixes background processes used in every LCA process (such as there exist consequential databases in which every LCA process uses consequential background processes). Future work can provide new electricity production processes for those that will occur in the future, as is the objective of the PREMISE project.	CFF must be explored after the expected modification in the next version of PEF. Another round of consensus building can be considered to see if CFF should replace cut-off in the methodology Future work can provide details on how to handle multifunctionality in V2X cases since these technologies are expected to become more relevant with in the future.

III. Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is a crucial component of Life Cycle Assessment (LCA), for evaluating the environmental impacts of a product or process throughout its entire life cycle. LCIA quantifies, classifies and characterizes the potential environmental impacts associated with various life cycle stages, from raw material extraction to end-of-life disposal.

While LCIA has been widely adopted, inconsistencies in methodology and data can hinder accurate and reliable impact assessments. To address this challenge, the TranSensus-LCA methodology standardizes key elements of LCIA, including impact categories, impact indicators, impact assessment methods, and normalisation. By aligning with widely accepted standards, guidelines, scientific articles, and policy documents, the methodology seeks to foster consistency and comparability in LCIA studies.

Textbox III-1: Prospective and fleet-LCA – No deviation for LCIA Topic

The recommendations provided in the LCIA session stay the same for Prospective and Fleet LCA as for the product LCA.

The mindmap below summarizes all TranSensus-LCA requirements for LCIA.

Figure III-1: Life cycle impact assessment requirements of TranSensus-LCA in a form of a mindmap

III.1 Calculation of LCIA results

Life cycle impact assessment systematically categorizes and aggregates LCI data to quantify its contributions to each environmental impact category. Characterization models quantify the environmental relationship between LCI data (extractions and emissions) and the category indicator of each Impact Category (IC). Each IC is linked to a unique characterization model. The TranSensus-LCA selection of environmental impact categories is comprehensive, encompassing a wide range of relevant issues within the product's supply chain. TranSensus-LCA experts analysed a list of existing LCA impact categories and evaluated the relevance of each impact for zero emission vehicles (ZEVs) life cycle assessment. This evaluation has been performed by scoring each impact regarding a set of 5 criteria:

- Science based criteria: 1) robustness of the impact, and 2) relation to planetary boundaries.
- Other criteria: 3) importance for ZEVs, 4) data availability, and 5) easy-to-use.

The Table III-1 summarizes recommendations that obtained a qualified majority from TranSensus-LCA voting sessions and are therefore now requirements of the methodology.

The subsections and tables below provide a **Mandatory** and **Optional** list of impact categories and related assessment methods. For a TranSensus followed LCA study, all impact categories that are listed in mandatory impact categories **shall** be calculated using related assessment method, without exclusion.

III.1.1 Mandatory set of Impact Categories (IC)

The following list of mandatory environmental impacts categories, indicators and LCIA methods (last version of EF method[52]) **shall** be applied and calculated, without exclusion.

Table III-1: Mandatory environmental impact category list from TranSensus-LCA

Mandatory Impact Category	Impact Category Indicator	Unit	Characterization model
Climate change, total[53]	Radiative forcing as global warming potential (GWP100)	kg CO_2eq	Baseline model of 100 years of the IPCC (based on IPCC 2013 [1])

[53] The "Climate change, total" is comprised of three constituent sub-indicators: Climate Change (fossil), Climate Change (biogenic), and Climate Change (land use and land use change). Should any of these sub-categories exceed a 5% contribution to the total climate change score, it is imperative to report them separately.

Mandatory Impact Category	Impact Category Indicator	Unit	Characterization model
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOCeq	LOTOS-EUROS model (Van Zelm *et al.*, 2008 [2]) as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H^+eq	Accumulated Exceedance (Seppälä *et al.* 2006 [3], Posch *et al.*, 2008 [4])
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP 2016 [5])
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs *et al.*, 2009 [6]) as implemented in ReCiPe
Cumulative Energy Demand[54] [55]	Renewable and non-renewable cumulative energy demand (CED)	MJ	Hischier *et al.,* 2010 [7] Frischknecht *et al.,* 2015 [8]
Resource use, minerals and metals[56]	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML 2002 (Guinée *et al.*, 2002 [9]) and van Oers *et al.* 2002 [10]

For more information on last version of EF method, the European Commission has published a recommendation on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations in the Official Journal of the European Union [11, 12].

More detailed information on mandatory impacts categories, indicators and LCIA methods proposed within TranSensus-LCA may be found in the LCIA annex.

Hydrogen (H_2) emission flow **shall** also be included as mandatory indicator. Sensitivity analysis including hydrogen emission greenhouse gas impacts for LCAs of hydrogen fuelled ZEVs **shall** be performed, until a formalised GWP is available according to IPCC/within the EF method.

By default, hydrogen emission impact calculation **shall** follow two principles bellow:

i. In the absence of supplier-specific information on fugitive hydrogen emissions from the supply chain, include default estimated H_2 supply chain emission rates for hydrogen produced from natural gas or via electrolysis – see Cooper *et al.* [13].

[54] CED should be considered as a total as well as separated into renewable and non-renewable shares. CED_total should be used with caution. For details, please refer to the Annex.
[55] TranSensus-LCA recommends using CED indicator with care and taking into account the uncertainties that come with. The assumptions taken while using CED should be clearly stated as it can influence the results.
[56] The impact category result should be interpreted with caution, as the normalized ADP values may be subject to overestimation.

ii. Use of GWP100 of 11.6[57] for characterising the impacts of hydrogen emissions for the sensitivity analysis.

Detailed information is provided in the LCIA Annex document.

In the future, should/when a formalised GWP become available for IPCC/within the EF method/UNECE IWG, then the hydrogen emissions and impacts resulting from them **should** be expected to be captured within the Climate Change impact category by default, and it **may** not be necessary to continue to report the H_2 emission flow as a mandatory indicator and to conduct the supplementary sensitivity analysis.

[57] A multi-model assessment of the Global Warming Potential of hydrogen | Communications Earth & Environment. https://www.nature.com/articles/s43247-023-00857-8

Table III-2: Default H2 supply chain emission rates for hydrogen produced from (i) steam reforming of natural gas, (ii) electrolysis of water; derived and simplified from (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022)

	Production and processing	Compression	Storage and transport	Liquefaction	Shipping	Regasification	Transmission and storage	Distribution	Use in H_2 ICEV, FCEV and FC-REEV*	Total
H_2 from natural gas (production in same region as use)	0.55%	0.17%	0.31%				0.05%	0.02%	0.50%	1.61%
H_2 from natural gas (imported to region of use - as LH2)	0.55%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	2.05%
H_2 from electrolysis (production in same region as use)	2.05%	0.17%	0.31%				0.05%	0.02%	0.50%	3.13%
H_2 from electrolysis (imported to region of use - as LH2)	2.05%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	3.57%

Notes: Hydrogen has a high tendency to leak, which makes it difficult to be contained; primarily due to safety concerns, many studies have assessed the potential for hydrogen leakage from fuel cell electric vehicles, both in stationary conditions and from operation. However, such studies generally do not contextualise hydrogen leakage rates in terms of the overall supply of hydrogen to the vehicle. Engine slip of H_2 in ICEVs fuelled by hydrogen is reported to range from 0 to 12%, and a value of 0.5% is assumed by (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022). In the absence of other information, a similar rate is assumed also for hydrogen vehicles using fuel cells.

III.1.2 Optional set of Impact Categories (IC)

The following list of optional environmental impacts categories, indicators and LCIA methods **may** be applied.

Table III-3: Optional impact category list from TranSensus-LCA

Optional Impact Category	Impact Category Indicator	Unit	Characterization model
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state ODPs as in (WMO 2014 + integrations)
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte *et al.*, 2017 [14])
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte *et al.*, 2017 [14])
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U^{235} eq	Human health effect model as developed by Dreicer *et al.* 1995 [15] (Frischknecht., 2000 [16])
Eutrophication, terrestrial	Accumulated Excedance (AE)	mol N eq	Accumulated Exceedance (Seppälä *et al.*, 2006 [17], Posch *et al.*, 2008 [18])
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs *et al.*, 2009 [19]) as implemented in ReCiPe
Ecotoxicity, fresh-water	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fankte *et al.*, 2017 [14])
Land use	- Soil quality index - Biotic production - Erosion resistance - Mechanical filtration - Groundwater replenishment	- Dimensionless (pt) - kg biotic production - kg soil - m^3 water - m^3 groundwater	Soil quality index based on LANCA (Beck *et al.*, 2010 [20] and Bos *et al.*, 2016 [21])
Water use	User deprivation potential (deprivation-weighted water consumption)	m^3 world eq	Available WAter REmaining (AWARE) as recommended by UNEP, 2016 [22]
Criticality	GeoPolRisk	kg Cu eq	(Santillán -Saldivar *et al.*, 2022 [23] ; Koyamparambath *et al.*, 2024 [24])
Dissipation[58]	Average Dissipation Rate (ADR) Environmental Dissipation Potential (EDP)	kg Fe eq kg Cu eq	Charpentier Poncelet *et al.*, 2021 Van Oers *et al.*, 2020

[58] As part of the TranSensus -LCA methodology, both studied impact assessment methods are proposed as options for application; answering to two potential scenarios of technical and economic development. For more information see LCIA Annex.

More detailed information on optional impacts categories, indicators and LCIA methods proposed within TranSensus-LCA is available in the LCIA Annex.

Biodiversity and circularity indicators **should not** yet part of mandatory nor optional list of indicators for remaining robustness and completeness issues of existing indicators. Nevertheless, biodiversity and circularity indicators **should** be included in TranSensus-LCA methodology when a robust indicator is available. For more details refer to the LCIA Annex.

III.2 Normalisation

Normalisation **may** be used in LCAs followed by TranSensus-LCA. Also, when reporting LCAs following TranSensus-LCA, midpoint impact data **should** always be reported before normalized values.

III.2.1 Normalisation Factor

Global Planetary Boundary based normalisation factors **should** be used to perform normalisation. Global planetary boundaries-based normalisation factors recommended here are based on the scientific article by Sala, 2020. Also note that the Global planetary boundaries-based normalisation factors are not mature yet. So, practitioners must be following the updates regarding these normalisation factors. For more information on Normalisation refer to Annex.

III.3 Software Testing

The Life Cycle Assessment (LCA) results analysis for electric vehicle battery production reveals significant differences between data sourced from the ecoinvent and Environmental Footprint (EF) databases. The study focused on various environmental impact categories, particularly climate change, and identified that the ecoinvent database generally reported higher impacts across most categories than the EF database. A reverse-engineering approach was employed to investigate these discrepancies, revealing that a small number of substances accounted for over 95% of the total impact. Key factors contributing to the differences included methodological variations in process documentation, system boundaries, technological representativeness, and data quality. The analysis also highlighted how energy modelling differences and data updates influenced the results, with the EF process benefiting from more recent and comprehensive data inputs. Overall, the findings underscore the importance of methodology and data quality in accurately assessing environmental impacts in battery production processes. For more details refer to Annex.

IV. Life Cycle Interpretation

Task 2.5 of TranSensus-LCA has defined an approach for the interpretation phase of LCA (part A) and S-LCA (part B). Recommendations for conducting sensitivity analysis, scenario analysis and/or uncertainty analysis are proposed. In view of the overall objective to pave the path towards an LCA-driven product development, this task also conceptualizes how decision-making and frontloading processes should be implemented into industrial product development processes along the supply chain. The goal is to enable engineers and managers according to their profile (industry, RTO, academia, policy, regulation, etc.) to select solutions and technologies (both existing and emerging) based on their environmental and social impacts. Furthermore, recommendations on how to verify and report the results in a clear, consistent, and transparent way are proposed.

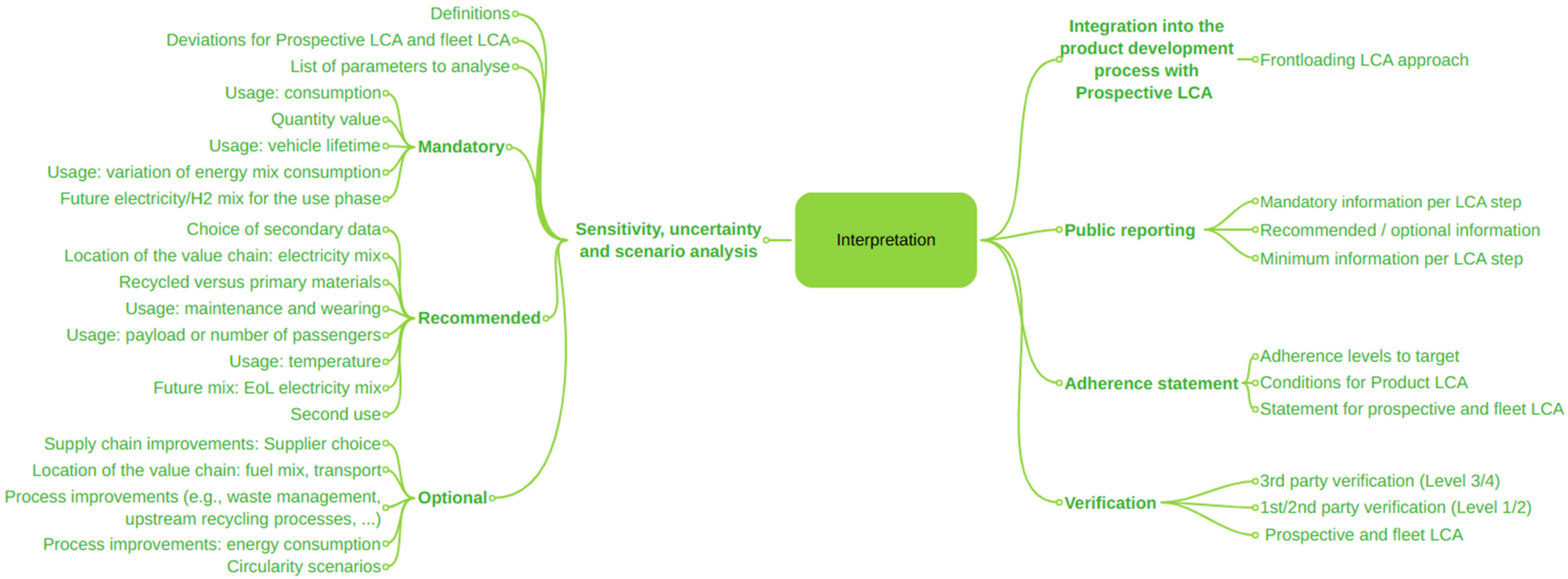


Figure IV-1 : Interpretation requirements of TranSensus-LCA in a form of a mindmap.

IV.1 Scenario analysis, uncertainty analysis and sensitivity analysis

IV.1.1 Definitions and methodology

Scenario analysis, uncertainty analysis, and sensitivity analysis are essential to determine the robustness of the LCA results and to identify and quantify the most influential factors. Together, these analyses provide a comprehensive understanding of the LCA's reliability and could help stakeholders make informed decisions. Scenario analysis allows for exploration of alternative contexts and decisions, while uncertainty analysis addresses the variability in data and assumptions. Sensitivity analysis determines how changes in input parameters affect the LCA results, identifying key areas of influence. Table IV-1 provides definitions of these terms as agreed in TranSensus-LCA. A longer version of these definitions can be found in Table XII-1 in the Annex.

Table IV-1 : Definition of scenario analysis, uncertainty analysis, and sensitivity analysis in TranSensus-LCA.

Analysis type	Definition
Scenario analysis	A scenario represents a storyline that determines a variation of key parameters/assumptions (applies well where parameters are correlated) of the model.
Uncertainty analysis	The uncertainty analysis focuses on how well we know the absolute value of the result (e.g., Monte Carlo).
Sensitivity analysis	The sensitivity analysis focuses on the influence each parameter has on the result (e.g., OAT on location of the electricity mix).

The methodology to propose recommendations for conducting scenario analysis, uncertainty analysis and/or sensitivity analysis consisted of three steps. First, which parameters **shall**, **should** or **may** be analysed for all LCIA mandatory impacts as mandatory, recommended and optional is presented in this document. Secondly, which type of analysis (i.e., sensitivity, uncertainty or scenario analysis) **shall or should** be used for each parameter. To reduce complexity, only the type of analysis required for mandatory and recommended parameters were proposed. The type of analysis to be applied to the optional parameters is left to the practitioner. Finally, the approach on how to conduct the analysis for the mandatory and recommended parameters is recommended. The following subsections describe the proposed approach for each mandatory and recommended parameter. The discussion for optional parameters is included in the Annex.

Mandatory parameters

- Usage: consumption
- Quantity value
- Usage: vehicle lifetime
- Usage: geographical variation of energy mix consumption
- Future mix: use phase electricity/H2 mix

Recommended parameters

- Choice of secondary data
- Location of the value chain: electricity mix
- Supply chain improvements: recycled vs. primary materials
- Usage: maintenance & wearing
- Usage: payload/nb of passengers
- Usage: temperature
- Future mix: EoL electricity/H2 mix
- Second use

Optional parameters

- Supply chain improvements: supplier choice
- Location of the value chain: fuel mix, transport distance & means
- Process improvements (waste management, upstream recycling processes, packaging...)
- Process improvements: energy consumption
- Circularity scenarios (e.g., car sharing, vehicle-to-grid, reuse, recycling, and second-life applications.

Figure IV-2 : Categorisation in mandatory, recommended, and optional analysis of parameters

In addition to the mandatory, recommended, and optional parameters mentioned above, due to the growing importance of circularity to reduce the environmental and social impact over the life cycle of product systems, a scenario analysis **may** be performed on this topic. Since it is categorized as optional, the analysis is left to the practitioner. However, circularity scenarios may include parameters such as car sharing, vehicle-to-grid, reuse, recycling, and second-life applications.[59]

Textbox IV-1: [Prospective and fleet LCA] - Deviation for the assessed parameters

Prospective and fleet level LCA are also covered by the proposed approach to analyse the parameters but may need some adaptation of the parameters. Additional parameters that are not included within Product LCA (e.g. composition of the fleet) **may** also be assessed.

IV.1.2 Mandatory analysis of parameters

The following five mandatory parameters **shall** be assessed: usage consumption, quantity value, vehicle lifetime activity, variation of energy mix consumption and future mix on use stage electricity/H_2 mix. Table IV-2 summarizes the type of analysis that **shall** be followed for each parameter, while the following paragraphs define each parameter and provide additional details about the approach.

[59] The choice of circularity as a parameter to be analysed was not based on a vote but was defined as very relevant for future applications.

Table IV-2 : Summary of mandatory parameters and analysis type.

Parameter	Analysis type
Usage: consumption	Sensitivity analysis
Quantity value	Sensitivity analysis
Usage: vehicle lifetime	Sensitivity analysis
Usage: variation of energy mix consumption	Scenario analysis
Future electricity/H_2 mix for the use stage	Scenario analysis
Hydrogen emission flow[60]	Sensitivity analysis

IV.1.2.1 Usage: consumption

Definition of parameter: This parameter refers to the amount of energy consumed during the use stage of a vehicle, which is one of the highest contributors to the life cycle impacts of a vehicle.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **shall** be studied with a sensitivity analysis.

Analysis approach: The sensitivity of the LCA results to energy consumption during vehicle usage **shall** be assessed considering alternative values to those set by default. It should be noted that energy consumption depends on many factors, such as ambient temperature, the scope of the study, and the choice of representative vehicle. For simplification and practicality, for LDVs, the default methodology for energy consumption is to use WLTP adjusted to real-world performance (see subsection II.2.1.1). For values and factors to be considered in the sensitivity analysis: the practitioner **should** also conduct a sensitivity also using just the WLTP values, and **may** also conduct additional sensitivity analyses using alternative adjustment factors or energy consumption values based on different driving cycles/behaviour. Concerning HDV, the sensitivity analysis **should** consider relevant drive cycles for the vehicle type (e.g. those used to form the certification weighted average, such as urban delivery, long haul, etc.).

The sensitivity analysis **should** be performed according to the general guidance for the use stage electricity consumption "dynamic" modelling approach in subsection II.2

[60] With Task 2.4, it was voted for to analyse the H_2 emission flow as a mandatory indicator and to conduct the supplementary sensitivity analysis (see subsection III.1.1).

IV.1.2.2 Quantity value

Definition of parameter: The quantity value refers to the amount of any LCI flow associated with specific foreground data[61] (e.g., the input amount of a component/material/energy or the output amount of a substance emitted to air, water, or soil). For supplier-specific data, quantities are typically measured, often accompanied by statistical information on measurement accuracy. For secondary data, however, quantities are often retrieved from literature or databases and may come with higher uncertainty. In some cases, when the quantity is unknown, assumptions must be made. In all cases, the potential impact of the quantity value variability on the LCA results **shall** be carefully considered.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **shall** be studied with a sensitivity analysis.

Analysis approach: A mandatory sensitivity analysis of the quantity value for critical LCI flows associated with activities identified as hotspots shall be performed. Hotspots refer to a specific unit process or product/environmental flow within a process or value chain where the environmental impacts are notably significant. The sensitivity analysis **should** use minimum and maximum ranges derived from measurements or relevant literature (e.g., minimum and highest electricity consumption values for a specific manufacturing process as reported in the literature).

Special provisions: Certain activities or LCI flows **may** be excluded from the analysis if justification is provided that their values are fixed. This includes, for example, a vehicle specific BOM.

IV.1.2.3 Usage: vehicle lifetime activity

Definition of parameter: The lifetime activity of the vehicle stated as kilometres driven is one of the key parameters that has large influence on the LCA results. The lifetime activity may vary substantially depending on, e.g., how and by whom the vehicle is driven (e.g., taxi car or family car). Therefore, the influence of this parameter on the LCA results **shall** be subject to further analysis.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **shall** be studied with a sensitivity analysis.

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[61] Foreground product data relates directly to the product being assessed, including the inputs and outputs across its life cycle. It is referred to as foreground data because it encompasses everything in the immediate product system, such as the energy (e.g., MJ, kWh) consumed or the materials (e.g., kg, m^2) used during production. https://helpcenter.ecochain.com/en/articles/9842753-explained-data-in-lca

Analysis approach: The sensitivity analysis **should** consider a low and high value for the lifetime activity for the assessed vehicle. Low and high estimates **should** be derived from the company's internal statistics on vehicles or from literature. The data used should be properly documented and reported. Table IV-3 provides an example of sensitivity analysis for passenger cars based on Ricardo et al[62]. Here, the low value for lower medium passenger car (i.e., 150 000 km) was based on the typical value found in this latest up to date available literature, while the high estimate assumes a 20 % increase in lifetime km activity.

Table IV-3: Example of sensitivity analysis on vehicle lifetime activity. Based on Ricardo study[62].

Vehicle type	Segment	Default [km]	Low [km]	High [km]
Passenger car	Lower medium (C)	200 000	150 000	270 000
	Large (Others)	260 000	180 000	300 000
LCV	Small/medium/large	240 000	200 000	300 000

IV.1.2.4 Usage: variation of energy mix consumption

Definition of parameter: ZEVs are often produced in a specific location but may be used across various regions depending on the target markets (e.g., EU, China, etc.). This parameter is intended to assess the impact of the energy mix used during the vehicle's use stage, considering different regions and contexts where the vehicle might be driven. For instance, an EV driven and charged in Norway, with its predominantly renewable electricity mix, could have significantly lower life cycle climate change impacts compared to a vehicle driven in Poland, where electricity generation is largely reliant on fossil fuels. This analysis **shall** be performed regardless of whether a static or dynamic mix is used in the initial model.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **shall** be studied with a scenario analysis.

Analysis approach: Scenario analysis **should** be performed considering different electricity mixes for the use stage, either based on national mixes or based on a mix composed of different renewable shares. Scenarios considering vehicle usage in specific countries, using the corresponding national electricity mixes, **may** be included provided that the choice of these mixes is carefully documented and justified. This justification may be based on the major markets where the vehicle is sold (e.g., EU, China, and the US), or on representing a range of renewable energy penetration, such as Norway for a highly renewable mix and Poland for a highly fossil fuel mix. Alternatively, national electricity mixes may be replaced with a renewable mix to represent a

[62] European Commission, Directorate-General for Climate Action, Hill, N., Amaral, S., Morgan-Price, S., Nokes, T., et al., Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA : final report, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2834/91418

scenario where the vehicle is driven in a context with full availability of renewable electricity generation.

IV.1.2.5 Future electricity/H_2 mix for the use stage

Definition of parameter: This parameter refers to the generation of the electricity used to charge BEVs (and other plug-in electric powertrains and vehicles operating on electric road systems (ERS)) and the hydrogen production and supply chain for ZEV powertrains using hydrogen (i.e. FCEVs, FC-REEVs and H_2 ICEVs). Electricity is typically sourced from a grid mix that comprises different electricity generation technologies, the relative shares of which are subject to change over time and, critically, over the service life of the vehicle. In many regions of the world, due to political and legislative pressure to meet climate targets, the electricity grid mixes have been evolving towards lower shares of conventional fossil fuel-based power plants and higher shares of low-carbon technologies such as variable renewable energies (primarily wind and solar PV) and nuclear energy. Similar trends are expected to continue into the next decades.

Similarly, hydrogen can be supplied from different sources and processes (currently steam reforming natural gas, or water electrolysis, e.g., using grid electricity or renewable electricity). Compared to electricity, there is relatively much greater uncertainty on the future hydrogen supply mix and how this is likely to change over time.

Therefore, to provide a more accurate assessment of the environmental impacts over the vehicle life cycle, TranSensus-LCA methodology **shall** account for this dynamic evolution of the electricity and H_2 mix in the LCI modelling phase. This is of even more importance in comparative LCAs, where the environmental impacts of xEVs are compared to those of ICEVs, since failure to account for the progressive decarbonisation of the electricity grid mix would result in an overestimation of the GHG emissions of the xEVs during their use stage, putting them at an artificial competitive disadvantage vs. ICEVs.

Analysis type: Whatever the choice of default electricity/H_2 mix modelling in LCI modelling phase, the influence of this parameter on all mandatory LCIA impacts **shall** be studied with a scenario analysis.

Special provisions: This analysis **shall** also be conducted in cases where legal responsibilities prevent OEMs from adopting a dynamic electricity mix (i.e., where a static mix is used by default). In such instances, the sensitivity of the LCA results to the use of a dynamic mix **shall** still be evaluated.

Analysis approach: Scenario analysis **should** be conducted using alternative future projections for the electricity/H_2 supply mix in the geographical region of interest. In TranSensus-LCA, a decision has already been reached that a conservative dynamic electricity mix projection approach shall be used to model the electricity modelling input to the use stage of BEVs (with special provision for deviating from this, as detailed below). Testing alternative future projections for the electricity mix have been identified as important, also to assess the uncertainty in this area. This analysis involves considering more ambitious climate scenarios (such as the Sustainable Development Scenario (SDS) from the IEA). The electricity grid mix composition under these alternative scenarios shall be estimated according to the methodology outlined for this (see subsectino II.2.2.1).

A similar approach is also proposed for hydrogen. However, this is currently limited by the comparative lack of availability of robust future projections of hydrogen production and supply, compared to the availability of projections for future electricity supply mixes. The H_2 supply mix composition under the alternative scenarios **shall** be estimated based on the methodology outlined for this (see subsection II.2.2.2).

IV.1.2.6 Hydrogen emission flow

The lifecycle impacts of hydrogen fuelled ZEVs (i.e. FCEV, FC-REEV and H_2 ICEV) are particularly influenced by the impacts from production, supply and use of hydrogen fuel. Whilst most LCA studies address impacts resulting from hydrogen production, impacts from fugitive hydrogen emissions are not generally included. There is some uncertainty on the GWP100 value of hydrogen itself, and it was not included in IPPC AR6 (and consequently also not in relevant LCI and impact methodologies). However, recent scientific evidence from (Sand, et al., 2023) suggests these impacts double those previously estimated, making lifecycle GWP impact of hydrogen emissions potentially significant for vehicles using it as a fuel.

Hydrogen emissions are not commonly captured in LCI datasets, and a characterisation factor for hydrogen is currently not included (e.g. in the EF method) due to its exclusion from the explicit list of greenhouse gases in AR6. There is currently mixed support for including hydrogen as a greenhouse gas (with GWP based on the best current scientific evidence) at the UNECE Informal Working Group on Automotive LCA. Therefore, it is recommended that accounting for hydrogen as a greenhouse gas **should** be included by default in the future only once consensus has been reached formally on the GWP value, and/or its inclusion within the EF method.

However, in order to future-proof the TranSensus-LCA methodology, users **shall** for now (until hydrogen's GWP is formalised/agreed) assess the total lifecycle emissions of hydrogen as a mandatory flow indicator and additionally conduct a sensitivity on the potential GWP impacts of these. For more details refer to Annex.

IV.1.3 Recommended analysis of parameters

The following eight parameters are **recommended** to (**should**) be assessed: choice of secondary data, location of the value chain regarding electricity mixes, supply chain improvements regarding recycled and primary materials, maintenance & wearing in the use stage, payload or number of passengers, temperature in the use stage, future electricity/H_2 mix for the EoL, and second use. Table IV-4 summarizes the type of analysis that **should** be followed for each recommended parameter, while the following paragraphs define each parameter and provide additional details about the approach.

Table IV-4 : Summary of recommended parameters and analysis type.

Parameter	Analysis type
Choice of secondary data	Sensitivity analysis
Location of the value chain: electricity mix	Scenario analysis
Supply chain improvements: recycled versus primary materials	Scenario analysis
Usage: maintenance and wearing	Scenario analysis
Usage: payload or number of passengers	Scenario analysis
Usage: temperature	Scenario analysis
Future mix: EoL electricity mix	Scenario analysis
Second use	Scenario analysis

IV.1.3.1 Choice of secondary data

Definition of parameter: This choice arises when several datasets are available to represent a LCI flow and the LCA practitioner does not know which one suits their model best. Thus, the decision to use one dataset rather than another one is often arbitrary and leads to uncertainty in the results.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a sensitivity analysis.

Analysis approach: This analysis **should** be performed with a one-at-a-time sensitivity analysis by changing one dataset at a time and evaluate the impact on the LCA results (e.g., changing the dataset for the cobalt sulphate used in battery manufacturing, and evaluate the influence on the carbon footprint of the EV). The datasets selected for this analysis **should** be justified based on a hotspot analysis with the biggest contributors to an impact and **should** be dependent on data availability.

IV.1.3.2 Location of the value chain: electricity mix

Definition of parameter: The location of some suppliers along the value chain might not be known to the LCA practitioner (i.e., supplier-specific data may be unavailable). In such cases, an average or non-representative LCI dataset might be used, introducing additional uncertainty into the LCA results. While the "choice of secondary data" parameter tests the sensitivity of the LCA results to the selection of different datasets, this parameter specifically evaluates how changes in the electricity mix within the used average or non-representative datasets affect the results. For simplicity and practicality, the analysis is limited to the electricity mix, as it is both feasible to vary and typically a major contributor to environmental impacts.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: The scenarios could involve assessing alternative supply chains based on potential production locations for the same product (e.g., synthetic graphite supply from China vs. USA). The alternative supply chains are modelled by varying only the electricity mix (country-specific) used in key processes. No specific guidelines are provided in this regard, so the practitioner must select the most appropriate choice and justify it accordingly. Due to potential data availability constraints (requiring access to disaggregated unit process datasets), this analysis **should** be conducted, at a minimum, for the most critical tier-1 processes. This analysis **should not** be performed for all suppliers along the value chain, but only for relevant processes/suppliers e.g., leading to hotspots or energy intensive processes. The justification for selecting these key processes **should** be based on the hotspot analysis with the biggest contributors to the impact.

Special provision: This analysis is recommended only for hotspots input flows modelled with average datasets due to the lack of supplier-specific data. LCI flows modelled with supplier-specific data (e.g., LCA conducted by OEMs that know their supply chain) **may** be excluded.

IV.1.3.3 Supply chain modifications: recycled versus primary materials

Definition of parameter: This parameter assesses the influence of recycled content in input materials on the LCA results. Recycled content plays a key role in determining the life cycle impacts of materials used in ZEV, with higher recycled content often leading to lower impact intensities.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: Scenarios with varying rates of recycled content in the input materials used in the vehicle **should** be considered. A minimum-maximum recycled content scenario analysis is recommended. The minimum case scenario **may** involve either 0% incorporation of recycled material or the minimum recycled content based on regulatory targets. For example, in cases such as EV batteries, mandatory shares of secondary materials **may** define the minimum scenario. The maximum recycled content scenario **may** reflect the highest achievable shares within the industry at a specific time. In all cases, the practitioner **should** document and justify the definition of the assessed scenarios. Moreover, this analysis doesn't have to be performed on all materials but only those deemed relevant by the LCA practitioner (see subsection II.3).

IV.1.3.4 Usage: maintenance & wearing

Definition of parameter: This parameter is linked to the way the vehicle will be driven and by whom. A more intensive use might lead to more maintenance and wearing of some parts/components. The list of maintenance and wear parts is given in Table II-3. It contains tyres, starter battery (i.e. 12V), brake pads, etc. Sometimes, the fuel cell or the traction battery should also be replaced (refer to subsection II.2.4for details).

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis. For the specific case of battery replacement, if the method used to calculate the durability is based on the simplified methodology or default values (step 2 or 3 of the hierarchy described in subsection II.2.4), then the influence of the number of battery replacements **should** also be studied.

Analysis approach: If available: Different scenarios depicting low and high wearing and maintenance requirements **should** be analysed.

IV.1.3.5 Usage: payload or number of passengers

Definition of parameter: This parameter is linked to the way the vehicle is driven and (/or) by whom (e.g., family of six or single person). This parameter can have a large influence on the results due to its role in the functional unit. For passenger cars, this parameter refers to the occupancy rate which is directly considered in the functional unit as defined in TranSensus-LCA (i.e., passenger-km). Regarding freight vehicles, this parameter refers to the payload that is considered in the defined functional unit (i.e., ton*km).

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: Scenario analysis on the number of passengers for passenger cars and payload for freight vehicles is recommended. For passenger cars, the analysis **should** consider low-high scenarios for the number of passengers, where low is 1 passenger and high corresponds to the maximum capacity of the vehicle (e.g., 5 passengers). Regarding freight vehicles, the analysis **should** consider low-high scenarios for the payload. The used range **should** be based on the typical payload range (e.g., 25-100%). The **minimum requirement** is to consider the influence of these changes through the functional unit (e.g., attributing the impacts to 1 passenger vs. 5 passengers). However, it should be noted that increasing the number of passengers affects energy consumption during usage and potentially other inventory flows. Similarly, changing the payload could also influence other parameters such as the consumption/maintenance and wear. Therefore, a more advanced analysis **may** be performed considering these dynamics, provided that data is available.

IV.1.3.6 Usage: temperature

Definition of parameter: This parameter is associated with how and where the vehicle will be driven (e.g., in Spain or Norway). Ambient temperature can significantly impact factors such as aging, range, and the performance of specific components like the battery. For instance, a car driven in Norway during winter may experience cold temperatures that reduce efficiency and decrease overall range. Conversely, a car driven in Spain during summer requires additional cooling for both passengers and the battery, leading to higher energy consumption.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: The scenario analysis **should** be performed considering different locations with different annual average temperatures for comparison (e.g., Norway vs southern Italy). When conducting this analysis, it is important to note that varying the temperature affects the EV range, with direct implications for energy consumption during usage and potentially on several other inventory flows. The scenario analysis **should** capture these effects and transparently document the assumptions made.

IV.1.3.7 Future mix: EoL electricity mix

Definition of parameter: From a temporal perspective, it is acknowledged that the time the vehicle reaches EoL lies in the future. Therefore, electricity consumed for EoL processes will be sourced from the national grid during that particular timeframe. This presents the requirement to account for future projected electricity mix when modelling the EoL stage.

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: Scenario analysis **should** be performed considering future projected electricity mixes when modelling the vehicle EoL. The projected electricity mix **should** correspond to the location and the year when the vehicle reaches EoL. The step-by-step approach is detailed below:

1) The same scenario for the expected future evolution of the electricity grid mix in the geographical region of interest should be adopted, as previously selected for the dynamic modelling of the use stage electricity (see subsection II.2.2.1.1), according to the following order of preference:

a. Official scenario for the country or geographical region of interest (e.g., EU Reference Scenario 2020)

b. Stated Policies Scenario (STEPS) from the most recent International Energy Agency's World Energy Outlook (IEA WEO) report, for the geographical region of interest[63]

c. IF NEITHER a. NOR b. IS AVAILABLE for the geographical region of interest, then the most recent "static" grid mix composition should be used instead.

2) The grid mix composition for the specific year of vehicle decommissioning (i.e., year of vehicle registration + expected lifetime) should be estimated (i.e., the shares $S_{i,N}$ 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 should be built in the LCA software package of choice (e.g., "LCA for Experts", or "SimaPro"), 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[64].

IV.1.3.8 Second use

Definition of parameter: This parameter evaluates the influence on the LCA results of considering a second use of the traction battery. Due to the increasing importance of second use in the context of zero-emission road transport, an in-depth analysis **should** be performed.

[63] IEA WEO region-specific datasets for STEPS are available for purchase for the following regions: North America, USA, Central & South America, Brazil, Europe, EU-27, Africa, Middle East, Eurasia, Russia, Asia Pacific, China, India, Japan, Southeast Asia, OECD, non-OECD, Emerging and developing economies.

[64] For Variable Renewable Energy (VRE) generators like solar photovoltaics (PV) and Wind, improved accuracy may be attained by adjusting the database processes to account for more accurate region-specific Capacity Factors (CF are defined as the ratio of the electricity actually delivered in a year [kWh] to the product of the nameplate installed power [kW_p] times the number of hours in a year).

Analysis type: The influence of this parameter on all mandatory LCIA impacts **should** be studied with a scenario analysis.

Analysis approach: This scenario analysis **should** be performed considering that the battery at its EoL is repurposed for use in stationary applications. Repurposing requires several processes, including battery collection, battery dismantling to module/cell level, SoH testing, and battery refurbishment. A critical parameter in this analysis is the percentage of battery cells suitable for second use. That percentage should be evaluated under both worst-case and best-case scenarios. For instance, Koroma *et al.*[65] assumed 50% of cells are reusable, with sensitivity testing covering a range from 10% to 100%. Cells deemed unsuitable for reuse will require replacement during refurbishment.

As presented in LCI part, the "cut-off approach" shall be applied by default in TranSensus-LCA to model the EoL of vehicles. According to this approach, the reusable battery is considered burden-free for the next application (see Figure *II-7*). In practice, this means that adding a second use for the battery is not reflected in the results, providing limited insights from such an analysis. To address this limitation, alternative approaches to default multifunctionality approach (cut-off) **may** be considered for the purpose of this analysis. In this context, the substitution approach **may** be used, assuming that the repurposed battery avoids the production of an equivalent battery, and the avoided emissions **may** be accounted for to evaluate the potential benefits of second use. The choice of an alternative approach to default multifunctionality and credits obtained for this analysis should be documented.

IV.1.4 Optional analysis of parameters

Parameters described in the following subsection **may** be subjected to part of an optional scenario analysis, uncertainty analysis and sensitivity analysis. If one or more of the parameters are important for the involved stakeholder with respect to their business, the parameters **may** be analysed in depth, further increasing the informative value and the needed effort of the LCA. The type of analysis to be applied to the optional parameters is left to the practitioner.

[65] Michael Samsu Koroma, Daniele Costa, Maeva Philippot, Giuseppe Cardellini, Md Sazzad Hosen, Thierry Coosemans, Maarten Messagie, Life cycle assessment of battery electric vehicles: Implications of future electricity mix and different battery end-of-life management, Science of The Total Environment, Volume 831, 2022, 154859, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.154859.

Table IV-5 : Summary of optional parameters.

Parameter	Explanation
Supply chain improvements: supplier choice	This parameter is linked to the decision of the OEM to change supplier(s) for some parts/ materials/ components. This analysis doesn't have to be performed on all suppliers along the value chain but only those deemed relevant by the LCA practitioner.
Location of the value chain: fuel mix, transport distance & means	This is another parameter linked to the location of the value chain and the different suppliers. Changing the location of suppliers or factories will affect the fuel mix, the transport distance and means between each step of the value chain. Once again, this analysis might not be relevant to perform on all suppliers/factories but only those deemed relevant to the LCA practitioner.
Process improvements (e.g., waste management, upstream recycling processes, packaging, on-site electricity production, fluids and consumables, materials consumption)	Example: What if the OEM decides to have on-site electricity production by installing solar panels on their factory? Sensitivity on the process improvements (e.g., waste management, upstream recycling processes, packaging, on-site electricity production, fluids and consumables, materials consumption) depending on the OEM strategic decisions.
Process improvements: energy consumption	This parameter covers process improvements and optimization regarding the energy consumption.
Circularity scenarios	Circularity scenarios may include factors such as car sharing, vehicle-to-grid, reuse, recycling, and second-life applications.

IV.2 Integration into the product development process with Prospective LCA

In view of the overall objective of TranSensus-LCA to pave the path towards an LCA-driven product development, a study has been performed to conceptualise how decision-making and frontloading processes can be implemented into the automotive product development processes. The goal is to enable engineers and managers according to their profile (industry, research and technology organisations, academia, policy, regulation, etc.) to select solutions and technologies (both existing and emerging) based on their environmental and social impacts, while balancing all other requirements.

TranSensus-LCA aims to develop a baseline for a European-wide harmonised, commonly accepted and applied single life cycle assessment approach for a zero-emission road transport system. The framework for the TranSensus-LCA process, including the assumptions, process steps, studies and reporting as shown on the left side of *Figure IV-3* have been developed and agreed by the project partners. One objective for TranSensus-LCA project is to assess how the LCA processes defined by the TranSensus-LCA framework can be effectively applied for frontloading and decision making within the product development process.

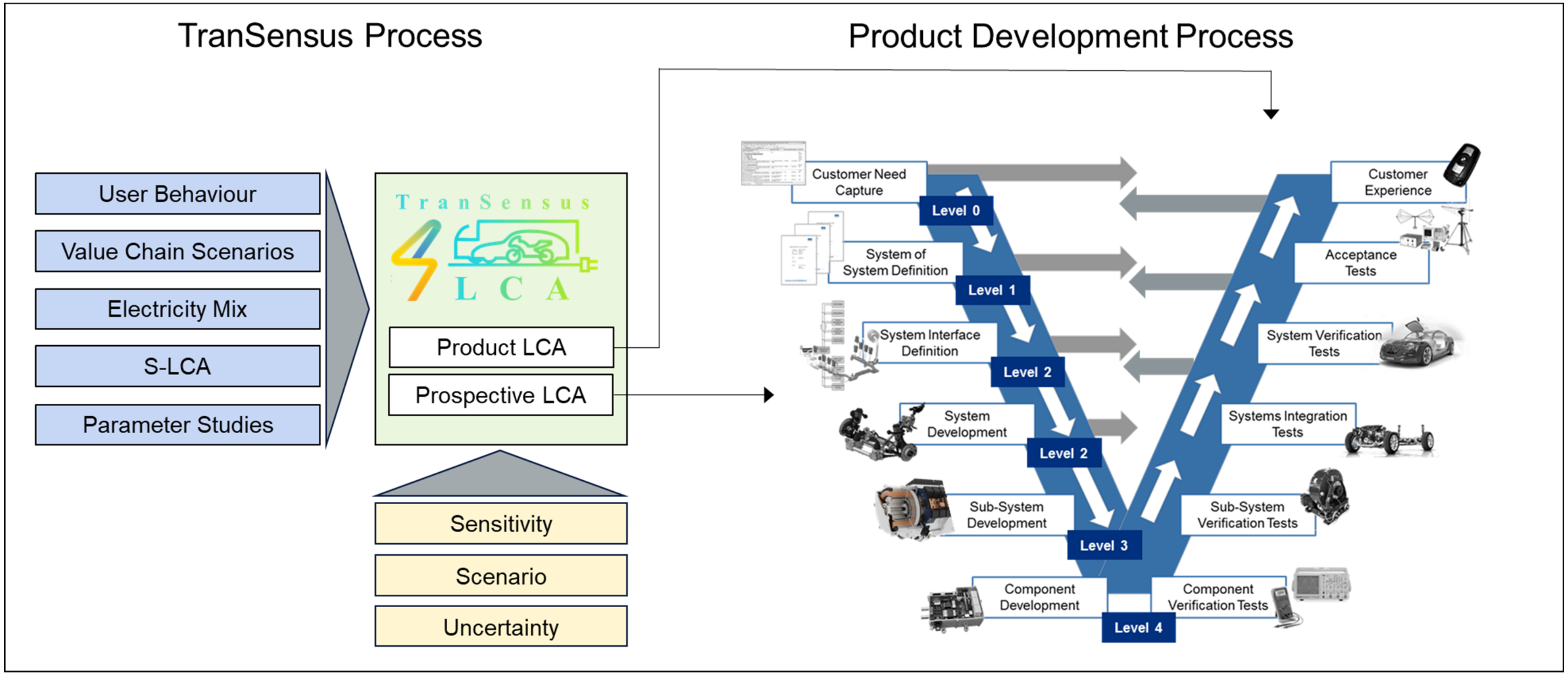

Figure IV-3 : Implementation of TranSensus-LCA Process in the Product Development Process

The product development process is shown on the right-hand side of Figure IV-3. The product development process is represented by a V-diagram which is a widely used representation used within systems engineering. The V-diagram is used in a simplistic form within ISO15288 where a generic lifecycle development model is used to describe the various engineering technical processes involved in a system engineering approach. The V-model is further developed and detailed within The International Council on Systems Engineering (INCOSE) Handbook. The representation shown within Figure IV-3 is a Ricardo automotive representation of the product development phases within this process.

The lifecycle model describes the product development process[66], including capturing the customer needs (Level 0) and requirements, the systems design process (Level 1 to 4), and the validation (right side of the V). Within the V-model, time travels on a left to right axis. The project therefore begins with collating the customer needs and project requirements before system and interface definition. On the left-hand side of the V there is an evolving baseline of approved status and consideration of new designs under progressive management. At any point in time, which would be represented by a vertical line along the left to right axis, the development team can shift their focus from the highest available viewpoint (the requirements) to the lowest level of detail available which progresses from systems, to sub-systems and components. Risk management is performed by addressing development options along this timeline. These decisions direct the selection of the technology, supplier, manufacturing options or designs to ensure the requirements can be achieved. It is important, therefore, for LCA to interface with the systems engineering process to include life cycle considerations and manage environmental risk.

On the right-hand side of the V, verification can identify problems and causes and also approval that the performance is acceptable. Information flows between the left-hand side and right-hand sides of the V, for example to show the requirements at each level and the validation status.

Finally, as shown on the figure, Product LCA as it is defined in TranSensus-LCA should actually be applied at the end of the illustrated product development process as it needs a nearly finalised bill of materials of all parts available. Prospective LCA, as defined in TranSensus-LCA, should be applied within the V to enable ecodesigned vehicles.

A study was performed by TranSensus-LCA with the partner OEM's and Tier 1 suppliers to identify common methods or best practice frontloading of prospective LCA within the product

[66] It is important to note that the product development process, as represented in Figure IV-3, is included in the systems engineering lifecycle but is not included within the boundaries of the TranSensus Life Cycle Analysis framework. Product development is specifically excluded from the boundary for vehicle LCA as impacts are likely to be very low versus other aspects of the lifecycle and harder to objectively quantify. For example, there are no agreed methods of how to spread development impacts consistently and objectively over the number of vehicles eventually manufactured.

development V-Model. The following frontloading LCA approach should be applied for the integration of environmental considerations into product development.

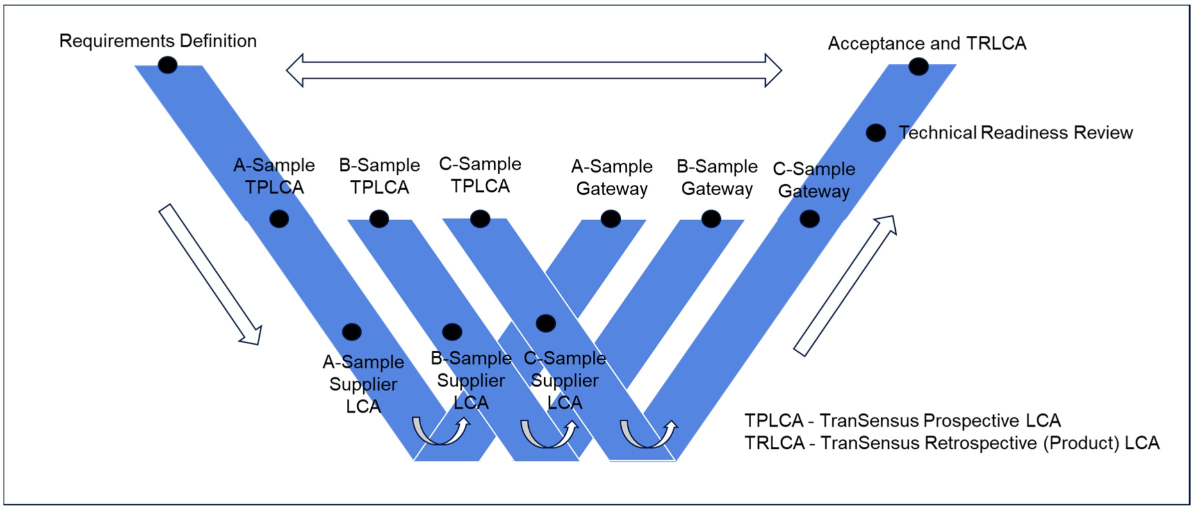

Figure IV-4 : TranSensus-LCA Calculations within Product Development Process

Prospective LCA should frontload support to the engineering development process of new vehicles and automotive components (adaptation from V-Model). In this adapted V-model, multiple staggered Vs are shown to represent the development phases and design freeze gateways typical in automotive development. There are three phases shown, nominally named as A-Sample, B-Sample and C-Sample. A-sample is the initial concept design with each subsequent phase increasing in the level of design maturity. The naming convention and number of phases may vary dependant on the OEM process or the project content. The LCA effort should be performed as early as practicably possible within the development process to support decision-making on technology, design and manufacturing choices from an environmental perspective. The LCA process should follow the recommended TranSensus framework for prospective LCA. The review and development of a harmonized process for Prospective LCA is included within the TranSensus project scope. This harmonized process will be developed and reported in other TranSensus-LCA deliverables (for example WP1 Review of Current Practices and WP2 Conceptualising LCA approach). LCA Models with a subset of key indicators can be used to provide early direction to the design and manufacturing teams within the OEM or Tier 1. These models should be updated and iterated as the design matures and more accurate input data is provided by suppliers and design teams. Best Practice is to iterate the LCA calculation at every major phase gateway. The results should used to assess suitability of the designs against the requirements at a product level and enable a “go” or “no-go” decision at each gateway based on the environmental performance.

IV.3 TSLCA Adherence statement

A product LCA **shall** claim two levels of **adherence** with TSLCA methodology (A or B). LCA practitioners using TSLCA **should** target profile A reporting requirements. But TSLCA also recognises discrepancies in usual information disclosed to the public, as well as variable external communication and legal rules that may prevent some of the previous information from being published by industrials. In this case, LCA practitioner **may** aim for profile B which will be reached by reporting a minimum set of information. Even when targeting profile B, TSLCA encourages LCA practitioner to disclose the maximum of information he or she is allowed, between minimum and mandatory ones, to contribute to TSCLA objectives.

Adherence levels **shall** be claimed in the following circumstances:

Adherence level A: Study shall be stated as carried out "following the full TranSensus-LCA methodology" if:

- All mandatory requirements from TSLCA (including those on supporting information to report) are followed, i.e., respectively:
  - Requirements with no choice possibilities → requirements strictly followed
  - Requirements with choices → choice shall be publicly reported with disclosed results, documentation and justifications shall be provided for verification.
- Recommended or optional requirements (including those on public reporting) may or may not be followed.

Adherence level B: Study shall be stated as carried out "following the TranSensus-LCA methodology, reporting excluded" if:

- All mandatory requirements from TSLCA (excluding those on supporting information to report) are followed, i.e., respectively:
  - Requirements with no choices possibilities → requirements strictly followed
  - Requirements with choices → choice shall be publicly reported with disclosed results, documentation and justifications shall be provided for verification.
- One (or more) mandatory requirements from TSLCA on public reporting are NOT followed.
- Recommended or optional requirements (including those on public reporting) may or may not be followed. Review comments on recommendations followed or not by the practitioner can be part of the verification report.

Note: public reporting stands as well for a public LCA report as for a public summary.

	A: Carried out following the **full** TSLCA methodology		**B**: Carried out following the TSLCA methodology, reporting excluded	
TSLCA methodology requirements	% of requirements satisfied		% of requirements satisfied	
	Mandatory requirements	Recommended or optional	**Mandatory** requirements	Recommended or optional
Goal and Scope	100%	0% to 100%	100%	0% to 100%
Life Cycle Inventory	100%	0% to 100%	100%	0% to 100%
Life Cycle Impact Assessment	100%	0% to 100%	100%	0% to 100%
Interpretation	100%	0% to 100%	100%	0% to 100%
Reporting	100%	0% to 100%	Bmin[67]< T< 100%	0% to 100%

Figure IV-5: *Description of two levels of adherence to TSLCA that can be claimed.*

("%" refers to % of TSLCA requirements that are strictly followed, and for which any methodological choices (where allowed) are made transparently and with justification)

Any other exception to mandatory requirements implies that the study shall not be claimed to follow previous level of adherence.

When profile A or B is not reached for the considered product LCA, the study **shall claim "using best practices from TranSensus-LCA methodology"** as long as it **cites** the methodology and it **provide the list** of best practices followed and/or deviations made at least in a public annex.

Textbox IV2: Prospective LCA, OEM-fleet LCA, Macro-fleet LCA - Adherence statement

Prospective LCA, OEM-fleet LCA, Macro-fleet LCA **shall claim "using best practices from TranSensus-LCA methodology"** as long as it **cites** the methodology and it **provides the list** of best practices followed and/or deviations made at least in a public annex.

IV.4 Result display and public reporting

To ensure understandability and indirect comparability of studies claiming following TranSensus-LCA, different types of information have to be reported:

[67] Bmin is the minium required for B adherence level. For each item, requirement or not for B adherence level is decribed in List of all reporting requirements

1. **Results** of the LCA study.
2. **Choices** made along the requirement application of TranSensus-LCA methodology
3. **Supporting information** to understand the results

IV.4.1 Results of the LCA study

TranSensus-LCA (TSLCA) methodology enables LCA practitioner to produce absolute value of impacts scaled to FU or other expression of absolute values, normalisation results, contribution analysis which identify sources of impacts (life cycle phase, parts, processes, substances), comparisons results, scenario, uncertainty and sensitivity analysis.

IV.4.2 Choices made along the requirement application of TranSensus-LCA methodology:

TranSensus-LCA methodology requires sometimes within requirements to conduct a choice among several approaches or allows to deviate from a default approach. 19 of the 56 mandatory requirements and 8 of the 52 recommended requirements are concerned. For example, the electricity modelling in the production stage requires a choice between location-based, 100% market-based or mixed modelling approach under certain conditions. These deviation allowances or choices induces variability in implementing the methodology and prevent direct comparisons between distinct studies. Transparency regarding these choices could maintain the possibility of indirect comparisons of results with limited variation in their framework. "Indirect comparison" meaning that these comparisons would need a supplementary step than with a direct one to normalize each framework of compared results to a chosen reference, enabling fair comparisons.

Below are some detailed explanations concerning what is meant by 'choice' for each one:

- Functional unit (FU): lifetime values
  - Choice between default or deviation allowed for other values for lifetime kilometre per segment for passenger car & LCV. Choice between segment basis or generic values. In addition, values chosen if they are different from default.
  - Choice between default or deviation allowed for other values for full-service lifetime in years per vehicle type. In addition, values chosen if they are different from default.
- System boundary: cut-off
  - Choice between default no intentional cut-off or deviation allowed for a cut-off approach of less than 3% impacts.

- Production stage modelling:
  - Data requirements for level 3
  - The list of parts (e.g. car body, rims) chosen to meet the 20% of supply chain GWP with tier-1 specific data besides the battery system. Detailed BOM is not expected here.
  - Electric energy supply
  - Choice between location based or 100% market-based or mixed modelling approach for electric energy supply of the production stage.
  - Regarding the use of safeguards for EACs, choice between hourly, monthly or yearly synchronization frequency for time consistency.
  - Choice between modelling residual mixes based on characteristics prescribed by co-ordinating entities or based on national mixes without renewables and nuclear.
  - Choice between hourly, monthly or yearly consumption proof for on-site electricity production processes.
- Use stage modelling
  - Energy requirements of vehicles
    - Choice to use OEM-specific data or default values from LDV CO_2 regulations or UNECE A-LCA or EC JRC' 2018 analysis for Real-World adjustment factors.
    - Choice between third-party verified OEM/supplier specific methodology or data with average operational power level or default values to calculate the degradation factor for fuel cell electric vehicles.
  - WTT - Electricity
    - Within dynamic modelling, choice of scenario selected for the future evolution of the electricity grid mix (official published, official based on current policy, STEPS from IEA or most recent "static" grid). Choice for the representative grid mix composition over the full-service life between arithmetic or weighted average.
    - Choice between "dynamic" modelling or "static" modelling.
  - WTT - Hydrogen
    - Choice of scenario selection for the future evolution of H2 supply (official published, official based on current policy, H2 from electrolysis with conservative future grid mix, with most recent "static" grid, or from steam reforming of natural gas and 100% renewables).

        - Choice for representative H2 supply mix composition over the full-service life, between arithmetic or weighted average.
    - Non-exhaust emissions - hydrogen leakage
        - Choice to use official governmental or supplier-specific or default estimates.
- End-of-life stage modelling
    - Choice of data between company-specific or generic secondary data.
- Multifunctionality problems
    - Approach for production and use stage
        - Multifunctionality choices based on the hierarchy (substitution/system expansion/economic/ physical allocation) for each multifunctional processes of the foreground system. A table format should be used. Details like allocation factor or economic value are not needed.
        - Choice to use global/regional market prices or processing costs or other factors as economic factor to calculation economic value for allocation.
    - Approach for end-of-life
        - Choice to use of market value determined or preset cut-off points for typical waste streams.
- Mandatory set of impacts categories - Hydrogen (H2) emission flow:
    - Choice between default approach or integration into GWP indicator. In the latter case, reference supporting it.
    - Choice between conducting a sensitivity analysis of the impact of H2 emissions on GWP of H2 fuelled ZEVs or direct integration into GWP indicator.

If not provided before, choice between default or supplier-specific estimates.

IV.4.3 Supporting information

In addition to results and choices in the implementation of TranSensus-LCA, additional supporting information of the LCA is expected to be publicly reported to ensure understandability and indirect comparability of studies claiming following TranSensus-LCA. Following subsections detail supporting information that shall, should or may be publicly reported by life cycle stage.

IV.4.4 List of all reporting requirements

Underneath table provides the list of all reporting requirements whether it is LCA results, choices within the methodology or supporting information that shall, should or may be publicly reported. Reference column contains the information of category of information to be reported between LCA result (Re), choice within TranSensus-LCA (Ch), supporting information (Si) detailed in previous subsections. Then, the reference provides the type of requirement between mandatory (M), recommended (R) and optional (O) with a following number corresponding to the order of appearance of the information in the category of information and type of requirement. Columns 'Minimum info to be publicly reported for 'A' adherence level to TranSensus-LCA' and ''Minimum info to be publicly reported for 'B' adherence level to TranSensus-LCA' list the minimum info to be publicly reported for 'A' or 'B' adherence level to TranSensus-LCA (info needed when there is a 'x').

Table IV-6: List of all reporting requirements

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
LCA typology	Confirmation of attributional LCI modelling approach	**M**	x	x	Supporting Information (Si)	Si-M1
LCA typology	Precise whether it is product/fleet/prospective LCA	**M**	x	x	Supporting Information (Si)	Si-M2
LCA typology	Standards/methodologies adhered to (i.e. ISO, level of adherence to TranSensus-LCA, UNECE Level (3) if applicable, etc.)	**M**	x	x	Supporting Information (Si)	Si-M3
Vehicle description	Vehicle's name	**M**	x	x	Supporting Information (Si)	Si-M4
Vehicle description	Vehicle's segment (according to internal practices)	**M**	x		Supporting Information (Si)	Si-M5
Vehicle description	Vehicle's manufacturer	**M**	x	x	Supporting Information (Si)	Si-M6
Vehicle description	Vehicle's make/model, year of production	**M**	x	x	Supporting Information (Si)	Si-M7

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Vehicle description	Vehicle's specific configuration(s)/options studied	**M**	x		Supporting Information (Si)	Si-M8
Vehicle description	Vehicle's size	**M**	x		Supporting Information (Si)	Si-M9
Vehicle description	Vehicle's mass: Gross Vehicle Weight (GVW) or DIN kerb weight or Technically Permissible Maximum Laden Mass (TPMLM) and unladen total vehicle mass (kg)	**M**	x		Supporting Information (Si)	Si-M10
Vehicle description	Vehicle's maximum number of passengers (number of seats), commercial vehicles' maximum payload	**M**	x		Supporting Information (Si)	Si-M11
Vehicle description	Vehicle's powertrain	**M**	x	x	Supporting Information (Si)	Si-M12
Vehicle description	Peak power rating	**M**	x		Supporting Information (Si)	Si-M13

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Vehicle description	Official certified energy consumption (according to WLTP for light vehicles and to VECTO for HDV)	**M**	x	x	Supporting Information (Si)	Si-M14
Vehicle description	For dual-fuel / REEV (Range-extended electric vehicle) powertrains : Electric or hydrogen range (according to WLTP for light vehicles and to VECTO for HDV)	**M**	x		Supporting Information (Si)	Si-M15
Vehicle description	For mono-fuel powertrains: Electric or hydrogen range (according to WLTP for light vehicles and to VECTO for HDV)	R			Supporting Information (Si)	Si-R1
Vehicle description	Battery capacity (gross or net)	**M**	x	x	Supporting Information (Si)	Si-M16
Vehicle description	Battery mass (pack kg) or Battery energy density (kWh/kg)	**M**	x		Supporting Information (Si)	Si-M17

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Vehicle description	Battery chemistry (at least 'NMC', 'LFP', etc, but ideally more specific).	**M**	x		Supporting Information (Si)	Si-M18
Vehicle description	Number of batteries in the vehicle and during lifetime	**M**	x		Supporting Information (Si)	Si-M19
Vehicle description	Fuel cell power rating (kW)	**M**	x		Supporting Information (Si)	Si-M20
Vehicle description	H2 storage capacity (kg H2)	**M**	x		Supporting Information (Si)	Si-M21
Vehicle description	H2 storage type (e.g. 700 bar compressed)	**M**	x		Supporting Information (Si)	Si-M22
Vehicle description	HDV: number of axles and wheels	**M**	x	x	Supporting Information (Si)	Si-M23
Vehicle description	Material Breakdown in % according to VDA material classes	**M**	x		Supporting Information (Si)	Si-M24
Functional unit (FU)	Clear statement of functional unit	**M**	x	x	Supporting Information (Si)	Si-M25

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Functional unit (FU)	Lifetime km per segment (Passenger car & LCV) - Choice: default or other valuers - segment basis or generic + value if different from default	**M**	x	x	Choice within TSLCA (Ch)	Ch-M1
Functional unit (FU)	Full-service lifetime in years per vehicle type - Choice: default or other values + value if different from default	**M**	x		Choice within TSLCA (Ch)	Ch-M2
Functional unit (FU)	Precision of passenger or freight loading assumption (ideally both in absolute units - i.e. #passengers or kg payload - and % capacity).	**M**	x		Supporting Information (Si)	Si-M26
System boundary	Confirmation of Cradle-to-grave	**M**	x	x	Supporting Information (Si)	Si-M27

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
System boundary	Simple system diagram or flowchart to illustrate, overview or a figure of the system boundary which also shows when e.g. second use or V2G are integrated (especially relevant for prospective LCA)	**M**	x		Supporting Information (Si)	Si-M28
System boundary	High-level description of inclusions and exclusions	**M**	x		Supporting Information (Si)	Si-M29
System boundary	Cut-off - Choice : default no intentional or <3% impacts cut-off	**M**	x		Choice within TSLCA (Ch)	Ch-M3

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Geographical considerations	Material extraction regions: geographical scope of supply chain modelling approach for most impacting materials (e.g. global average model or EU-sourcing mainly with some exceptions or specific sourcing)	**M**	x		Supporting Information (Si)	Si-M30
Geographical considerations	Key Components origin: geographical scope of supply chain modelling approach for most impacting key components (e.g. global average model or EU-sourcing mainly with some exceptions or specific sourcing)	**M**	x		Supporting Information (Si)	Si-M31

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Geographical considerations	Battery production: electrode manufacturing, cell assembly and pack assembly continent (Europe, Asia, North/south America, Africa, Oceania...) at least	**M**	x		Supporting Information (Si)	Si-M32
Geographical considerations	Location (country at least) of the vehicle production factory(ies)	**M**	x		Supporting Information (Si)	Si-M33
Geographical considerations	Use stage regions considered	**M**	x	x	Supporting Information (Si)	Si-M34
Geographical considerations	Geographical considerations for end-of-life	**M**	x		Supporting Information (Si)	Si-M35
Geographical considerations	Noting any particularity in European region: in-/ex-clusion of UK, CH…	**M**	x		Supporting Information (Si)	Si-M36
Geographical considerations	Noting any differences between different stages	O			Supporting Information (Si)	Si-O1
Third party verification	Third party verification: yes or no + verification statement publicly available	**M**	x	x	Supporting Information (Si)	Si-M37

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Third party verification	Organisation/individual verifier	**M**	x		Supporting Information (Si)	Si-M38
Third party verification	Validity period: date until when the LCA is valid	R			Supporting Information (Si)	Si-R2
General information on data	Database(s) used: name & version	**M**	x		Supporting Information (Si)	Si-M39
General information on data	Clear statement of important limitations	**M**	x		Supporting Information (Si)	Si-M40
General information on data	Short summary of where primary data (OEM's in-house production), supplier specific data (and which level tier 1 etc.) and generic data has been used	**M**	x		Supporting Information (Si)	Si-M41
General information on data	Statement of third-party review of data received (and according to which standard/guideline)	R			Supporting Information (Si)	Si-R3
General information on data	Software used: name & version	R			Supporting Information (Si)	Si-R4

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Production stage modelling	Data requirements for level 3 - Choice: List of parts (e.g. car body, rims) chosen to meet the 20% of supply chain GWP with tier-1 specific data besides the battery system* (detailed BOM is not asked for public reporting)	**M**	x		Choice within TSLCA (Ch)	Ch-M4
Production stage modelling	Electric energy supply - modelling approach - Choice: location based or 100% market-based or mixed modelling	**M**	x	x	Choice within TSLCA (Ch)	Ch-M5
Production stage modelling	Electric energy supply - safeguards employed if EACs use	**M**	x		Supporting Information (Si)	Si-M42

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Production stage modelling	Electric energy supply - safeguards for EACs use - time consistency - Choice: hourly, monthly or yearly synchronization frequency	**M**	x		Choice within TSLCA (Ch)	Ch-M6
Production stage modelling	Electric energy supply - guidance for residual mixes modelling - Choice: residual mixes characteristics prescribed by coordinating entities or national mixes without renewables and nuclear.	**M**	x		Choice within TSLCA (Ch)	Ch-M7
Production stage modelling	Electric energy supply - on-site electricity production processes - Choice: hourly or yearly consumption proof	**M**	x		Choice within TSLCA (Ch)	Ch-M8
Production stage modelling	Energy and electricity mixes datasets used	**M**	x		Supporting Information (Si)	Si-M43

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Production stage modelling	The name of the datasets used to model each product flow used in the model (i.e. feeding the foreground unit processes)	**M**	x		Supporting Information (Si)	Si-M44
Production stage modelling	Non-exhaustive list of components modelled with supplier-specific data (regarding recycled content and/or process inventory...)	R			Supporting Information (Si)	Si-R5
Production stage modelling	Description OR diagram of main/simplified steps of the vehicle production	R			Supporting Information (Si)	Si-R6
Production stage modelling	Summarised information on production locations and sites where specific data has been utilised	R			Supporting Information (Si)	Si-R7
Production stage modelling	Recycled content of the vehicle	R			Supporting Information (Si)	Si-R8

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Production stage modelling	More detailed list of components with main materials, weights, sources, geographical locations, production processes	O			Supporting Information (Si)	Si-O2
Use stage modelling	Energy requirements of vehicles - Real-World adjustment factors - Choice: OEM-specific data or default values from LDV CO2 regulations or UNECE A-LCA or EC JRC' 2018 analysis	**M**	x		Choice within TSLCA (Ch)	Ch-M9
Use stage modelling	Energy requirements of vehicles - degradation factor - Choice: third-party verified OEM/supplier specific methodology or data with average operational power level or default values	**M**	x		Choice within TSLCA (Ch)	Ch-M10

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Use stage modelling	Energy requirements of vehicles - Real world (RW) and efficiency degradation correction adjustment factor(s) where applied	**M**	x		Supporting Information (Si)	Si-M45
Use stage modelling	WTT - Electricity - general guidance - Choice: "dynamic" modelling or "static" modelling	**M**	x	x	Choice within TSLCA (Ch)	Ch-M11
Use stage modelling	WTT - Electricity - dynamic modelling - Choice: scenario selected for the future evolution of the electricity grid mix (official published, official based on current policy, STEPS from IEA or most recent "static" grid)	**M**	x	x	Choice within TSLCA (Ch)	Ch-M12

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Use stage modelling	WTT - Electricity - dynamic modelling - Choice: arithmetic or weighted average representative grid mix composition over the full-service life	**M**	x	x	Choice within TSLCA (Ch)	Ch-M13
Use stage modelling	WTT - Energy mix for use stage (including period used for average for dynamic mix, where used). Can be high-level (e.g. 'Renewable'/'Nuclear'/'Fossil' share) if need to protect detail from paid sources (e.g. IEA or EU-27 electricity grid mix with X kg CO_2/kWh)	**M**	x		Supporting Information (Si)	Si-M46

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Use stage modelling	WTT - Hydrogen - general guidance - Choice: scenario selection for the future evolution of H2 supply (official published, official based on current policy, H2 from electrolysis with conservative future grid mix,with most recent "static" grid, or from steam reforming of natural gas and 100% renewables)	**M**	x	x	Choice within TSLCA (Ch)	Ch-M14
Use stage modelling	WTT - Hydrogen - representative H2 supply mix composition over the full-service life - Choice: arithmetic or weighted average	**M**	x	x	Choice within TSLCA (Ch)	Ch-M15
Use stage modelling	WTT - Hydrogen mix/origin	**M**	x		Supporting Information (Si)	Si-M47
Use stage modelling	Non-exhaust emissions - Summary of emissions included	**M**	x		Supporting Information (Si)	Si-M48

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for 'A' adherence level to TranSensus-LCA	Minimum info to be publicly reported for 'B' adherence level to TranSensus-LCA	Information type	Reference
Use stage modelling	Non-exhaust emissions - hydrogen leakage - Choice: official governmental or supplier-specific or default estimates	M	x	x	Choice within TSLCA (Ch)	Ch-M16
Use stage modelling	Maintenance - justification if deviation from minimum required by TSLCA	M	x		Supporting Information (Si)	Si-M49
Use stage modelling	Maintenance - More detailed list of Consumable and maintenance parts assumptions (e.g. consumables/part replacement frequency/# per lifetime)	O			Supporting Information (Si)	Si-O3
Use stage modelling	Maintenance - battery/fuel cell replacement and lifetime calculation method	R			Supporting Information (Si)	Si-R9
Use stage modelling	Thermal management of the vehicle: use of external heater, refrigerated truck?,…	O			Supporting Information (Si)	Si-O4

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
End-of-life stage modelling	Brief description of EoL modelling approach	**M**	x	x	Supporting Information (Si)	Si-M50
End-of-life stage modelling	Brief description of modelled EoL processes	**M**	x		Supporting Information (Si)	Si-M51
End-of-life stage modelling	Data - Choice: company-specific or generic secondary data	**M**	x	x	Choice within TSLCA (Ch)	Ch-M17
End-of-life stage modelling	Electric energy supply for EoL - Energy mix for End-of-life stage	**M**	x		Supporting Information (Si)	Si-M52
End-of-life stage modelling	Overall recycling efficiency of EoL modeled	R			Supporting Information (Si)	Si-R10
End-of-life stage modelling	Yield of each process modeled in EoL value chain	R			Supporting Information (Si)	Si-R11

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Multifunctionality problems	Approach for production and use stage - Description of the multifunctionality processes (i.e. naming the MF processes encountered in the foreground system, no need to describe the solutions in background databases)	**M**	x		Supporting Information (Si)	Si-M53

Topic	Information to be publicly reported	Type of re-quirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Multifunctionality problems	Approach for production and use stage - Choice:- The multifunctionality choices based on the hierarchy (substitution/system expan-sion/economic/ physical allocation) for each multifunctional processes reported above in the foreground system (table format recom-mended, no need of details like allocation fac-tor or economic value, justification of choice can only documented for verification) - Use of global/regional market prices or processing costs or other factors as economic factor to cal-culation economic value for allocation	**M**	x		Choice within TSLCA (Ch)	Ch-M18
Multifunctionality problems	Approach for end-of-life - Choice: use of mar-ket value determined or preset cut-off points for typical waste streams	**M**	x		Choice within TSLCA (Ch)	Ch-M19

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Multifunctionality problems	End-of-life stage modelling - Statement of respect of TSLCA for EoL modeling and cut-off point	R			Supporting Information (Si)	Si-R12
Multifunctionality problems	End-of-life stage modelling - confirmation of verification of complete system in case of recycling was done	O			Supporting Information (Si)	Si-O5
DQR	Summary of data quality assessment results according to TSLCA recommendations	**M**	x		Supporting Information (Si)	Si-M54
LCIA General information	Impact assessment method name, version and year	**M**	x	x	Supporting Information (Si)	Si-M55
LCIA General information	List of impact categories reported, name and source	**M**	x	x	Supporting Information (Si)	Si-M56
Mandataroy set of impacts categories	Hydrogen (H2) emission flow- Choice: default approach or integration into GWP indicator and reference supporting it	**M**	x	x	Choice within TSLCA (Ch)	Ch-M20

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Mandataroy set of impacts categories	Hydrogen (H2) emission flow - Choice: Sensitivity analysis of the impact of H2 emissions on GWP of H2 fuelled ZEVs or direct integration	**M**	x	x	Choice within TSLCA (Ch)	Ch-M21
Mandataroy set of impacts categories	Hydrogen (H2) emission flow- Choice: Default or supplier-specific estimates	**M**	x	x	Choice within TSLCA (Ch)	Ch-M22
Absolute value of impacts scaled to FU	Absolute value of results for all TSLCA mandatory impacts	**M**	x	x	LCA results (Re)	Re-M1
Absolute value of impacts scaled to FU	Absolute value of results for TSLCA optional impacts that only shows significance in normalisation (if conducted)	R			LCA results (Re)	Re-R1
Absolute value of impacts scaled to FU	Absolute value of results for optional EF impacts (not mandatory ones)	R			LCA results (Re)	Re-R2
Absolute value of impacts scaled to FU	Absolute value of results for all TSLCA optional impacts	O			LCA results (Re)	Re-O1

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Normalization	Confirmation of planetary boundaries NF used if normalised results are shown	**M**	x		Supporting Information (Si)	Si-M57
Normalization	Normalization results	O			LCA results (Re)	Re-O2
Other expression of absolute values	Absolute values of a selection of impacts scaled to lifetime	R			LCA results (Re)	Re-R3
Other expression of absolute values	Absolute values of a selection of impacts on the Cradle-to-gate perimeter for 1 vehicle	R			LCA results (Re)	Re-R4
Contribution analysis	Cradle-to-gate and gate-to-grave contribution to mandatory impacts results	**M**	x		LCA results (Re)	Re-M2
Contribution analysis	Life cycle stages contribution to mandatory impacts results (4 stages if possible: raw materials acquisition, production, use, end-of-life)	**M**	x		LCA results (Re)	Re-M3

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Contribution analysis	Main hotspots by life cycle stage contribution to mandatory impacts results (like battery+electricity for production, electricity/H2 for use, air emissions for EoL)	**M**	x		LCA results (Re)	Re-M4
Comparisons	With previous models	O			LCA results (Re)	Re-O3
Comparisons	With other powertrains (owned studies)	O			LCA results (Re)	Re-O4
Comparisons	With other vehicles (not owned studies)	O			LCA results (Re)	Re-O5
Scenario (Sc.) analysis, uncertainty (u.) analysis and sensitivity (s.) analysis	Brief description of type and parameters studied through sensitivity, scenario and uncertainty analysis.	**M**	x		Supporting Information (Si)	Si-M58
Sc., u. and s. analysis	Qualitative summary of influence of all mandatory parameters on mandatory impact results	**M**	x		LCA results (Re)	Re-M5

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Sc., u. and s. analysis	Variability (quantification expected) induced by all mandatory parameters on all mandatory impact results	**M**	x		LCA results (Re)	Re-M6
Sc., u. and s. analysis	Qualitative summary of influence of all mandatory parameters on relevant optional impact results	R			LCA results (Re)	Re-R5
Sc., u. and s. analysis	Variability (quantification expected) induced by all mandatory parameters on relevant optional impact results	R			LCA results (Re)	Re-R6
Methodology checks	Summary about completeness and consistency checks	R			Supporting Information (Si)	Si-R13
Methodology checks	% of mandatory TSLCA requirement satisfied (100% if TLSA adherence profile A, can be detailed by LCA step)	O			Supporting Information (Si)	Si-O6

Topic	Information to be publicly reported	Type of requirement	Minimum info to be publicly reported for **'A' adherence level** to TranSensus-LCA	Minimum info to be publicly reported for **'B' adherence level** to TranSensus-LCA	Information type	Reference
Methodology checks	% of recommended topics followed (0%= LCA results are following TLSA with or without minimum reporting, 100% = extremely complete study/report)	O			Supporting Information (Si)	Si-O7

IV.5 Verification process

Following verification process **shall** be implemented to ensure studies referring to TranSensus-LCA methodology accurately follow its requirements:

- Level 3 or 4 (UNECE) product LCA **shall** conduct a 3rd party verification. The ISO 14040/44 type and format for the extensive reporting needed by the verification shall be followed. A checklist shall be included for 3rd party verification according to previous principles of TSLCA adherence.
- Level 1 or 2 (UNECE) product LCA **should** conduct a 1st or 2nd party verification (Catena-X definition).

Following table from UNECE details possible comparisons, vehicle and manufacturing modelling, representativeness required for each level. Underneath definitions of 1st, 2nd and 3rd party (Catena-X, adaptation from ISO 17029[68]) shall be used:

- 1st party: Personnel from the same, i.e. supplier organization/company.
- 2nd party: Personnel from an organization/company that is customer of the first party.
- 3rd party: Personnel from an organization/company that is neither supplier, customer nor competitor.

Textbox IV-3: Prospective LCA, OEM-fleet LCA, Macro-fleet LCA - Verification process

Prospective LCA, OEM's and macro-fleet LCA **may** also implement 1st, 2nd or 3rd party verification to validate their effort in following the methodology.

[68] https://catenax-ev.github.io/docs/next/non-functional/overview

Table IV-7: Level concept as proposed by the UNECE working group and as adopted by TranSensus-LCA (see SG4 - 3nd meeting - Transport - Vehicle Regulations - UNECE Wiki)

SUPPLY CHAIN & PRODUCTION	Possible Comparison[1]	Vehicle modelling	Representativeness[2]	Supply chain modelling	OEM manufacturing Processes	Supplier manufacturing process	Individual decarbonisation measures
Level 1	General concept of drivetrains (e.g. BEV vs. ICEV)	Generic material composition & average vehicle curb weight	Global average / regional	generic footprint per kg of vehicle curb weight			none
Level 2	General concept of drivetrains (e.g. BEV vs. ICEV) based on exemplary „real" car vehicle model	BOM & Material information system (CMDS / IMDS[3])	Global average / regional	global secondary data material footprints (incl. generic information for production processes)			none
Level 3	A representative vehicle of OEM A VS A representative vehicle of OEM B	BOM & Material information system (CMDS / IMDS) & „part-by-part" for hotspots	Regional & individual SC for hotspots	primary information for the vehicle hotspot parts secondary information for the rest	Optional: primary data for OEM's inhouse hot spot processes Secondary information for the rest or average values per vehicle from OEM's Scope 1 & 2 emissions	primary information for the manufacturing of vehicle hotspot parts secondary information for the rest	included
Level 4	e.g. OEM A's BEV model vs. OEM B's BEV model	BOM („part-by-part")	individual SC	regional or primary data based part (& material) footprints	included	included	included

IV.6 Summary of all TranSensus-LCA requirements (for E-LCA)

Below is the table **summarizing all TranSensus-LCA requirements**.

Table IV-8: List of TranSensus-LCA requirements

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
Number	Phase of LCA	Topic	Requirement	Type	Deviation allowance		Reference
1	Goal & scope	Goal definition	LCA types	I			I1
2	Goal & scope	Technology coverage	List of powertrains	I			I2
3	Goal & scope	Technology coverage	List of vehicle types	I			I3
4	Goal & scope	Functional unit	Functional units according to vehicle types	**M**			M1
5	Goal & scope	Functional unit	Default lifetime km per segment (Passenger car & LCV)	**M**✓	Process to justify other values Segmentation deviation allowed for OEMs	(D&J)	M2
6	Goal & scope	Functional unit	Default lifetime km per segment (HDV)	**M**			M3
7	Goal & scope	Functional unit	Default lifetime km per segment (two-wheelers)	**M**			M4
8	Goal & scope	Functional unit	Default full-service lifetime in years per vehicle type	**M**✓	Other values allowed if documented & justified	(D&J)	M5
9	Goal & scope	Functional unit	Deviations for Prospective LCA	R		D&J	R1
10	Goal & scope	Functional unit	Deviations for Macro-fleet LCA	R		D&J	R2
11	Goal & scope	System boundary	Cradle-to-grave	**M**			M6

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
12	Goal & scope	System boundary	List of default processes to include and exclude	M			M7
13	Goal & scope	System boundary	Default Cut-off	M✓	If <3% of impacts & screening LCA documented	(D)	M8
14	Goal & scope	System boundary	Deviations for Prospective LCA	R		D&J	R3
15	Goal & scope	System boundary	Deviations for Macro-fleet LCA	R		D&J	R4
16	Goal & scope	OEM fleet LCA	Passenger cars	R		D&J	R5
17	Goal & scope	OEM fleet LCA	HDV	R✓	Adaptation allowed if justified and documented	D&J	R6
18	Goal & scope	OEM fleet LCA	Two-wheelers	R✓	Adaptation allowed if justified and documented	D&J	R7
19	LCI	Production stage modelling	Data requirements for level 3	M✓	- Allowance to choose which parts to model with company-specific data with an iterative approach. - H2 storage vessel (FCEV, FC-REEV, H2-ICEV) may be treated similarly to batteries	D&J	M9
20	LCI	Production stage modelling	Electric energy supply - time consistency	M		D&J	M10
21	LCI	Production stage modelling	Electric energy supply - modelling approach choice	M✓	For industries wanting to use their EACs	(D&J)	M11
22	LCI	Production stage modelling	Electric energy supply - same modelling approach for comparative LCAs	M			M12

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (**R**), Optional (**O**) or Informational (I)		Documentation for verification	
23	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA - general approach	R		D&J	R8
24	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA - Use of PREMISE to model future electricity mixes	O		D&J	O1
25	LCI	Production stage modelling	Electric energy supply - follow all safeguards for EACs use	**M**			M13
26	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - additionality	**M**		D&J	M14
27	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - geographical consistency	**M**		D&J	M15
28	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - time consistency	**M**✓	Synchronization frequency	D&J	M16
29	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - excess of production	**M**		D&J	M17
30	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - others	**M**		D&J	M18
31	LCI	Production stage modelling	Electric energy supply - every safeguards for EACs use -	R			R9

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (R), Optional (**O**) or Informational ( )		Documentation for verification	
			verification by practitioner along its LCA				
32	LCI	Production stage modelling	Electric energy supply - guidance for residual mixes modelling	**M**✓	Use of national mixes without renewables nor nuclear Best possible manner according to available ressources	D&J	M19
33	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA of guidance for residual mixes modelling	R		D&J	R10
34	LCI	Production stage modelling	Electric energy supply - on-site electricity production processes	**M**✓	Frequency basis of the consumption proof	D&J	M20
35	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA for on-site electricity production processes	R		D&J	R11
36	LCI	Use stage modelling	Energy requirements of vehicles - default approach	**M**	Other cycles to estimate energy consumption allowed in additional sensitivity analysis		M21
37	LCI	Use stage modelling	Energy requirements of vehicles - Real-World adjustment factors	**M**✓	Allowance for LDVs to choose between 3 prioritised approaches according to data availability		M22
38	LCI	Use stage modelling	Energy requirements of vehicles - degradation factor	**M**✓	Allowance to use OEM/supplier-specific data/approach for fuel cell durability assumption		M23

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (**R**), Optional (**O**) or Informational (I)		Documentation for verification	
39	LCI	Use stage modelling	WTT - Electricity - general guidance	**M**✓	Dynamic modelling: - allowance to choose between 3 prioritised scenario selection for the future evolution of the electricity grid mix - allowance to most recent "static" grid mix composition compared to 100% renewable if no availability in the geographical region of interest - weighted average representative grid mix composition over the full-service life if vehicle's use intensity change over time General approach: Use of a more conservative "static" modelling approach allowed for OEM	D&J	M24
40	LCI	Use stage modelling	WTT - Electricity - same modelling approach for comparative LCAs	**M**			M25
41	LCI	Use stage modelling	WTT - Electricity - deviation for prospective LCA - general guidance	R✓	General approach: deviation from specific average grid mix based on Product LCA approach allowed if there is a hypothesis of use of PPAs	D&J	R12
42	LCI	Use stage modelling	WTT - Electricity - deviation for prospective LCA - Use of	O			O2

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (R), Optional (**O**) or Informational (I)		Documentation for verification	
			PREMISE to model future electricity mixes				
43	LCI	Use stage modelling	WTT - Electricity - on-site electricity production processes excluded	**M**			M26
44	LCI	Use stage modelling	WTT - Electricity - on-site electricity production processes - deviation for both fleet Level LCA types	R✓	Frequency basis of the consumption proof	D&J	R13
45	LCI	Use stage modelling	WTT - Electricity - on-site electricity production processes - deviation for prospective LCA	R		D&J	R14
46	LCI	Use stage modelling	WTT - Hydrogen - general guidance	**M**✓	- allowance to choose betwen 4 prioritized scenario selection for the future evolution of H2 supply - allowance to use a H2 produced with natural gaz compared to low-carbon H2 if no availability in the geographical region of interest - weighted average representative hydrogen supply over the full-service life if vehicle's use intensity change over time		M27

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
47	LCI	Use stage modelling	Non-exhaust emissions - hydrogen leakage	M✓	Allowance to use default H2 supply chain emission rates in the absence of official governmental or supplier-specific information		M28
48	LCI	Use stage modelling	Non-exhaust emissions - refrigerant with GWP≥150kgCO2eq/kg	M		D	M29
49	LCI	Use stage modelling	Non-exhaust emissions - refrigerant with GWP<150kgCO2eq/kg	O		D	O3
50	LCI	Use stage modelling	Non-exhaust emissions - tyres and Brake wearing	M	Allowance to other data than EMEP if justified	D&J	M30
51	LCI	Use stage modelling	Maintenance - mandatory items to include	M	Allowance to exclude if no replacement needed	J	M31
52	LCI	Use stage modelling	Maintenance - recommended items to include	R			R15
53	LCI	Use stage modelling	Maintenance - mandatory items to include - battery or fuel cell replacement calculation method	R✓	- Allowance to use a simplified methodology with a sensitivity analysis if data for default methodology is not available - Allowance to use default values in the absence of manufacturer-specific data on the battery cycle life	D&J	R16
54	LCI	End-of-life stage modelling	Data choices - company-specific data	M✓	Allowance to use secondary generic data if EoL processes are outside the control of the LCA study		M32

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
55	LCI	End-of-life stage modelling	Electric energy supply for EoL - general guidance	**M**		D&J	M33
56	LCI	End-of-life stage modelling	Electric energy supply for EoL - deviation for prospective LCA	R✓	General approach: deviation from specific average grid mix based on use phase approach allowed if there is a hypothesis of use of PPAs	D&J	R17
57	LCI	End-of-life stage modelling	Electric energy supply for EoL - use of PREMISE to model future electricity mixes	O			O4
58	LCI	End-of-life stage modelling	Electric energy supply for EoL - on-site electricity production excluded	**M**			M34
59	LCI	Multifunctionality problems	Three-step approach to identify multifunctionality problems	R			R18

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
60	LCI	Multifunctionality problems	Approach for production and use stage	M✓	- System expansion allowed if subdivision impossible or ineffective- Substitution allowed if just one of the functional flows is assessed- Allocation allowed if at least one condition to implement substitution is not satisfied- use of processing costs or other factors as economic factor to calculation economic value for allocation if global/regional market prices are unavailable.- physical relationship based allocation if economic value ration ≤ 4 and relevant	D&J	M35
61	LCI	Multifunctionality problems	Approach for production and use stage - deviation for both fleet-level LCA	R			R19
62	LCI	Multifunctionality problems	Approach for production and use stage - deviation for prospective LCA	O			O5
63	LCI	Multifunctionality problems	Approach for end-of-life	M✓	use a preset cut-off points for typical waste streams in case market value is hard to determine		M36
64	LCI	Multifunctionality problems	Approach for end-of-life - deviation for prospective LCA	R			R20

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (**R**), Optional (**O**) or Informational (I)		Documentation for verification	
65	LCI	Multifunctionality problems	Approach for end-of-life - deviation for both fleet-level LCA	R			R21
66	LCI	Data quality rating (DQR)	Conduct a data quality assessment	**M**			M37
67	LCI	Data quality rating (DQR)	Apply same DQR method as background database	R			R22
68	LCIA	Mandataroy impact categories	Climate change, total	**M**			M38
69	LCIA	Mandataroy impact categories	Photochemical ozone formation, human health	**M**			M39
70	LCIA	Mandataroy impact categories	Acidification	**M**			M40
71	LCIA	Mandataroy impact categories	Particulate matter	**M**			M41
72	LCIA	Mandataroy impact categories	Eutrophication, freshwater	**M**			M42
73	LCIA	Mandataroy impact categories	Cumulative Energy Demand	**M**			M43
74	LCIA	Mandataroy impact categories	Resource use, minerals and metals	**M**			M44
75	LCIA	Mandataroy impact categories	Hydrogen (H2) emission flow	**M**✓	until a formalised GWP is available according to IPCC/within the EF method		M45
76	LCIA	Mandataroy impact categories	Default estimated H2 supply chain emission rates	**M**✓	supplier-specific information available		M46

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
77	LCIA	Mandataroy impact categories	Sensitivity analysis of the impact of H2 emissions on GWP of H2 fuelled ZEVs	M✓	until a formalised GWP is available according to IPCC/within the EF method		M47
78	LCIA	Optional Impact Categories	Ozone depletion	O			O6
79	LCIA	Optional Impact Categories	Human toxicity, cancer	O			O7
80	LCIA	Optional Impact Categories	Human toxicity, non-cancer	O			O8
81	LCIA	Optional Impact Categories	Ionising radiation, human health	O			O9
82	LCIA	Optional Impact Categories	Eutrophication, terrestrial	O			O10
83	LCIA	Optional Impact Categories	Eutrophication, marine	O			O11
84	LCIA	Optional Impact Categories	Ecotoxicity, freshwater	O			O12
85	LCIA	Optional Impact Categories	Land use	O			O13
86	LCIA	Optional Impact Categories	Water use	O			O14
87	LCIA	Optional Impact Categories	Criticality	O			O15
88	LCIA	Optional Impact Categories	Dissipation	O			O16
89	LCIA	Optional Impact Categories	Biodiversity indicators not recommended	R✓	Robust indicator available		R23

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (R), Optional (**O**) or Informational (I)		Documentation for verification	
90	LCIA	Optional Impact Categories	Circularity indicators not recommended	R✓	Robust indicator available		R24
91	LCIA	Normalisation	Normalisation	O			O17
92	LCIA	Normalisation	Global Planetary Boundary based normalization factors	R			R25
93	LCIA	Normalisation	Normalized values reported after midpoints values	R			R26
94	Interpretation	Scenario (Sc.) analysis, uncertainty (u.) analysis and sensitivity (s.) analysis	Definition of scenario, sensitivity and uncertainty analysis	I			I4
95	Interpretation	Sc., u. and s. analysis	Deviations for Prospective LCA and fleet LCA	O			O18
96	Interpretation	Sc., u. and s. analysis	List of parameters to analyse with the type of requirement (mandatory, recommended or optional)	I			I5
97	Interpretation	Mandatory analysis of parameters	Summary of manadatory parameter with mandatory type of analysis	I			I6
98	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Usage: consumption"	**M**			M48
99	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Usage: consumption"	R			R27
100	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Quantity value"	**M**			M49

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
101	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Quantity value"	R	Fixed LCI values may be excluded if justified	(J)	R28
102	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Usage: vehicle lifetime"	**M**		D	M50
103	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Usage: vehicle lifetime"	R			R29
104	Interpretation	Mandatory analysis of parameters	Scenario analysis of "Usage: variation of energy mix consumption"	**M**			M51
105	Interpretation	Mandatory analysis of parameters	Approach for the scenario analysis of "Usage: variation of energy mix consumption"	R		D&J	R30
106	Interpretation	Mandatory analysis of parameters	Future electricity/H2 mix for the use stage	**M**			M52
107	Interpretation	Mandatory analysis of parameters	Approach for the scenario analysis of "Future electricity/H2 mix for the use stage "	R			R31
108	Interpretation	Recommended analysis of parameters	Summary of recommended parameter with recommended type of analysis	I			I7
109	Interpretation	Recommended analysis of parameters	Sensitivity analysis of "Choice of secondary data"	R			R32
110	Interpretation	Recommended analysis of parameters	Approach for the sensitivity analysis of "Choice of secondary data"	R	Data availability	J	R33

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational ( )		Documentation for verification	
111	Interpretation	Recommended analysis of parameters	Scenario analysis of "Location of the value chain: electricity mix"	R			R34
112	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Location of the value chain: electricity mix"	R	Hotspots LCI flows modelled with supplier-specific data may be excluded	J	R35
113	Interpretation	Recommended analysis of parameters	Scenario analysis of "Supply chain modifications: recycled vs primary materials"	R			R36
114	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Supply chain modifications: recycled vs primary materials"	R		D&J	R37
115	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: maintenance & wearing"	R			R38
116	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Usage: maintenance & wearing"	R	Data availability		R39
117	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: payload or number of passengers"	R			R40
118	Interpretation	Recommended analysis of parameters	Minimal approach for the scenario analysis of "Usage: payload or number of passengers"	R			R41
119	Interpretation	Recommended analysis of parameters	Advanced approach for the scenario analysis of "Usage:	O	Data availability		O19

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
			payload or number of passengers"				
120	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: temperature"	R			R42
121	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Usage: temperature"	R		D	R43
122	Interpretation	Recommended analysis of parameters	Scenario analysis of "Future mix: EoL electricity mix"	R			R44
123	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Future mix: EoL electricity mix"	R			R45
124	Interpretation	Recommended analysis of parameters	Scenario analysis of "Second use"	R			R46
125	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Second use"	R	Alternatives to cut-off approach allowed		R47
126	Interpretation	Optional analysis of parameters	Summary of recommended parameter with recommended type of analysis	I	Approach left open to practitioner		I8
127	Interpretation	Integration into the product development process with Prospective LCA	Frontloading LCA approach	R			R48
128	Interpretation	Result display and public reporting	Public reporting of results of the LCA study (Re-M1to Re-M6 of reporting list)	**M**	Deviation allowed for Adherence level B if indicated in the Table		M53

				Type of requirement: (✓) choice required Mandatory (**M**), Recommended (**R**), Optional (**O**) or Informational ( )		Documentation for verification	
					'List of all reporting requirements'. More information allowed		
129	Interpretation	Result display and public reporting	Recommended results of the LCA study to report publicly (Re-R1 to Re-R6 of reporting list)	R			R49
130	Interpretation	Result display and public reporting	Optional results of the LCA study to report publicly (Re-O1 to Re-O5 of reporting list)	O			O20
131	Interpretation	Result display and public reporting	Public reporting of mandatory choices along TSLCA application (Ch-M1 to Ch-M22 of reporting list)	**M**	Deviation allowed for Adherence level B if indicated in the Table 'List of all reporting requirements'. More information allowed		M54
132	Interpretation	Result display and public reporting	Public reporting of justification and documentation of mandatory choices along TSLCA application to be report publicly (Ch-M1 to Ch-M22 of reporting list)	O			O21
133	Interpretation	Result display and public reporting	Justification and documentation of mandatory choices along TSLCA application provided to the verifier (Ch-M1 to Ch-M22 of reporting list)	**M**			M55

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
134	Interpretation	Result display and public reporting	Public reporting of recommended choices along TSLCA application	R			R50
135	Interpretation	Result display and public reporting	Public reporting of mandatory supporting information per LCA phase (Si-M1 to Si-M58 of reporting list)	**M**	Deviation allowed for Adherence level B if indicated in the Table 'List of all reporting requirements'. More information allowed		M56
136	Interpretation	Result display and public reporting	Public reporting of recommended supporting information per LCA phase (Si-R1 to Si-R13 of reporting list)	R			R51
137	Interpretation	Result display and public reporting	Public reporting of optional supporting information per LCA phase (Si-O1 to Si-O7 of reporting list)	O			O22
138	Interpretation	Adherence to TSLCA	Adherence levels to target	R			R52
139	Interpretation	Adherence to TSLCA	Conditions to claim adherence levels for Product LCA	**M**			M57
140	Interpretation	Adherence to TSLCA	Adherence statement for prospective and fleet LCA	R			R53
141	Interpretation	Verification process	3rd party verification for Level 3 or 4 (UNECE) product LCA	**M**			M58
142	Interpretation	Verification process	1st or 2nd party verification for Level 1 or 2 (UNECE) product LCA	R			R54

				Type of requirement: (✓) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
143	Interpretation	Verification process	Verification process for prospective and fleet LCA	O			O23

Part B: Social LCA

The TranSensus-LCA project aims to develop a harmonized, European-wide approach for life cycle assessment (LCA) of zero-emission vehicles (ZEVs). As part of this initiative, the project incorporates Social Life Cycle Assessment (S-LCA) framework, which forms a crucial building block in evaluating the social and socio-economic impacts of ZEVs throughout their lifecycle. The S-LCA guidelines for the TranSensus-LCA project are structured around four phases, such as those of LCA specifically tailored for zero-emission vehicles, as described in the following subsections. The mindmap below summarizes all TranSensus-LCA requirements for S-LCA.

Textbox IV-4: [Product S-LCA - Deviation]

Prospective S-LCA and Fleet S-LCA are out of scope in the discussions of TranSensus-LCA

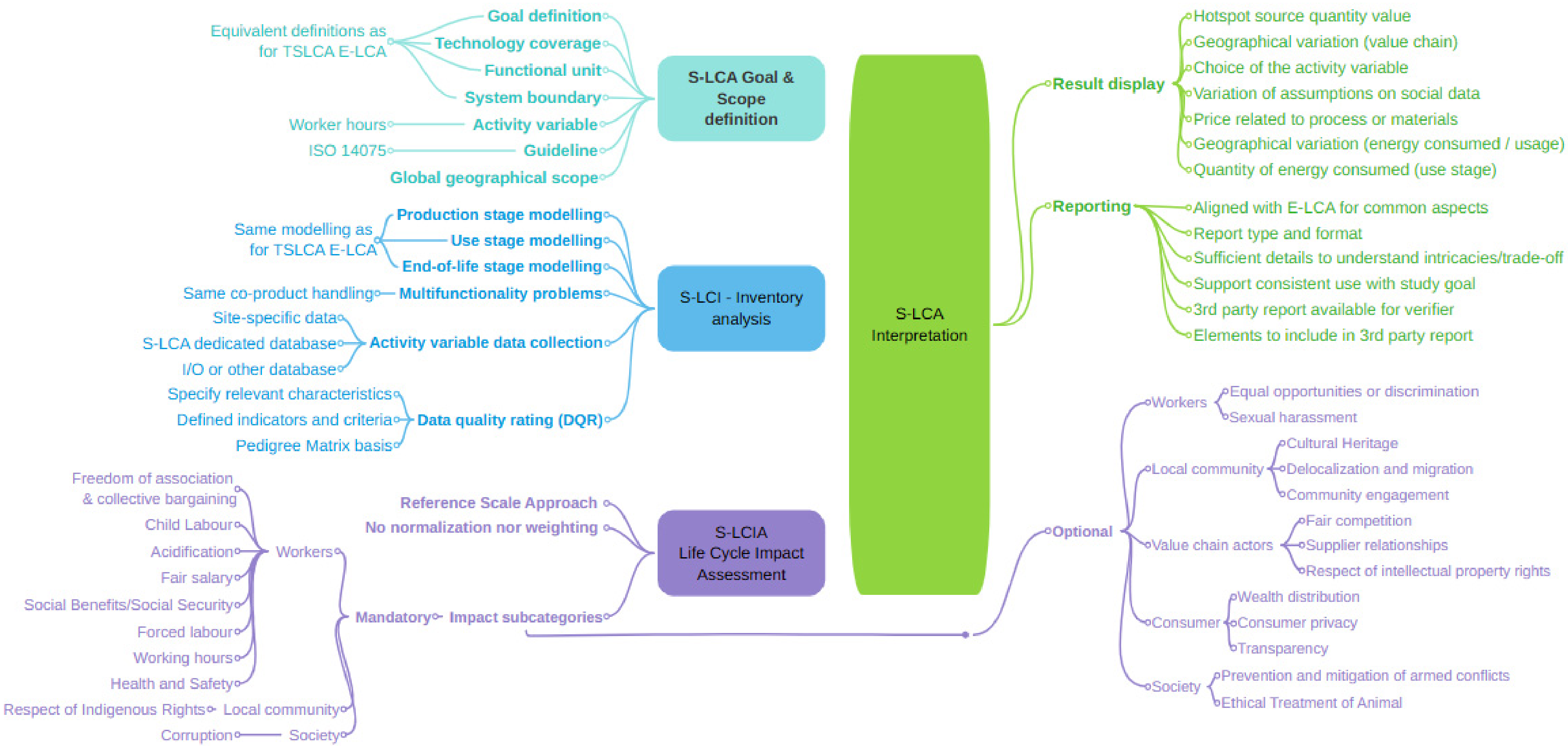

Figure IV-6 : Requirements of TranSensus-LCA for Social-LCA in a form of a mindmap.

V. S-LCA Goal and scope

In this first phase, the objectives of the S-LCA for ZEVs are clearly defined. This includes determining the Application of S-LCA, Activity Variable, Standard/Guideline followed, Geographical Scope, Product System Boundaries, and Functional Units, relevant to ZEVs. The S-LCI and S-LCIA phases (described in chapters VI and VII) will address other aspects than the Goal and Scope, such as Data collection sources, Data Quality Evaluation, Impact Assessment Methodology, Stakeholder Category, Impact Subcategory and Indicator selection.

The definitions listed in the Goal and Scope of LCA (subsection I.1) for the Goal, Functional Unit, System Boundary, and Technology Coverage, should be used for S-LCA. These definitions must be comparable to or equivalent to those in LCA to create consistency between both methodologies.

Other attributes in the Goal and Scope phase, such as the Application of S-LCA, Activity Variable, Regulations, Standards and guidelines followed, and Geographical Coverage are all independently decided for S-LCA.

Application of S-LCA studies related to ZEVs can be the following:

- Assessing Social Performance or Social Risk.
- Decision making.
- Identification of social hotspots.
- Enhancing sustainability reporting.
- Comparing alternatives.
- Supply chain management.
- Policy development and regulations.
- Worker Hours should be used as **activity variable** for S-LCA studies following TranSensus-LCA methodology. Adopting worker hours as an activity variable provides advantages, but it also has disadvantages. Consequently, any future changes made to the Activity Variable for use in S-LCA studies should be followed.
- TranSensus-LCA developed the foundational elements of TranSensus S-LCA primarily by adhering to the United Nations Environment Programme's Guidelines for Social Life Cycle Assessment of Products and Organisations, 2020. However, where accessible, ISO 14075, the standard that addresses "Principles and framework for social life cycle assessment," should be used as the standard or guideline to carry out S-LCA for ZEVs.
- A Global **geographic scope** for the S-LCA studies should be chosen. For ZEVs in Europe, the S-LCA geographical scope should be formulated as global rather than European for

several significant reasons, including supply chain complexity, sourcing of raw materials, manufacturing considerations, comprehensive impact assessment, and stakeholder inclusivity.

VI. Social Life Cycle Inventory (S-LCI) Analysis

This phase involves collecting and organizing data on social and socio-economic aspects related to ZEVs. It mainly includes gathering information for different Stakeholder categories, Impact sub-categories, all the Inputs and Outputs related to the system boundary of ZEVs, and data to apply the Activity Variable.

The main aspects of S-LCI discussed in this chapter are the Collection of data to create the reference scales, Multifunctionality, Database & Software, Data for activity variable, Collection of data for the different stakeholder categories and the different subcategories and Data Quality Assessment.

Production stage modelling (subsection II.1), Use stage modelling (subsection II.2), End of life stage modelling (subsection II.3), as described in LCI chapter II., should be followed.

VI.1 Collection of data to create the Reference Scales (RS)

The reference scales established by PSILCA and SHDB, which they use in their databases, should be followed.

To establish a reference scale for ZEVs, it is crucial to have a comprehensive understanding of both international and national regulations, standards, and norms pertinent to the countries participating in the entire ZEV value chain, spanning from the extraction of raw materials to the product's end-of-life stage. This understanding serves as the foundation to conduct a social life cycle impact assessment using the RS methodology. RSs are case-specific. Therefore, their development is not in the scope of TranSensus-LCA. In the future, however, product or sector-specific RS should be used, whenever available.

VI.2 Multifunctionality

Sometimes a system under study produces many co-products or serves multiple purposes. It could be required to narrow the system limits or only assign a portion of the social consequences to this product when evaluating the social and socio-economic effects of just one of these items. Due to the nature and scope of social data, this is not always necessary or simple. Allocation and partitioning in S-LCA are sometimes not relevant.

Co-products for S-LCA may be handled by following the procedures outlined in the Multifunctionality Problems of LCA (see subsection II.5).

VI.3 Data for activity variable stakeholders and impact subcategory

To define worker hours as the activity variable for S-LCA, several types of data are required. Firstly, modelling data is necessary to ensure that the assessment captures the entire life cycle and provides quantitative metrics that can assist when justifying the study boundaries and scoping choices. Secondly, social impact data is necessary to evaluate the social impacts associated with each stage of the life cycle, for example, the working conditions of the employees. The Social Hotspots Database (SHDB) and the Product Social Impact Life Cycle Assessment (PSILCA) database are examples of databases that provide social impact data. Finally, working time data is necessary to calculate the worker hours for each process in the life cycle. Worker hours are selected for all indicators, and this variable determines the working time (in hours) required to produce the reference product. Both PSILCA and SHDB also use worker hours as the activity variable. Therefore, to define worker hours as the activity variable for S-LCA, modelling data, social impact data, and working time data are required.

Three approaches should be followed by TranSensus-LCA to collect activity variables data:

1. Through site-specific data collection;
2. Use of a S-LCA dedicated database (SHDB or PSILCA);
3. Through input-output or other databases

VI.4 Data Quality Assessment

Certain relevant characteristics of data quality, such as timeliness, geographical or technological compliance of the datasets with the activity, etc., may be specified to evaluate the quality of the data obtained itself. The defined indicators and criteria, such as reliability, timeliness, geographic match, completeness and technical conformance, may be rated by ordinal evaluation rules, with scores from 1 to 5 corresponding to a qualitative assessment of the data. This contributes to a structured evaluation of the quality of both the measurement methods and the collected data.

TranSensus-LCA recommends using the Pedigree Matrix based on Guidelines for social life cycle assessment of products and organisations 2020 for Data Quality Assessment.

VII. Social Life Cycle Impact Assessment

The third phase focuses on translating the inventory data into meaningful **social impact categories**. For ZEVs, this may include assessing impacts on

- Job creation in new green technologies,
- Changes in community structures due to shifts in the automotive industry,
- Potential human rights issues in the supply chain of critical ZEV components.

VII.1 Calculation of S-LCIA results

Social life cycle impact assessment systematically categorizes and aggregates S-LCI data to quantify its contributions to each **social impact subcategory**. Impact assessment method builds the social relationship between S-LCI data and the category indicator of each Impact Subcategory. Each Impact Subcategory is linked to a unique characterization model for the Impact Pathway Approach and unique reference scales in the Reference Scale Approach. The TranSensus-LCA selection of social impact subcategories and its indicators is comprehensive, encompassing a wide range of relevant issues within the product's supply chain. TranSensus-LCA experts analysed a list of existing S-LCA **stakeholder categories**, **impact subcategories** and **indicators**, and then evaluated the relevance of each for zero ZEVs S-LCA. This selection of impact subcategories has been performed following consecutive steps of filtration such as materiality assessment following policy documents, frameworks, and TranSensus participants associated with ZEVs, Identifying the relevant Impact Sub-Categories from the Sustainability Assessment Questionnaire from Drive Sustainability, and Matching Impact Subcategories with those in PSILCA and SHDB. Impact Subcategories that passed the filtration steps are defined as mandatory while others are listed as optional Impact Subcategories. More details are provided in the Annex.

Similarly, the indicators for each mandatory Impact Subcategories were selected following the methodology involving a Multi-Criteria Decision Analysis (MCDA) that evaluated each indicator based on four criteria: i) achievability; ii) feasibility; iii) ease of interpretation, and; iv) relevance. Each criterion was then scored on a scale from 0 to 3. More details are provided in the Annex.

The tables below provide a Mandatory and Optional list of impact subcategories. For a TranSensus followed S-LCA study, all impact subcategories that are listed in mandatory impact categories **shall** be calculated using related assessment method, without exclusion.

VII.1.1 Mandatory set of Impact Subcategories

The goal of this subtask is to define the mandatory set of Stakeholder Categories, Impact subcategories, and its indicators for S- LCIA for TranSensus-LCA. The list of mandatory social impact subcategory, given in **Table *VII-1***, **shall** be used.

Table VII-1: Mandatory social impact subcategory list from TranSensus-LCA

Stakeholder Category	Mandatory Impact Subcategory	Impact Subcategory Indicator	Unit	Reference Scale Model	Source/Database
Worker	Freedom of association and collective bargaining	Right of Association, Right of Collective bargaining, Right to strike	4-point scale	3 = no risk: 2 = low risk: 1 = high risk: 0 = very high risk: no data	PSILCA
	Child Labour	Children in employment, total	% of all children ages 7-14	0% = no risk: 0%-<2.5% = very low risk: 2.5%-<5% = low risk: 5%-<10% = medium risk: 10%-<20% = high risk: >=20% = very high risk: n.a. = no data	PSILCA
	Fair salary	Minimum wage, per month and Living wage, per month	USD	Data for LW (Living-Wage) is available: LW-MW (Minimum-Wage) -ratio>=1.2 OR ratio>=1 and MW<300USD = very high risk: ratio=1-<1.2 and MW>=300USD OR ratio=0.8-<1 and MW<300USD = high risk: ratio=0.8-<1 = medium risk and MW>300USD: ratio=0.5-<0.8 = low risk: ratio<0.5 = very low risk	PSILCA
	Social Benefits /Social Security	Social security expenditures	% of GDP	0-2.5 = very high risk: >2.5-7.5 = high risk: >7.5-15% = medium risk: >15-20% = low risk: >20% = very low risk: n.a. = no data	PSILCA
	Forced Labour	Overall country sector risk forced labour and Forced labour risk (Global Slavery Index)	%	1.5 = very low risk: 3.1: 3.3 and 3.4 = medium risk: 4.0 = high risk: 4.2 = very high risk: n.a. = no data	PSILCA

Stakeholder Category	Mandatory Impact Subcategory	Impact Subcategory Indicator	Unit	Reference Scale Model	Source/Database
	Working Hours	Weekly hours of work per employee	hr	40 - <48 = low risk: 30 - <40 and 48 - <55 = medium risk: 20 - <30 and 55 - <60 = high risk: <20 and >60 = very high risk: n.a.= no data	PSILCA
	Health and Safety	Rate of fatal accidents at workplace and Rate of non-fatal accidents at workplace	number/yr and 100 000 employees	0-<7.5 = very low risk: 7.5-<15 = low risk: 15-<25 = medium risk: 25-<40 = high risk: >40 = very high risk: no data	PSILCA
Local Community	Respect of Indigenous Rights	Presence of indigenous population	Y/N	0 = no = no risk: 1 = yes = medium risk	PSILCA
Society	Corruption	Corruption Perception Index (CPI)	Semi -quantitative Indicator	80-100 = very low risk (low perceived corruption); 60-<80 = low risk; 40-<60 = medium risk; 20-<40 = high risk; 0-<20 = very high risk (high perceived corruption)	Social Hotspots Database

Note: If the database listed in the table above is unavailable, select equivalent indicators from another database that is available.

VII.1.2 Optional set of Impact Subcategories

The goal of this subtask is to select and recommend an **optional set of Impact subcategories**, for S-LCIA for TranSensus-LCA. Table VII-2 includes the selected optional impact subcategories that should be used. In this project, the specific impact subcategory indicators were not predefined; however, examples of relevant social indicators can be found in established sources such as the PSILCA database, the Social Hotspots Database (SHDB), and the UNEP Guidelines for Social Life Cycle Assessment of Products and Organizations. These sources provide a foundation of widely recognized indicators.

Table VII-2: Optional impact subcategory list from TranSensus-LCA.

Stakeholder Category	Optional Impact Subcategory
Worker	Equal opportunities/discrimination
	Sexual harassment
Local community	Cultural Heritage
	Delocalization and migration
	Community engagement
Value chain actors	Fair competition
	Supplier relationships
	Respect of intellectual property rights
	Wealth distribution
Consumer	Health and safety
	Consumer privacy
	Transparency
Society	Prevention and mitigation of armed conflicts
	Ethical Treatment of Animal

VII.1.3 General Guidance on Reference Scale Approach

The most used Reference Scale Approach (RS S-LCIA) should be used for Hotspot Analysis/Risk/Performance Assessment. For those that base their assessments on the PSILCA and SHDB databases, reference scales can be utilized as indicated. However, the Impact Pathway approach may be used in the future, as diverse social impact's qualitative or quantitative pathways are established. Normalisation or weighting factors should not be applied in S-LCA.

VIII. Social Life Cycle Interpretation

The final phase involves analysing the results, identifying significant issues, and drawing conclusions. For ZEVs, this might include comparing the social impacts of different zero-emission technologies, evaluating the social sustainability of the transition to electric mobility, and providing recommendations for improving social performance in the ZEV life cycle. By integrating these S-LCA guidelines into the broader TranSensus-LCA framework, the project aims to provide a comprehensive assessment tool that considers not only environmental but also social aspects of zero-emission vehicles. This holistic approach will enable stakeholders to make more informed decisions in the development and implementation of sustainable transport solutions.

VIII.1 Results display

The TranSensus-LCA project developed a set of S-LCA interpretation parameters that should be used. This set is provided in the following table:

Table VIII-1 : Recommended interpretation parameters

Recommended S-LCA Interpretation Parameters
Quantity value for certain components/materials/flows leading to hotspots
Geographical variation of the value chain
Choice of the activity variable (e.g. working hour vs. value added)
Variation of assumptions on social data
Price related to process or materials
Geographical variation of the energy consumed (electricity mix or H2 mix) during usage
Quantity of energy consumed during the use stage

VIII.2 Reporting

S-LCA reporting **shall** be aligned with LCA reporting regarding common aspects (e.g FU or MF). S-LCA reporting **shall** also follow underneath recommendations for the rest:

The type and format of the report **shall** be determined during the scope phase of the study.

The S-LCA results and findings must be completely and accurately conveyed without bias to the intended audience.

The conclusions, data, techniques, assumptions, and limitations **shall** be transparent and provided with sufficient detail for the reader to understand the intricacies and trade-offs inherent in the S-LCA.

The report **shall** also allow the results and interpretation to be used in a manner consistent with the goals of the study. It can be helpful to include a graphical representation of the S-LCI and S-LCIA data in the report, but keep in mind that doing so encourages inferred inferences and comparisons.

Study documentation that includes confidential data that is not always included in the third-party report may serve as the basis for the third-party report. Therefore, the third-party report is referred to a document and **shall** be made available to any third party to whom the communication is made.

The following elements **shall** be included in the third-party report:

- General aspects:
  - Any modifications to the Goal and scope aspects, proposed in TranSensus together with their justification;
  - S-LCA commissioner and practitioner of S-LCA
  - date of report;
  - statement that the study has been conducted in accordance with the requirements of TranSensus LCA approach.
- Goal of the study:
  - reasons for carrying out the study;
  - its intended applications;
  - the target audiences;
  - statement as to whether the study intends to support social comparative assertions intended to be disclosed to the public.
- Scope of the study:
  - function, including:
    - statement of performance characteristics;
    - any omission of additional functions in comparisons;
  - functional unit, including:
    - consistency with other goal and scope aspects;
    - functional unit definition;
  - system boundary, including:
    - omissions of life cycle stages, processes or data needs;
    - quantification of energy and material inputs and outputs;
    - assumptions about electricity production;

- type of inputs and outputs of the system as elementary flows;
- decision criteria;
- cut-off criteria for initial inclusion of inputs and output, including:
  - description of cut-off criteria and assumptions;
  - effect of selection on results;
  - inclusion of mass, energy and environmental cut-off criteria.

- Social life cycle inventory analysis:
  - data collection procedures;
  - qualitative and quantitative description of unit processes;
  - sources of published literature;
  - calculation procedures;
  - validation of data, including:
    - data quality assessment;
    - treatment of missing data;
  - sensitivity analysis for refining the system boundary;
  - allocation principles and procedures, including:
    - documentation and justification of allocation procedures;
    - uniform application of allocation procedures.
  - Reference scale assessment, where applicable:
    - the reference scale assessment procedures, calculations and results of the study;
    - limitations and relationship of the reference scale assessment results relative to the defined goal and scope of the S-LCA;
    - the relationship of the reference scale assessment results to the S-LCI results,
  - impact categories/impact subcategories and category indicators considered, based on TranSensus, justify for any deviations
  - descriptions and reference to all value-choices used in relation to impact categories, weighting and, elsewhere in the, a justification for their use and their influence on the results, conclusions and recommendations;
  - a statement that the reference scale assessment results are relative expressions and do not predict impacts on category end points, the exceeding of thresholds, safety margins or risks; and, when included as a part of the S-LCA, also:
  - a description and justification of the definition and description of any new impact categories, category indicators used for the reference scale assessment;
  - a statement and justification of any grouping of the impact categories;

- any further procedures that transform the category indicator results and a justification of the selected references, weighting factors, normalisation factors etc.;
- any analysis of the category indicator results, for example sensitivity and uncertainty analysis or the use of social data, including any implication for the results;
- data and category indicator results reached prior to any normalisation, grouping or weighting shall be made available together with the normalized, grouped or weighted results.

- Social Life cycle impact assessment (Impact pathway Approach), where applicable:
  - the S-LCIA procedures, calculations and results of the study;
  - limitations and relationships of the S-LCIA results relative to the defined goal and scope of the S-LCA and S-LCI results;
  - impact categories/impact subcategories and category indicators considered, based on TranSensus, justify for any deviations
  - descriptions and reference to all characterization models, characterization factors and methods used, including all assumptions and limitations;
  - a statement that the S-LCIA results are relative expressions and do not predict impacts on category end points, the exceeding of thresholds, safety margins or risks; and, when included as a part of the S-LCA, also:
  - a description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the S-LCIA;
  - a statement and justification of any grouping of the impact categories;
  - any further procedures that transform the category indicator results and a justification of the selected references, weighting factors, normalisation factors etc.;
  - any analysis of the category indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results;
  - data and category indicator results reached prior to any normalisation, grouping or weighting shall be made available together with the normalized, grouped or weighted results.
- Life cycle interpretation:
  - the results;
  - assumptions and limitations associated with the interpretation of results, both methodology and data related;
  - full transparency in terms of value-choices, rationales and expert judgements.
- Critical review, where applicable:

- name and affiliation of reviewers;
- critical review reports;
- responses to recommendations.

VIII.3 Summary of TranSensus requirements for S-LCA

Table VIII-2: List of TranSensus-LCA requirements for S-LCA

				Type of requirement: (ü) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
Number	Phase of LCA	Topic	Requirement	Type	Deviation allowance		Reference
144	S-LCA	General	Conduct a S-LCA	R			R55
145	S-LCA Goal & Scope	LCA type	Prospective and fleet LCA out of S-LCA scope of TSLCA	R			R56
146	S-LCA Goal & Scope	Definitions	Comparable or equivalent definitions as for TSLCA E-LCA for Goal & Scope, Functional unit, System Boundary and Technology coverage	R			R57
147	S-LCA Goal & Scope	Activity variable	Worker hours	R			R58
148	S-LCA Goal & Scope	Guideline	ISO 14075	R	when accessible		R59
149	S-LCA Goal & Scope	Geographical scope	Global geographical scope	R			R60
150	S-LCI	Modelling	Same production phase modelling, use stage modelling, EoL stage modelling as for TSLCA E-LCA	R			R61
151	S-LCI	Reference scales	Reference scales established by PSILCA and SHBD. In the future: product or sector-specific reference scale	R			R62

				Type of requirement: (ü) choice required Mandatory (**M**), Recommended (**R**), Optional (**O**) or Informational (I)		Documentation for verification	
152	S-LCI	Multifunctionality	Co-products to be handled with the same TSLCA procedure as for E-LCA	R			R63
153	S-LCI	Data collection	3 approaches to collect Activity variable data: - through site-specific data collection - use of S-LCA dedicated database (SHDB or PSILCA) - through input-output or other databases	R			R64
154	S-LCI	DQR	Specify certain relevant characteristics of data quality to evaluate the quality of data obtained	O			O24
155	S-LCI	DQR	Rating of the defined indicators and criteria	O			O25
156	S-LCI	DQR	Pedigree Matrix based on Guidelines for S-LCA of products and organisation 2020	R			R65
157	S-LCIA	Mandatory Impact subcategory	Workers / Freedom of association and collective bargaining	**M**			M59
158	S-LCIA	Mandatory Impact subcategory	Workers / Child Labour	**M**			M60

				Type of requirement: (ü) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
159	S-LCIA	Mandatory Impact sub-category	Workers / Fair salary	**M**			M61
160	S-LCIA	Mandatory Impact sub-category	Workers / Social Benefits /Social Security	**M**			M62
161	S-LCIA	Mandatory Impact sub-category	Workers / Forced Labour	**M**			M63
162	S-LCIA	Mandatory Impact sub-category	Workers / Working Hours	**M**			M64
163	S-LCIA	Mandatory Impact sub-category	Workers / Health and Safety	**M**			M65
164	S-LCIA	Mandatory Impact sub-category	Local community / Respect of Indigenous Rights	**M**			M66
165	S-LCIA	Mandatory Impact sub-category	Society / Corruption	**M**			M67
166	S-LCIA	Optional Impact sub-categories	Workers / Equal opportunities/discrimination	R			R66
167	S-LCIA	Optional Impact sub-categories	Workers / Sexual harassment	R			R67
168	S-LCIA	Optional Impact sub-categories	Local community / Cultural Heritage	R			R68
169	S-LCIA	Optional Impact sub-categories	Local community / Delocalization and migration	R			R69
170	S-LCIA	Optional Impact sub-categories	Local community / Community engagement	R			R70
171	S-LCIA	Optional Impact sub-categories	Value chain actors / Fair competition	R			R71

				Type of requirement: (ü) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
172	S-LCIA	Optional Impact sub-categories	Value chain actors / Supplier relationships	R			R72
173	S-LCIA	Optional Impact sub-categories	Value chain actors / Respect of intellectual property rights	R			R73
174	S-LCIA	Optional Impact sub-categories	Value chain actors / Wealth distribution	R			R74
175	S-LCIA	Optional Impact sub-categories	Consumer / Health and safety	R			R75
176	S-LCIA	Optional Impact sub-categories	Consumer / Consumer privacy	R			R76
177	S-LCIA	Optional Impact sub-categories	Consumer / Transparency	R			R77
178	S-LCIA	Optional Impact sub-categories	Society / Prevention and mitigation of armed conflicts	R			R78
179	S-LCIA	Optional Impact sub-categories	Society / Ethical Treatment of Animal	R			R79
180	S-LCIA	Reference Scale Approach	Most used Reference Scale Approach.	R	Reference scale indicated in PSILCA and SHDB. In the future, impact pathway approach may be used.		R80
181	S-LCIA	Normalization and weighting	Not to be applied	R			R81
182	S-LCA Interpretation	Results display	Quantity value for certain components/materials/flows leading to hotspots	R			R82

				Type of requirement: (ü) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
183	S-LCA Interpretation	Results display	Geographical variation of the value chain	R			R83
184	S-LCA Interpretation	Results display	Choice of the activity variable (e.g. working hour vs. value added)	R			R84
185	S-LCA Interpretation	Results display	Variation of assumptions on social data	R			R85
186	S-LCA Interpretation	Results display	Price related to process or materials	R			R86
187	S-LCA Interpretation	Results display	Geographical variation of the energy consumed (electricity mix or H2 mix) during usage	R			R87
188	S-LCA Interpretation	Results display	Quantity of energy consumed during the use phase	R			R88
189	S-LCA Interpretation	Reporting	Reporting aligned with E-LCA reporting for common aspects (eg FU or MF or mandatory impacts results...)	**M**			M68
190	S-LCA Interpretation	Reporting	Report type and format determined during the Scope phase of the study	**M**			M69
191	S-LCA Interpretation	Reporting	Conclusions, data, techniques, assumptions and limitations transparent and provided with sufficient details	**M**			M70

				Type of requirement: (ü) choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification	
			for the reader to understand the intricacies and trade-offs				
192	S-LCA Interpretation	Reporting	Published results and interpretation supports their use in a manner that is consistent with the goal of the study	**M**			M71
193	S-LCA Interpretation	Reporting	A thrid-party report made available to the verifier	**M**			M72
194	S-LCA Interpretation	Reporting	Elements to include to third party report	**M**			M73

Summary and Conclusion

This report is deliverable D2.3 "Final harmonised approach" of the TranSensus-LCA project. It delivers a robust, transparent, commonly accepted and applied single life cycle assessment approach for zero emission vehicle, including environmental and social aspects. This work is in the continuity of previous deliverable D2.2 that presented an initial description of the building blocks of this recommended approach. To reach such harmonised methodology, the work has been integrated in a consensus process including votes and feedback of associated partners.

The TranSensus-LCA methodology proposed in this document consists in more than 137 requirements (56 mandatories) and covers all phases of life cycle assessment for zero emission vehicle. This methodology has been developed for product LCA and gives guidelines and rules for a prospective LCA as well as OEM and macro fleet LCA.

This conceptualised approach will be tested in WP2 through task T2.6 "Feasibility & applicability", validated within WP3 and presented in deliverable D3.3 "Definition of test cases and results".

The WP5 will structure TranSensus-LCA guidance document based on this deliverable D2.3 "final harmonised approach".

> This report describes the mandatory, recommended and optional requirements that build the harmonised, robust, transparent, commonly accepted and applied single life cycle assessment approach for zero emission road transport system, including environmental and social aspects.

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Annex

Towards a European-wide harmonised transport-specific LCA Approach

TranSensus LCA

Coordinated and Support Action (CSA)

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TranSensus-LCA methodology

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EXECUTIVE SUMMARY

Zero tailpipe emissions vehicles (ZEVs) are a promising option for more sustainable mobility services. Action needs to be taken in Europe and globally to foster more sustainable road transportation prioritizing climate-neutrality targets. To this end, decision-making processes need to be informed via robust methodologies to evaluate and monitor sustainability performance. Life cycle-based methodologies, such as Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), are the logical choice as these can provide a holistic sustainability perspective. LCA, S-LCA, and LCC are increasingly used within policy making, industry, and science to obtain sustainability information related to products, services, or technologies, as well as systems on a larger scale, including that of ZEVs. However, not all methods are equally mature (e.g. S-LCA being a newer method) and all methods include a number of choices that can lead to variations in results. Currently, there is not enough harmonization on these choices, which leads to variations in results, **hinders the comparability of studies, and limits the usefulness of the methods for guiding decision makers.**

TranSensus-LCA project aims at developing a consensus methodology for environmental LCA of ZEVs as a first priority, but aims also at casting light on similar issues in **S-LCA**. The consortium includes influential European academic and industrial partners in the mobility field. This report stands for **Deliverable 2.3** of the TranSensus-LCA project. It delivers a **Final harmonised approach** to enable fair comparison of LCAs of Zero-emission vehicles.

The development of this methodology relies on **a scientific and democratic approach within WP2**, divided according to ISO 14040 LCA framework based on intermediate deliverable D2.2 on *Initial description of the building blocks of a recommended approach.* Discussions on practices, scientific alternatives and methodologies enabled to provide requirements or a limited number of alternatives to address each treated topic. Project beneficiaries and associated partners voted to select recommendations or options prepared by the TranSensus-LCA working groups. Methodology documented in this deliverable concerns E- (environmental) and S- (social) LCAs of existing **product LCA** as well as **prospective** and **fleet LCA.** It gathers **137 methodological requirements (56 of which being mandatories) on E-LCA.**

A main document describes the different requirements, mandatory to optional, covering all aspects of (S)-LCA: goal & scope, inventory, impact assessment, interpretation and reporting. The annex document provides complementary information to help LCA practitioner to better apply TranSensus-LCA methodology and gives more details regarding the way recommendations were built. This methodology is currently being tested to validate its feasibility (T2.6) and success in regard with the project's objectives (T3.3). Future work will

EXECUTIVE SUMMARY
integrate wider consensus with advisory boards, consensus liaison group and plan its implementation into a roadmap. It will also be formatted into a guidance document (D5.2).

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Introduction

Structure of Deliverable

This deliverable is composed of 2 documents:

- A **main document,** which presents all requirements for all life cycle stages where the reader will find needed information to apply TranSensus-LCA methodology for ZEV: goal & scope, life cycle inventory, life cycle impact assessment, interpretation and reporting. It is applicable as well for S-LCA, as for product, prospective, OEM and macro fleet LCA. This document gives requirements for four LCA steps of environmental and social LCA:
    - **Goal & scope** including definition, technology coverage, functional unit, system boundary for all types of LCA.
    - **Life Cycle Inventory** with details for data collection, electricity modelling and multifunctionality.
    - **Life Cycle Impact Assessment** giving rules and requirements on mandatory and optional impact categories as well as normalisation.
    - **Interpretation & Reporting** of level of exigence (mandatory, recommended, optional) and level of adherence to the TranSensus-LCA methodology.
    - **Social LCA (S-LCA)** structured around the four previous phases, similarly to environmental LCA.
- An additional "**Annex**" document, which gives complementary information on the way recommendations were built, on options selection, and on inclusion or exclusion of some items for instance. The structure of this document is similar to the one from main document in order to let the reader easily find needed information. In this document, the LCA practitioner may also find some details regarding the consensus building when relevant.

Annex A: Background and justification of TSLCA requirements for Environmental LCA

I. Goal and scope requirements: background, justification & consensus building

I.1 Goal definition

Three main types of LCA were identified in the WP1 TranSensus-LCA deliverables:

- Retrospective LCA: The retrospective LCA is on the product level and is conducted for already existing products.
- Prospective LCA: The prospective LCA is also on the product level but it is performed for future products. This can be emerging technologies or products or also products that are still in development.
- Fleet level LCA: The fleet-level LCA is on a higher system level and can be performed in the present or the future.

Based on this, initial definitions from the ILCD (International Reference Life Cycle Data System) decision context were analysed in WP2.2 (Hauschild *et al.*, 2018). Inputs from partners were collected. The definition of retrospective vehicle LCA and the prospective vehicle LCA were well aligned with the understanding in the consortium. However, a different understanding of the fleet level existed – one seeing the fleet level as the ILCD on the macro economy level and one seeing the fleet level as the manufacturer level. Therefore, the fleet LCA was divided into two different levels. To provide more details, we decided to add the user of the LCA type to our definition.

I.2 Technology coverage

To define the zero emission vehicle (ZEV) in TranSensus-LCA, available definitions from literature were collected (Table I-1. In available literature ZEVs are defined as vehicles that operate without any tailpipe emissions. In all sources, this includes different powertrains:

- BEV – Battery electric vehicles
- FCEV – Fuel cell electric vehicles
- FC-REEV – Fuel cell range extended electric vehicles
- BEV-ERS – Battery Electric Vehicles with dynamic charging operation on Electric Road Systems (e.g. includes BCEV = battery catenary electric vehicles, as well as vehicles operating on dynamic wireless/inductive charging, or rail conductive charging)

Some sources include plug-in hybrid electric vehicles (PHEVs). This is not aligned with the understanding of ZEVs in TranSensus-LCA because, over their full life cycle, they do emit tailpipe emissions since they cannot operate fully electrically 100% of the time. Sometimes hydrogen-fuelled ICEs (ICE H_2) are included in ZEVs as well. While they do not emit CO_2 during use, they emit some other tailpipe emissions. Based on the voting, ICEs H_2 were included in the technology coverage.

Table I-1 : Definition of ZEVs in different sources of literature

Year	Author	Title	DOI / Weblink	Definition
2022	Axsen *et al.*	What Do We Know about Zero-Emission Vehicle Mandates?	10.1021/acs.est.1c08581	The definition of ZEV commonly includes any vehicle that can operate fully or partially with zero tailpipe emissions, namely battery electric (BEVs), plug-in hybrid electric (PHEVs), and hydrogen fuel cell vehicles (HFCVs).
2022	Rosales-Tristancho *et al.*	Analysis of the barriers to the adoption of zero-emission vehicles in Spain	10.1016/j.tra.2022.01.016	Zero-emission vehicles (ZEVs) are motor vehicles that do not produce direct tailpipe emissions. These vehicles can be divided into two groups: electric vehicles that store energy in a battery (Battery Electric Vehicles or BEVs), and electric vehicles in which energy is stored in the form of hydrogen (Fuel Cell Electric Vehicles or FCEVs).
2020	Miele *et al.*	The role of charging and refuelling infrastructure in supporting zero-emission vehicle sales	10.1016/j.trd.2020.102275	Following the governments of California, Canada and others, we use the term ZEV in reference to vehicles that can operate without emitting any tailpipe GHGs. This definition includes battery electric vehicles (BEVs) which are powered solely by electric batteries charged from the grid, **plug-in hybrid electric vehicles (PHEVs)** which can be powered interchangeably between electricity and gasoline (or both together), and hydrogen fuel cell vehicles (HFCVs) which are powered by hydrogen gas.
2002	Dixon *et al.* (RAND)	Driving Emission to Zero: Are the Benefits of Califonia's Zero Emission Vehicle Program Worth the Costs	–	ZEVs were defined as vehicles that produce zero exhaust emissions **under all operating conditions**. Battery-powered electric vehicles (BPEVs) and direct hydrogen fuel-cell vehicles (DHFCVs, which are fuelled with hydrogen gas) are the only ZEVs considered to be technically feasible for commercial production.
1995	Woods	Zero-emission vehicle technology assessment. Final report		The definition of ZEV used is based on Title 13, California Code of Regulations, Part 1900, as modified by the California Air Resources Board (CARB), and was approved by NYSERDA for this study: "A Zero Emission Vehicle (ZEV) is a vehicle that produces zero emissions of all criteria pollutants (carbon monoxide, oxides of nitrogen, non-methane

Year	Author	Title	DOI / Web-link	Definition
				hydrocarbons, and particulate matter [PM-10]) **under all possible operating modes and conditions**, with the exception of emissions from fuel-fired heaters. Fuel-fired heaters are permitted in ZEVs provided that the fuel system is completely sealed and leak-free and that the heater cannot operate when the ambient temperature exceeds 40°F."
2023	EU	EU CO_2 regulations for cars and vans	[Publications Office (europa.eu)]()	"... **Zero-emission vehicles currently include battery electric vehicles, fuel-cell and other hydrogen powered vehicles**, and technological innovations are continuing. Zero- and **low-emission vehicles, which also include well performing plug-in hybrid electric vehicles,…**"
2023	EC	Proposed CO_2 regulations for HDVs	[EUR-Lex - 52023PC0088 - EN - EUR-Lex (europa.eu)]()	'zero-emission vehicle' means the following vehicles: (a) a heavy-duty motor vehicle with not more than 5 g/(t·km) or 5 g/(p·km) of CO_2 emissions as determined in accordance with Article 9 of Regulation (EU) 2017/2400; (b) a heavy-duty motor vehicle fulfilling the conditions of point 1.1.4 of Annex I to this Regulation if no CO_2 emissions have been determined according to Regulation (EU) 2017/2400; (c) a trailer equipped with a device that actively supports its propulsion and has no internal combustion engine or has an internal combustion engine emitting less than 5 g CO_2/kWh as determined in accordance with Regulation (EC) No 595/2009 of the European Parliament and of the Council and its implementing measures or UNECE Regulation (EC) No 49.

Furthermore, vehicle types to include were collected based on typical means of road transport:

- Passenger car
- Light commercial vehicle
- Trucks
- Urban bus
- Coach
- Motorcycles/ Mopeds etc.
- Light Means of Transport (e-bikes, e-scooters..)

Although light means of transport add to a more comprehensive picture, are relatively easy to model and will probably become relevant in new regulations, they cannot be included in TranSensus-LCA methodologies to the full extent for several reasons:

- The light means of transport have a quite different purpose and mode of transport compared to the other vehicles. This limits the comparability.
- Due to the different modes of transport, the functional unit could be different to what is defined in this project.
- There is no industry partner in the consortium to define detailed guidance from an industry perspective (e.g. on default values in the FU)
- The project is quite limited with the time available to detail the guidelines. Therefore, we should focus on core topics.

This can be changed and updated in future versions of the guidelines.

Textbox I-1: Prospective LCA - Deviation for Technology Coverage

Based on the reached consensus for the technology coverage, the transferability to a prospective LCA was discussed based on the partner's expertise and common practice in the literature. While for the vehicle LCA, powertrain technologies could be defined based on existing powertrains on the market, it was agreed on that in the future new technologies might exist or be implemented in large scale. Therefore, it was decided to broaden the technology coverage as long as assessed technologies are in line with the definition of the ZEV provided in the guidelines.

I.3 Functional Unit

Several key findings were highlighted in the WP1 TranSensus-LCA deliverables regarding functional units:

- The most common functional units (FUs) for product-level vehicle LCAs (across all reviewed guidelines and standards, and scientific studies) were "passenger-km" (for passenger vehicle), "tonne-km" (for freight vehicles) and "vehicle-km".
- Almost all reviewed OEM reports adopted "transport of passengers or goods over the *vehicle service lifetime* (km)" as FU. Exceptions where the use of passenger-kilometre for buses and tonne-kilometre for some of the truck LCAs.
- All these FUs are acceptable, but it is worth pointing out that strictly speaking, the former two (i.e., "passenger-km" and "tonne-km") would be preferable, since they more directly relate to the intended "function" of the vehicles in question, i.e., respectively "transporting passengers" and "transporting goods", and they implicitly include considerations of capacity, which may lead to more meaningful comparisons across different vehicle types.

Therefore, we chose tonne-km for freight vehicles, passenger-km for busses and for passenger cars with the default assumption of one passenger for passenger cars which then equals to vehicle-km for passenger cars. If other information on occupancy rates is available, this can be used. We choose this approach for occupancy rates since passenger-km is the more accurate functional unit as it is more reflective of the actual function. However, estimating occupancy rates adds a layer of complexity and therefore uncertainty to the functional unit and hinders international comparisons.

The definition of the functional unit is based on the lifetime of the vehicle. Therefore, the lifetime considered is a key topic. The survey in WP 1 shows that industry mostly assumed lifetimes of their vehicles between 150 000 and 200 000 km. Only some differentiate based on the vehicle type. Occupancy rates are typically not included in the functional unit.

The inputs from the partners on functional unit and lifetimes were collected. The functional units are well aligned with the findings from the review by using the vehicle lifetime. How the lifetime is defined deviates. Some partners use the same lifetime for all vehicles, others differentiate per vehicle segment. CEA suggests a new approach by developing mission profiles for vehicles and using them as the base for the functional unit and the assumed lifetime. Mission profiles describe the typical use of a vehicle over the year and therefore the kilometre driven in total.

Furthermore, literature inputs on lifetime and durability were collected. It has to be noted that all the collected sources use assumptions and are based on well-known ICE vehicles. They do not consider degradation data from EVs.

Table I-2 : Literature inputs on lifetime and durability

Papers reviewed	Authors	Year of analysis	Lifetime miles assumed	Location and comments
A Range-Based Vehicle Life Cycle Assessment Incorporating Variability in the Environmental Assessment of Different Vehicle Technologies and Fuels https://www.mdpi.com/1996-1073/7/3/1467	Messagie *et al.*	2014	230 000 km (13.7 years)	Belgium
Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions https://www.mdpi.com/2071-1050/12/3/1241	Helmers *et al.*	2020	200 000 km (-)	Germany Today, batteries can offer > 90% of the original capacity even at 200 000 km [40, 41]. Use stage mileages between 150 000 and 200 000 km were most often applied in scientific reports [26,42]
Trends in life cycle greenhouse gas emissions of future light duty electric vehicles https://www.sciencedirect.com/science/article/pii/S1361920919310466	Ambrose *et al.*	2020	250 000 km (-)	US
The role of pickup truck electrification in the decarbonization of light-duty vehicles https://iopscience.iop.org/article/10.1088/1748-9326/ac5142	Woody *et al.*	2022	330 000 km (18 years)	US projected technological developments
Statistical analysis of empirical lifetime mileage data for automotive LCA https://link.springer.com/article/10.1007/s11367-015-1020-6	Weymar and Finkbeiner	2016	230 000 km (-)	US

Papers reviewed	Authors	Year of analysis	Lifetime miles assumed	Location and comments
Comparison of advanced fuels—Which technology can win from the life cycle perspective? https://www.sciencedirect.com/science/article/pii/S0959652619327490?via%3Dihub	Rosenfeld *et al.*	2019	200 000 km (-)	Austria
Comparative analysis of the life-cycle emissions of carbon dioxide emitted by battery electric vehicles using various energy mixes and vehicles with ICE http://www.combustion-engines.eu/Comparative-analysis-of-the-life-cycle-emissions-of-carbon-dioxide-emitted-by-battery,147159,0,2.html	Borkowski and Zawaslak	2022	300 000 km (20 years)	Europe and US
Vehicle's lightweight design vs. electrification from life cycle assessment perspective https://www.sciencedirect.com/science/article/pii/S0959652617318711	Mayyas *et al.*	2017	200 000 km	US
16 - Life cycle assessment of hybrid passenger electric vehicle https://www.sciencedirect.com/science/article/pii/B9780128237939000176	Candelaresi, D *et al.*	2022	200 000 - 300 000 km	Europe
Life Cycle Assessment of Traditional and Electric Vehicles https://link.springer.com/chapter/10.1007/978-981-15-9529-5_16	Ruben Boros, R *et al.*	2020	300 000 km	Europe

All sources are well aligned regarding using one vehicle as the functional unit and estimating its lifetime based on kilometres. Three main options regarding the functional unit exist:

- Vehicle-km for all vehicles
- Passenger-km (passenger vehicle) and tonne-km (freight vehicles)
- Vehicle-km (passenger vehicle) and tonne-km (freight vehicles)

Lifetime default values in kilometres were defined.

In the first voting, it was agreed to use km-based functional units and a segmentation for passenger cars. Therefore, default lifetime activity values per segment need to be provided. To get to the values, current guidelines, legislation and studies (VDA, PFA, Ricardo analysis, Directive 2009/33/EC) were analysed. All existing values are based on statistics for petrol and diesel vehicles.

While default values are necessary it should also be possible for the LCA practitioner to use different assumptions for the lifetime if they are sufficiently justified. Therefore, a process was defined in the working group on how to deviate from the provided default values. In general, the working group favoured default values per segment of passenger cars. To adapt to the needs raised by the OEMs, step 3 was added to the general approach.

For HDV, it was decided to follow the segmentation by the EU because this is widely established and accepted. To get the default values, current guidelines, legislations and studies were analysed. None of the existing values were following the segmentation by the EU. Therefore, these values cannot be taken as guidance for TranSensus-LCA. Therefore, default values were developed from VECTO and the MAN/Scania study on real fleet monitoring. VECTO provides yearly driven distances for each segment in the EU legislation. These yearly-driven distances are scaled to lifetime driven distances using scaling factors derived from the internal Scania/MAN study based on a real fleet monitoring. This scaling factor is not equal to the lifetime in years because the lifetime in years considers non-constant yearly-driven km over the lifetime.

For two-wheelers, first, default values based on an EU regulation were recommended. Based on the feedback received after the voting, these values were quite conservative. To be more consistent with the sources of default values for the other vehicle types (models and real-world data and not regulations), further data sources were explored and values based on the SIBYL model were suggested (Joint Research Center of the European Commission, 2024). The SIBYL model is based on the best available statistical data, such as new vehicle registrations, vehicle stock, average vehicle age, data from technical inspections and other relevant parameters. These values have been applied in numerous European studies (e.g., (Papadimitriou et *al.*, 2022)) and are frequently referenced by policymakers. However, it is important to acknowledge the inherent uncertainty in these results, which can fluctuate significantly from year to year and between Member States.

Furthermore, also default values for the lifetime in years were developed.

The lifetime in years is needed to support calculations for two important areas: (1) the dynamic modelling of the use stage and EoL energy mix (i.e. where the electricity or hydrogen supply mix varies over time), and (2) the calculated impacts of maintenance and component replacements (e.g. where these may be determined by a time-based replacement schedule, rather than km activity).

Information on the expected actual service lifetime of current and new vehicles is difficult to determine precisely, particularly for heavy-duty vehicles, as there are relatively few studies that have analysed this specifically across a significantly representative and broad range of vehicles.

For passenger cars, estimates from TranSensus-LCA OEMs based on data from their dealerships is around 10 years; however, these figures are not consistent with previous analyses of national vehicle licencing datasets (i.e. covering all registered vehicles), nor with broader industry statistics on the average AGE of vehicles in the fleet from ACEA (e.g. Figure I-1), which is already higher than this[1].

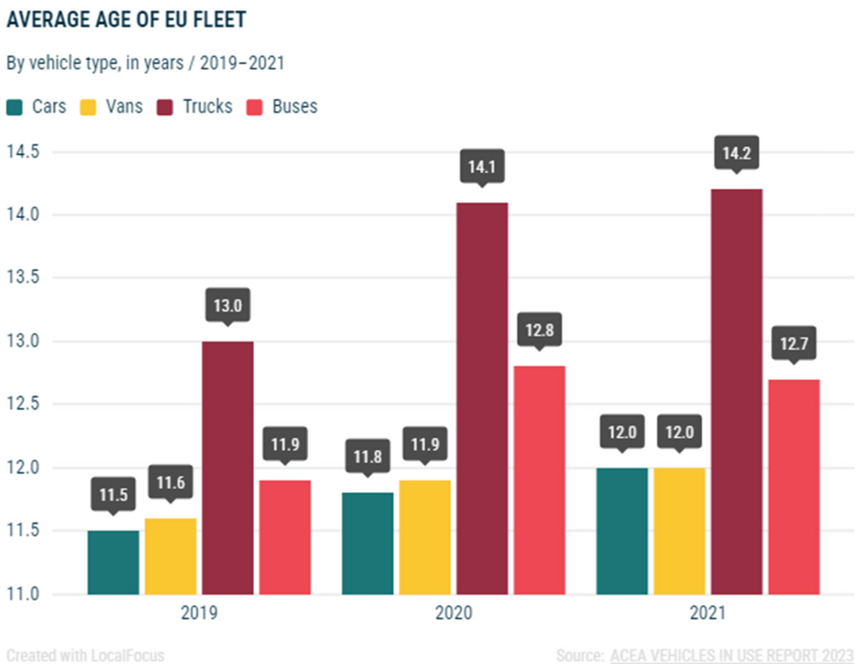


Figure I-1 : ACEA statistics on average of the EU fleet by vehicle category for 2019-2021 (ACEA, n.d.)

Previous Ricardo analysis of UK VDA licencing statistics (Dun et *al.*, 2015), found the average service lifetime of cars in 2013 to be around 14-15 years (having risen from by around 1 year

[1] The average vehicle age accounts for numbers of vehicles of different ages across the fleet, so there are vehicles much newer and much older included. It does NOT represent the average service life therefore, which will be significantly higher than this, depending also on a range of other factors.

over the preceding 6 years). A more recent analysis of UK licencing statistics by (Nguyen-Tien & Elliott, 2024) suggests the average retirement age could have reached over 18 years by 2024. This is also consistent with other analyses on end-of-life vehicles by (Mehlhart *et al.*, 2018) for ACEA, which concluded that the average age of ELVs was between 17 and 20 years. Similar figures have also been reported for other major European countries as referenced by ICCT in the UNECE IWG A-LCA – Sub-Group 4 (ICCT, 2024), with data for Germany (17-18 years in 2016), France (19 years in 2018), Poland (20 years in 2015) and Portugal (20 years in 2015). These figures also correlate with other similar data available in non-European regions for the US and Brazil, as reported by ICCT.

Currently, there is no robust statistical data available on the service life of modern electric vehicle models. However, a calendar lifetime for lithium-ion batteries of 15-20 years has previously been reported (Ricardo, 2019). A more conservative estimate of the service life for ZEVs of 15 years compared to available information on average ELVs (end-of-life vehicles) might therefore be justified on this basis. Previous analysis by Ricardo (Dun *et al.*, 2015) has also shown that the lifetimes of light commercial vehicles/vans is similar to those of passenger cars.

For heavy-duty vehicles, no equivalent analysis of licencing statistics has been identified. However, Scania, together with MAN, have previously analysed extensive data they hold on their in-use vehicles. This dataset is the base for the method (VECTO x factor) to get a representative lifetime driven distance for the FU. The same dataset has been used to investigate how many years in operation it takes for a vehicle in average to reach its lifetime driven distance. Due to that the results show a wide range depending on vehicle type (VECTO group), it is challenging to set one single default value representing all vehicle types. The suggestion is to use 16 years for trucks, 13 years for urban buses and 15 years for coaches, as these numbers can be considered reasonable for service life. For the trucks, the service life assumption has a tilt towards representing long haul more than urban trucks. Long haul is the bulk in truck sales and total travelled kilometres and transported tonnes.

Textbox I-2: Prospective and Macro Fleet LCA - Deviation for Functional Unit

Prospective LCA:

Based on the reached consensus for the functional unit, the transferability to a prospective LCA was discussed based on the partner's expertise and common practice in the literature. It was evaluated whether the functional unit or the reference flows should be changed. In general, the functional unit was deemed applicable and relevant for the prospective LCA as well. The default values for the reference flow stem from a retrospective assessment and might not be a well reflection in the future. Therefore, these may be adapted following the general process described in the guidelines. In the future, additional functions of the vehicle may come up (vehicle to grid, second use of the battery) that affect the lifetime of the vehicle. Therefore, it was also deemed relevant to adapt the functional unit and the reference flows accordingly. The condition is that all deviations shall be documented and justified.

Macro Fleet LCA:

Based on the reached consensus for the functional unit, the transferability to a prospective LCA was discussed based on the partner's expertise and common practice in the literature. There was a consensus that the scope and aim of a Macro Fleet LCA are quite different from a vehicle LCA. Therefore, the functional unit shall be adapted to the specific study and explained and documented.

I.4 System boundary

An overview of the input from guidelines and the survey on the life cycle stages to include and cut-off rules for processes was compiled. Inputs from all WP2 partners on their system boundaries and cut-off rules were collected.

System boundary

Several key findings were highlighted in the WP1 TranSensus-LCA deliverables and surveys, regarding system boundaries:

1. Guidelines & standards: As Table I-3 shows the guidelines either apply cradle-to-gate (potentially + use-stage) or cradle-to-grave. None of them mentions second life in their system boundary.
2. Survey: Figure I-2 shows that industry is also mainly applying cradle-to-gate and cradle-to-grave as their system boundary.
3. WP2 partners: Inputs were collected from WP2 partners regarding their practice for system boundaries. The answers are well aligned with the analysis of guidelines and standards and the survey by mostly using either cradle-to-gate or cradle-to-grave. Second life is typically not considered.

Based on the proposal and the goal in TranSensus, the system boundary should be cradle-to-grave to capture the full life cycle for ZEVs. Since the use stage is included, the energy in the use stage should be modelled well-to-wheel. Second use of the battery was excluded from the system boundary. While second use can be relevant, it is not sure at the moment if it will become a state of the art. With the limited time in the TranSensus-LCA project, the consortium decided to focus on the core life cycle stages in the system boundary. A second use of batteries should be addressed in further scenario analysis (see chapter on the life cycle interpretation). For trucks, it is not mandatory to model the production and the End-of-Life of the trailer since the manufacturer of the truck not necessarily can influence how the trailer will be produced and which will be used in the use stage. The trailer shall be included in the use stage (f.e. based on VECTO).

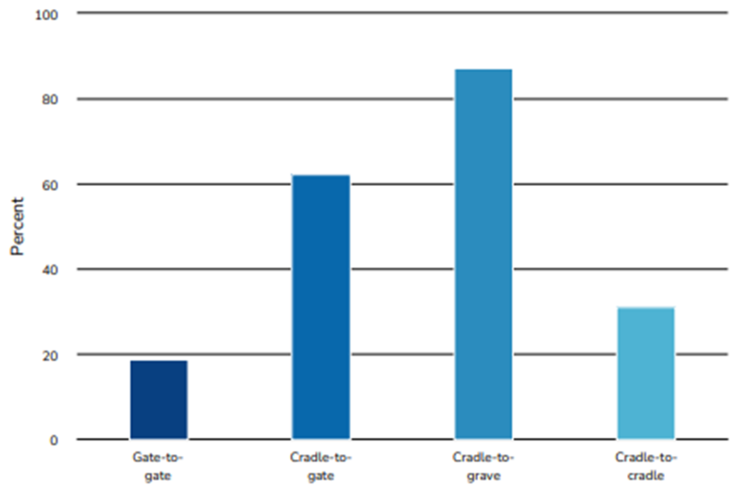
Table I-3 : System boundaries in guidelines and standards from WP1 (Eltohamy et al., 2023)

Guidelines and standards report[2]	System boundary
CATARC	Cradle-to-gate + use
GBA-rulebook	Cradle-to-gate (+ recycling in new version v1.5)
GRB-CBF_Carbon FootprintRules-EV	Cradle-to-grave: Raw material acquisition, manufacturing of the battery system, distribution, EoL

[2] See deliverable D1.1 "Review of current practices on life cycle approaches along the electromobility value chain" from TranSensus-LCA project

Guidelines and standards report[2]	System boundary
PEFCR Batteries	Cradle-to-grave
Catena-X Product Carbon Footprint Rulebook	Cradle-to-gate
eLCAr	Cradle-to-grave
PCR Buses and coaches v.2 EDP Int	Cradle-to-grave
RISE - LCA Guidelines for electric vehicles	Cradle-to-grave
VDA - - Guidance for Conducting Life Cycle Assessment Studies of Passenger Cars	Cradle-to-grave
PFA technical guidance	Cradle-to-grave

10. Which system boundary are you modelling?



Value	Percent	Responses
Gate-to-gate	18.8%	3
Cradle-to-gate	62.5%	10
Cradle-to-grave	87.5%	14
Cradle-to-cradle	31.3%	5

Figure I-2 : Survey results on system boundaries modelled

Cut off rules for flows and exclusion of processes

The ISO 14044 gives the following guidance on cut-off:

The cut-off criteria are defined as a *"Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study"*.

The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described. The effect on the outcome of the study of the cut-off criteria selected shall also be assessed and described in the final report.

Several cut-off criteria are used in LCA practice to decide which inputs are to be included in the assessment, such as mass, energy and environmental significance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental significance should also be used as cut-off criteria in this process.

A) Mass: an appropriate decision, when using mass as a criterion, would require the inclusion in the study of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled.

b) Energy: similarly, an appropriate decision, when using energy as a criterion, would require the inclusion in the study of those inputs that cumulatively contribute more than a defined percentage of the product system's energy inputs.

c) Environmental significance: decisions on cut-off criteria should be made to include inputs that contribute more than an additional defined amount of the estimated quantity of individual data of the product system that are specially selected because of environmental relevance.

Similar cut-off criteria may also be used to identify which outputs should be traced to the environment, e.g. by including final waste treatment processes. Where the study is intended to be used in comparative assertions intended to be disclosed to the public, the final sensitivity analysis of the inputs and outputs data shall include the mass, energy and environmental significance criteria so that all inputs that cumulatively contribute more than a defined amount (e.g. percentage) to the total are included in the study.

When looking at the standards and guidelines (Table I-4), there is no real differentiation between the cut-off of flows and the exclusion of processes. Cut off rules as defined in the existing guidelines deviate often from what the Din ISO 14044 proposes or focus on cut-off of processes instead of flows. OEMs seems to apply no cut-off of flows at all. There is no real consensus between the existing guidelines and none is giving full guidance on cut-off of flows and exclusion of system boundaries. The analysed OEM reports in WP1 were mostly in line with the ISO 14044.

Table I-4 : Overview of cut-off rules from WP1 report (Eltohamy et al., 2023)

Guidelines and standards report	Cut off rules
CATARC	Infrastructure and equipment excluded
GBA-rulebook	Cut off rule from the European Commission Recommendation on the use of the Environmental Footprint has been adopted
GRB-CBF_Carbon FootprintRules-EV	Manufacturing of capital goods for battery production, Battery use-stage, battery assembly with the OEM system components, auxiliary inputs not related to battery production to be excluded
PEFCR Batteries	Processes and elementary flows up to 3.0% (cumulatively) based on material and energy flows and the level of environmental significance (single overall score)
Catena-X Product Carbon Footprint Rulebook	Development/administration expenses and emissions from employee commuting are excluded. If based on the results of a screening study, individual material or energy flows are found to be insignificant for the carbon footprint, (up to max 3% of the total PCF) these may be excluded for practical reasons
eLCAr	Not specified
PCR Buses and coaches v.2 EDP Int	Upstream: exclusion of materials, energy and manufacturing facilities, transportation of raw materials, packaging Core: production equipment and building, travels. Downstream: waste treatment facilities, road infrastructure and services facilities, cleaning agents
RISE - LCA Guidelines for electric vehicles	Not specified
VDA - - Guidance for Conducting Life Cycle Assessment Studies of Passenger Cars	Components, processes or emissions can be excluded if the effort required for including them seems unjustified (e.g. short distance forklift transport of components within the production site). No intentional cut-off should be applied for the parts lists and bill of materials. The modelled weight of cars shall range within 3% of the certification weight. No cut-off criteria for manufacturing processes and emissions are defined. Capital goods shall not be included in the foreground system. Inbound logistic (delivery from suppliers) should be included if considered relevant. The replacement of wear parts and warranty parts, after sales services, and washing of cars do not have to be included (strongly user dependent). Recycling processes or environmental benefits resulting from the provision of secondary material shall be considered.
PFA technical guidance	The document recommends excluding: 1) Infrastructure of administration/marketing) 2) Commuting and travel business for employees 3) Manufacturing of supplier infrastructure and tools (optional to exclude or include) 4) Manufacture of packaging for the logistics of parts returning to the plant (recommendation to take lost packaging into account) 5) Manufacture of auxiliary materials for manufacturing (cutting oils, gloves, etc) : optional to include however they are usually integrated in used datasets 6) Manufacture of terminal plant infrastructure and tools or equipment manufacturing plant 7) Operation of the aftersales network and distribution of parts and accessories 8) Particulate emissions from tire wear and brake pads (optional)

Inputs from partners practices were collected. Either no intentional cut-off is applied or the specific cut-off rules are based on the project. A process on how to deal with cut-off of flows when it cannot be avoided is developed. Process stages/ elements that are frequently discussed whether to include them or not in the system boundary are analysed in WP2 to give recommendations for TranSensus-LCA. The first developed cut-off rule was as follows:

For the cut-off of flows, a hierarchical process is used. No intentional cut-off of flows should be done. In case, cut-off is needed, an absolute threshold based on 3% of mass and energy of the flows is applied. We don't recommend cut-off based on environmental significance because it is hard to estimate and highly depends on the impact category considered. Combined with the allowance thresholds, we provide a list of inputs and outputs that are known to be relevant from an environmental perspective, even if they have rather small shares of mass or energy and are therefore mandatory to include. When a cut-off is applied, a transparent documentation of the approach shall be done – why was something cut off and how.

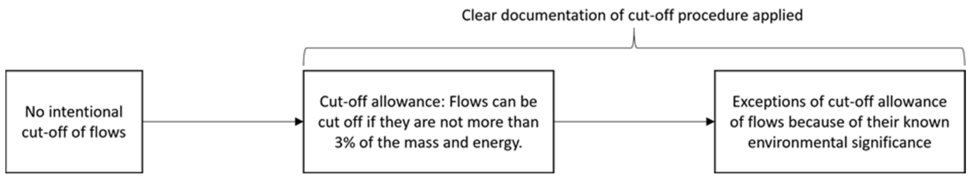


Figure I-3: Hierarchy on how to deal with cut-off of flows

From the best of knowledge and experience of the working group, the following list of input and output flows are highly relevant from an environmental perspective while they might have rather small shares of mass and energy and should therefore never be cut-off. This list does not claim to be exhaustive and might also experience changes in the future with new technologies.

Table I-5: Cut-off allowance exception : list of input and output flows not allowed to cut-off

Inputs	Outputs
Flow	Flow
Platinum Group Metals (PGM) - e.g. used in catalysts	All fluorinated gases (incl. CFCs, HCFCs, HFCs, HFEs, Halons, SF6, NF3, etc.)
Gold (Au) and Silver (Ag) - e.g. used in electronics	Heavy metals and their salts
Rare Earth Elements (REEs) and their salts - e.g. used in electric motors	NMP (n-methyl pyrrolidone)
Cobalt (Co), Lithium (Li), Nickel (Ni) and their salts – e.g. used in LIBs	Methane (CH4)
Graphite	Nitrous Oxide (N_2O)
Carbon fibres, VGCF, carbon nanotubes	Dioxins
Raw materials classified as critical by the EU	Furans
Printed circuit board	Polychlorinated biphenyls

However, the testing as part of WP2.6 showed challenges and concerns in the application:

- How to deal with flows that are neither measured in mass nor in energy?
  - Example 1: Internal plant logistics, typically in t.km
  - Example 2: Direct emissions during production and use stage
- The proposed table of "never cut-off flows" cannot be exhaustive. It remains a risk that environmentally significant flows get cut-off.

Therefore, cut-off allowance is changed to cut-off based on environmental significance.

Textbox I-3: Prospective and Macro Fleet LCA - Deviation for System Boundary

Prospective LCA:

Based on the reached consensus for the system boundary, the transferability to a prospective LCA was discussed based on the partner's expertise and common practice in the literature. There was a consensus on keeping the system boundary cradle-to-grave and keeping the rules for cut-offs of flows and processes. However, it was also agreed on that future market developments may lead to new business models and additional functions of the vehicle (second use of a battery, vehicle to grid,…). To assess these as part of the prospective LCA, for example, to guide the internal R&D and decide on future business models, the system boundary may be broadened and these processes may be included in the system boundary. Adaptions in the system boundary may lead to further processes that should be included or excluded from the system boundary. The list defined to the vehicle LCA should be revised accordingly. All adaptions shall be documented and justified.

Macro Fleet LCA:

Based on the reached consensus for the system boundary, the transferability to a prospective LCA was discussed based on the partner's expertise and common practice in the literature. As important aspect with regard to the general scope and aim of Macro Fleet LCAs was the revision of excluded processes identified. Processes regarding capital goods and charging stations/hydrogen refuelling stations should be included in the macro fleet LCA. The system boundary and all included and excluded processes shall be documented.

I.5 Other best practices

The OEM fleet LCA is an approach that builds on the retrospective vehicle LCAs and combines and scales them to reflect the whole fleet of an OEM. The main points to define where:

- the data basis for the different life cycle stages
- the minimum requirement for product LCAs needed to represent the fleet
- what a representative vehicle is that is scaled to reflect other vehicles
- on what basis the scaling is performed

Ongoing work at UNECE as well as the requirements and expertise of OEMs in TranSensus-LCA were used to develop the approach for passenger cars. In the next step, the transferability to heavy-duty vehicles and two-wheelers was discussed and vehicle type-specific adjustments were made.

Further suggestions which were not addressed included:

- Following more a “rolling stock” modelling approach
- Modelling the use stage not (only) based on WLTP values [→ not included as alignment of fleet LCA with product LCA is needed]
- Adding a metric for statistical dispersion

II. LCI requirements: background, justification & consensus building

II.1 Production stage modelling

II.1.1 Data requirements for level 3

- The *level concept* refers to the UNECE LCA typology (Figure II-1) which was adopted by TranSensus-LCA in the last voting. *Level 3* can only be reached by an OEM with access to a complete Bill of Materials (BOM) and supplier-specific information. Level 3 LCAs of two representative vehicles of different OEMs may be compared to each other if the same LCA methodology is applied (e.g. TranSensus-LCA) and the same minimum data requirements are used to define *Level 3*.

SUPPLY CHAIN & PRODUCTION	Possible Comparison[1)]	Vehicle modelling	Representativeness[2)]	Supply chain modelling	OEM manufacturing Processes	Supplier manufacturing process	Individual decarbonisation measures
Level 1	General concept of drivetrains (e.g. BEV vs. ICEV)	Generic material composition & average vehicle curb weight	Global average / regional	generic footprint per kg of vehicle curb weight			none
Level 2	General concept of drivetrains (e.g. BEV vs. ICEV) based on exemplary „real" car vehicle model	BOM & Material information system (CMDS / IMDS[3)])	Global average / regional	global secondary data material footprints (incl. generic information for production processes)			none
Level 3	A representative vehicle of OEM A VS A representative vehicle of OEM B	BOM & Material information system (CMDS / IMDS) & „part-by-part" for hotspots	Regional & individual SC for hotspots	primary information for the vehicle hotspot parts	Optional: primary data for OEM's inhouse hot spot processes	primary information for the manufacturing of vehicle hotspot parts	included
				secondary information for the rest	Secondary information for the rest or average values per vehicle from OEM's Scope 1 & 2 emissions	secondary information for the rest	
Level 4	e.g. OEM A's BEV model vs. OEM B's BEV model	BOM („part-by-part")	individual SC	regional or primary data based part (& material) footprints	included	included	included

Figure II-1: Level concept as proposed by the UNECE working group and as adopted by TranSensus-LCA (see SG4 - 3nd meeting - Transport - Vehicle Regulations - UNECE Wiki) – Check out the annex for higher resolution. The proposed data requirements only apply to BEVs (LDV & HDV).

- ‘**Company-specific data**’ refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It includes company-specific activity data and elementary flows. It is synonymous to 'primary data' or ‘supply-chain specific data’ or ‘manufacturer-specific’ data.
- ‘**Secondary data**’ means data not from a specific process within the supply-chain of the company performing a life cycle assessment. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third party, LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and may also be based on financial data, and contain proxy data, and other generic data.

- The EU Battery Regulation covers the whole battery system i.e. the component that represent a very high percentage of the production stage Global Warming of a Light-Duty Vehicle (LDV). It is still under review but will take effect in 2025. The data requirements in the current draft of the Battery Regulation are depicted in our decomposition tree. TranSensus-LCA partners with access to the Sharepoint, please, see [ProdBEV_decomposition_tree_w_bat_reg_rqrts.html)](ProdBEV_decomposition_tree_w_bat_reg_rqrts.html), Advisory Board members and others, please see Figure II-2 and Figure II-3.

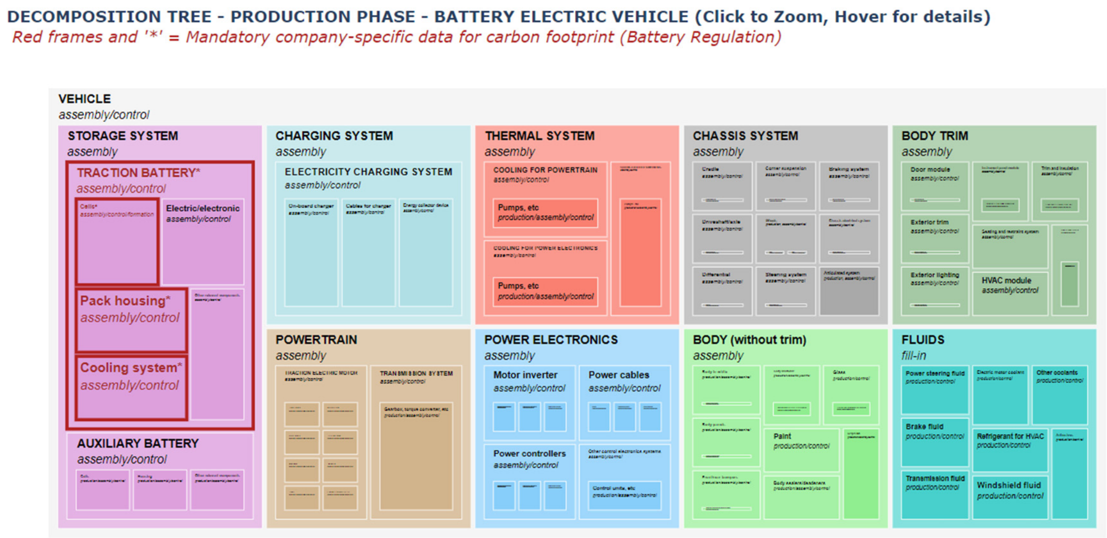


Figure II-2: Decomposition tree for battery electric vehicle at production stage showing company-specific data required by the Battery Regulation (carbon footprint) draft in a red frame.

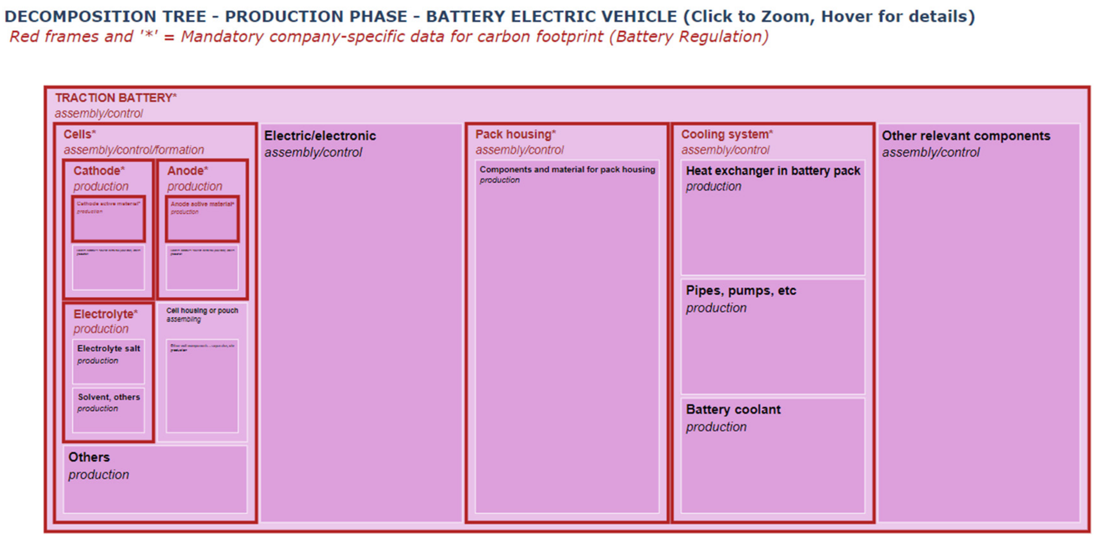
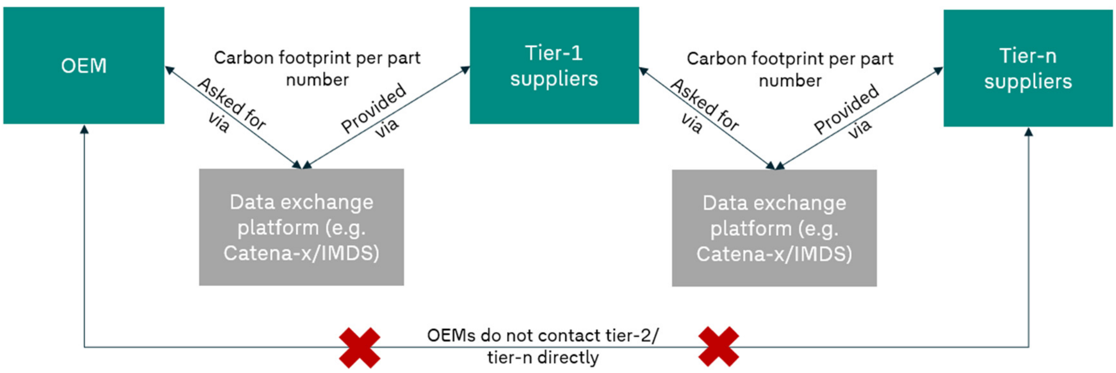


Figure II-3: Decomposition tree (zoom on the traction battery with Battery Regulation data requirements requirements)- Check out the annex for higher resolution.

- OEMs have a complete parts list available for each of their vehicles. Via the system IMDS (IMDS, 2000), the material composition of each part is known to the OEM. The OEM LCA practitioner then (semi-) automatically translates the provided materials list into the OEM's material typology and attaches the respective secondary data. The structure of a BOM, the denomination of parts and the secondary data used can differ between OEMs. Each vehicle part has a specific part number. Each part (number) can be sourced from different suppliers at the same time.
- Usually, OEMs are only in contact with their tier-1 suppliers. The manufacturing depth between OEMs can differ though: one OEM may buy the car body while another has their own press. The tier-structure therefore differs between OEMs (Figure II-4).
- OEMs' own company-specific data (their in-house production) is measured and collected in Environmental Information Systems (EIS). It is used for their scope 1 and scope 2 emissions reporting and as a data source for vehicle LCAs. This data is, however, only process-specific for hotspots like e.g. the press and paint shop and mostly added to the vehicle LCA as an average per vehicle as a whole.
- Collecting company-specific data for vehicle parts on a regular basis is relatively new for OEMs. The IT environment to facilitate this complex exchange of information is currently being built (see Figure II-4). As the current focus is put on GWP data exchange, TranSensus-LCA also focuses on GWP for the time being. This does not mean that other impact categories should be considered less; it is just a starting point.

How do/will OEMs collect company-specific data from suppliers?



- **Currently GWP focus**
- **Only aggregated values (carbon footprint per part number) are provided from one tier to another**
- **Starting point: Tier-1 provides carbon footprint per requested part number consisting of tier-1 company-specific data & secondary data**
    - **Subsequently, the share of specific data sourced from tier-n companies is increased but a share of secondary data remains**

Figure II-4: Current/future data exchange between OEMs and suppliers respectively between suppliers and suppliers.

- The iterative approach for OEMs to fulfil the Level 3 data requirements proposed here looks as follows (Figure II-5):

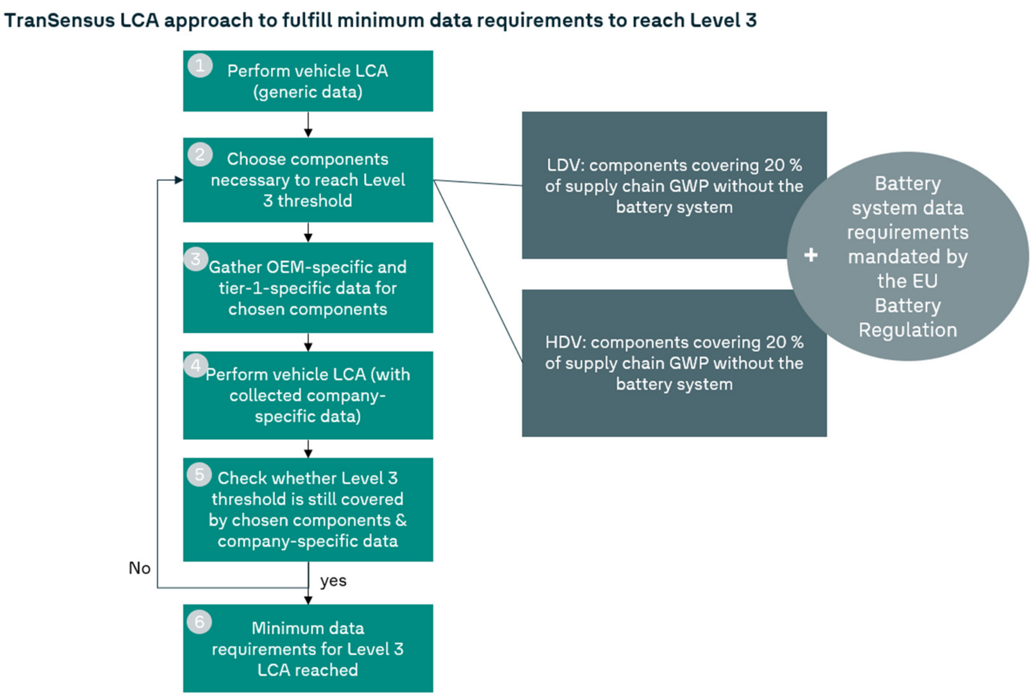


Figure II-5: Iterative approach to fulfil the TranSensus-LCA Level 3 minimum data requirements.

- The 20% minimum threshold to be covered by the TranSensus-LCA Level 3 data requirements does **not** mean that 20% of the supply chain GWP is covered with company-specific data. The threshold only serves as a guideline to choose the hotspot components that are, as a first step, to be modelled with tier-1 company-specific data. Secondary data will always be a part of the supply chain impact modelling, its share will just be lowered by exchanging specific data between the tiers (see Figure II-6 below)

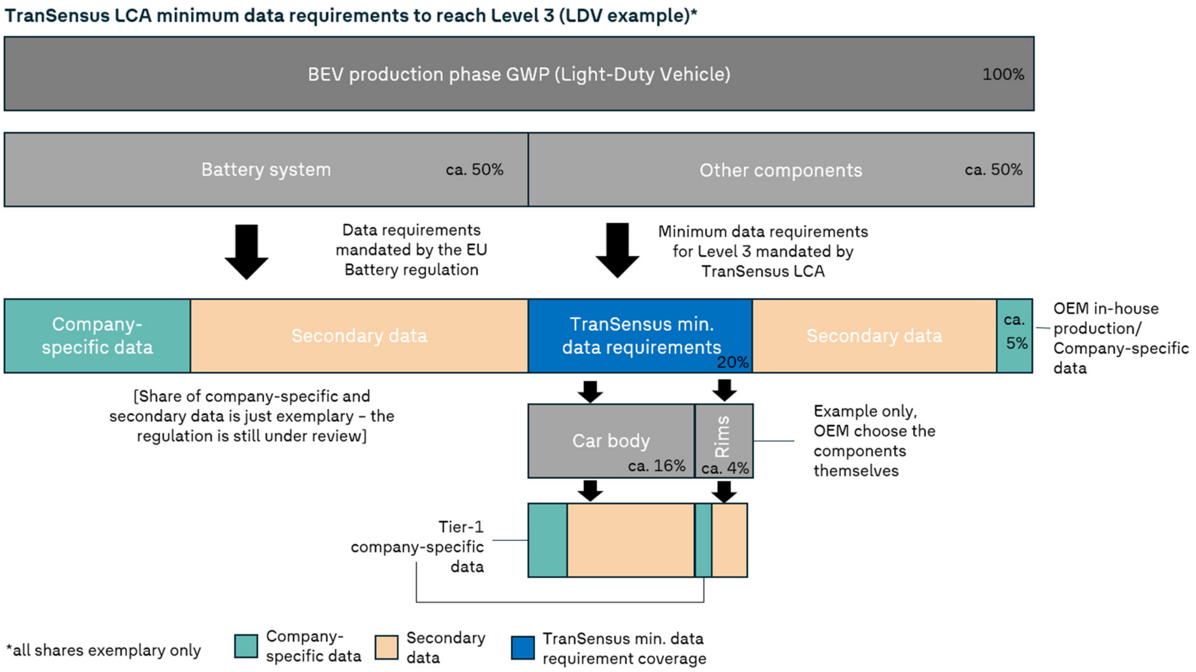


Figure II-6: Overview of the shares of company-specific and secondary data in supply-chain LCA modelling when following the Level 3 minimum data requirements.

- Another way to depict the tier-1 company-specific data requirement for components that in total make up for a 20% share of the BEV production stage apart from the battery system is shown below (Figure II-7).

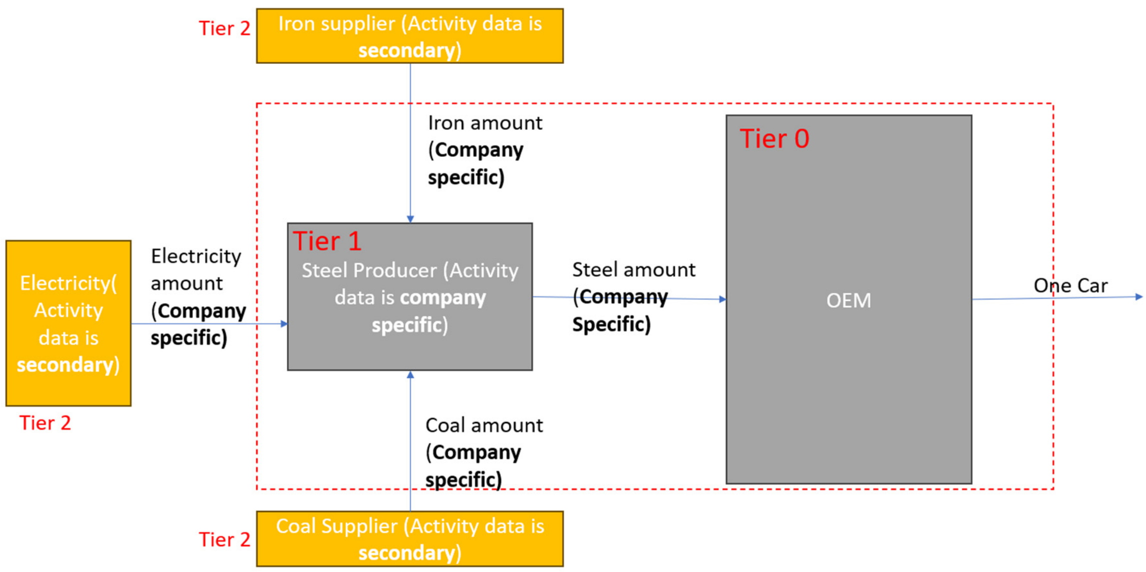


Figure II-7: Tier-1 company-specific data as requested for a Level 3 LCA: Tier-1 activity data is company-specific (i.e. directly measured) while tier-2/tier-n data can remain secondary (i.e. sourced from databanks).

II.1.2 Electric Energy supply in manufacturing

II.1.2.1 Definitions

Energy Attribute Certificate (EAC)

An **Energy Attribute Certificate (EAC)** is the official documentation to prove renewable energy consumption. Each EAC represents proof that 1 MWh of renewable energy has been produced and added to the grid.

Global EAC standards for renewable claims are primarily **Guarantees of Origin (GO)** in Europe, **Renewable Energy Certificates (RECs)** in North America and **International RECs (I-RECs)** in a growing number of countries in Asia, Africa, the Middle East and Latin America.

Attributes for EACs

Each MWh of produced electricity has its unique characteristics associated with it, such as:

- Time and date of production
- Location of the generation device
- Generation technology (eg. wind turbine, hydropower plant etc.)
- Age of a production device

These characteristics are called attributes, and the EAC market offers a tool for trading these attributes.

At its most basic level, the EAC system works as follows:

- a producer of (renewable) electricity generates 1 unit of electricity (generally this is 1 megawatt-hour (MWh))
- for each MWh of energy they inject into the grid the producer requests an EAC from the *issuer*; the EAC, which is an electronic certificate, contains factual information *attributes* about the specific unit of electricity such as the technology used to generate the power and where it is located.
- the EAC can be traded between market participants through *registries* with the ultimate claim of selling it to a consumer (also known as an end-user).
- The end-user or their representative consumes the EAC by cancelling it so that it cannot be used again – without cancellation, there is a risk that one EAC can be used twice (known as double counting)
- the consumer can then *claim* to have consumed the unit of energy that was represented by the EAC.

- The EAC market is separate to the electricity market. Even though each EAC is associated with a specific unit of electricity, EAC markets are not about allocating the electricity but are about allocating its *attributes*. Most often these are “renewable attributes” so that the electricity consumer can claim the consumption of renewable power.

Energy attribute certificate systems prevent the double sale or consumption of the attributes of a particular unit of electricity. *All* consumption of energy attributes should have the associated EAC cancelled, as there are no other means to ensure the prevention of double issuance or claiming.

Source: RECS

Bundled versus Unbundled GO

A GO can be sold either together with the underlying energy, or separately from it. When the GO and the underlying energy are traded in a contract together, it is described as “bundled.” When the GO and underlying energy are traded in separate contracts, it is described as “unbundled.” In either case, the basic principles of buying renewable electricity through the GO system apply.

Source: Guarantees of Origin and Corporate Procurement Options. RE-Source Platform, October 2021

Residual electricity mix

A **residual electricity mix** is defined as a mix which is not documented via an Energy Attribute Certificate (EAC) tracking system.

The Association of Issuing Bodies (AIB - Home | AIB (aib-net.org)) develops, uses and promotes a European, harmonised and standardised system of energy certification for all energy carriers: the European Energy Certificate System - "EECS".

The AIB is issuing residual mixes for most European countries (cf. figure below).

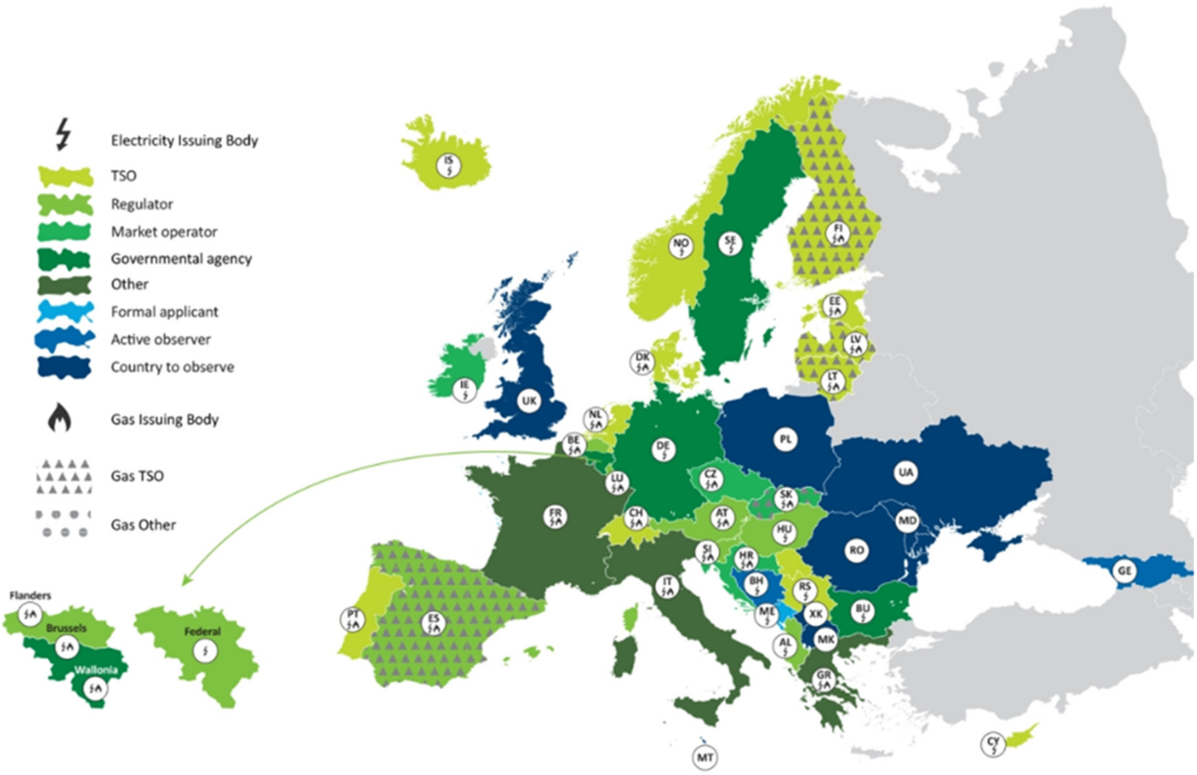


Figure II-8: Association of Issuing Bodies member countries

However, it is not uncommon, when more than one EAC system exists in the same geographical region, that no residual electricity mixture is defined. In order to facilitate feasibility of all modelling approaches a residual mix modelling approach is proposed (cf. question on residual mixes modelling for the product LCA production stage).

Power Purchase Agreement (PPA)

A **Power Purchase Agreement (PPA)**, or electricity power agreement, is a long-term contract between an electricity generator and a customer, usually a utility, government, or company. PPAs may last anywhere between 5 and 20 years, during which time the power purchaser buys energy at a pre-negotiated price.

Whether the electricity producing plant is located on the site of the customer (on-site PPA model) or connected to the customer site via a purpose-built direct or 'private' wire (private-wire PPA model), the electricity generated by the renewable energy installation is sold and consumed by the customer, and power surplus is fed to the grid. GOs are not generated for the power that is consumed by the customer behind the meter. Surplus power that is exported to the grid, and metered, would receive a GO certificate to prove that the power comes from a renewable energy source.

The off-site PPA models, whether Physical (i.e. with a physical transmission of electricity via the electricity grid) or Financial (i.e. with no physical transmission of power between the producer and the customer which allows the PPA to be signed across national borders), involves the signature of a contract or a series of contracts between a producer and a consumer. GOs are bundled (linked) with the power sold and transmitted from the installation owner to the consumer as part of the contract(s). (Bruce *et al.*, 2020)

To be noted: GOs bundled with physical PPAs are typical of virtuous additivity: customer is responsible, by a long-term contractual commitment, of the building of a new low carbon facility. Although electricity is delivered through the grid, contract is a specific arrangement between producer and customer, optimizing production on consumption needs, and is very similar to a private line PPA.

II.1.2.2 Electricity basics

At every moment, electricity consumption and production should be at an equilibrium through the grid, otherwise the grid would collapse. Electricity supply from the grid is the result of a complex collaboration of various actors to ensure the balance between production and consumption, subject to strong physical constraints.

The electricity Transmission and Distribution systems act in a way that the physical consumption cannot be traced back to a production: the physical reality of the electric grid means that electrons cannot be traced. It is not possible to trace the electricity consumed by an entity back to any particular grid-connected power plant. Therefore, the physical tracing of electrons is not performed in existing grids.

The electricity travels on average short distances (several hundreds of km).

II.1.2.2.1 Market-based and location-based approach

There are two main approaches to tackle electricity consumption modelling within a product LCA production stage: the location-based approach and the market-based approach.

The location-based electricity modelling approach is based on the physical average consumption mix of a country or region electricity-consuming facilities. The geographical scope of the electrical mixes to be considered should be sub-national (to be as precise as possible), national (i.e., country-specific electricity mix), or, if not possible, supra-national (i.e., EU grid mix).

The market-based electricity modelling approach uses contractual agreements, guaranteeing a unique claim for electricity from specific energy sources, such as Renewable Energy Sources, to model electricity consumption. For processes for which a contractual agreement has been concluded, the consumed electricity will be modelled according to the mix that is described in the agreement. For processes for which no contractual agreement has been concluded, the consumed electricity will be modelled using the sub-national residual mix (if available, to be as precise as possible), the national residual mix (i.e., country-specific), or, if not possible, a supra-national residual mix (i.e., EU residual mix). A residual electricity mix reflects the sources of the electricity supply that are not covered via an Energy Attribute Certificate (EAC) tracking system. In the absence of a residual mix, as a conservative option, residual mixes can be modelled as national mixes from which all the renewable production (hydro, wind, PV and biomass) and nuclear production has been taken out.

The location-based and market-based approaches are so different that they cannot be used simultaneously within one LCA. If there is to be a coherence between the emissions reported in the GHG inventories and the emissions to the atmosphere: it is crucial to be consistent in the modelling approach to avoid double counting the renewable energy generation and accurately represent environmental impact of the product. Double counting will arise when, within a given LCA, both approaches are mixed (i.e. national grid mixes are used along with mixes associated with contractual instruments). In such a case, the share of renewable energy power plants is over-estimated because it is double counted. And as a consequence, the share of fossil fuels power plants is under-estimated (see a fictitious example in the following section).

To be noted: When used systematically, for all consumers in a given bidding zone, the correct modelling of EAC-backed contracts combined with residual grid mixes, avoids double-counting. Similarly, when the location-based approach is used systematically, for all consumers in a given bidding zone, then there is no risk of double counting. However, TranSensus cannot force every LCA practitioner in a given bidding zone to use only one electricity modelling approach. Double counting will also arise when some companies, within or outside TranSensus, use the location-based approach while others use the market-based approach.

A third and mixed modelling approach is proposed here, based on OEMs experience. It relies on the use of the available location-based production processes in the databases as generic default while being able to use (market-based) specific electricity sources from suppliers or within the OEM's factories. It makes possible for OEMs to track their decarbonisation process while being transparent about the insufficient data availability and risk of double counting.

II.1.2.2.1.1 Pros and cons as found in WP1

All 3 approaches have limitations and merits associated with those as described in the main findings and learnings from WP1:

The debate about the choice of a market based or location-based modelling is still an open debate. In practice, D1.1 notes that in general, the most popular choices are the national or regional (i.e., Europe) average electricity mixes based on secondary data from a LCI database.

It also mentions that the GHG protocol Scope 2 guidance requires for corporations to report their scope 2 GHG emissions for both location-based approach and market-based one approach. Making it a so-called dual reporting and that guidance such as the Catena-X, PEFCR-Batteries, and CFB-EV suggest using emission factors appropriate for renewable energy consumed based on their source, by describing the EAC-type contractual instruments that can be invoked, such as RECs and GOs.

D1.1 mentions the difference which is made between bundled and unbundled RECs. Bundled RECs allow economic operators to claim “additionality” as a means of showcasing direct investment into new renewable energy generation plants and its added decarbonization contribution to the overall grid.

This bundled property is also identified in D1.2, as a key differentiating factor. It also warns against the risk of greenwashing associated with GOs and mentions that some advocate stricter requirements to strengthen the credibility of renewable energy claims based on Guarantees of Origin (GOs), including stricter time consistency criteria between energy generation and use and a stricter geographic link consistency criterion between energy generation and use.

D1.2 also reminds some pros and cons of both the market-based and the location-based approaches:

Table II-1 : Pros and cons of market-based and the location-based approaches

Location based pros / market-based cons	Location based cons / market-based pros
“real-life” approach and pushes towards lower carbon electricity contents at country/regional levels.	Location based does not account for the capacity of some suppliers that are located in contexts of “bad” electricity mixes to afford purchasing renewable energy.
When choosing a market-based approach, there is the need to carefully address the risk of double counting…	… and this is why residual mixes must be evaluated and systematically used when no specific contracts can be invoked.
Not all countries outside the EU and the US have such contractual instruments as RECs or GOs…	… but this is currently being pursued in China, UK and South Korea
There is a need to overcome potential “greenwashing” accusations when using a market-based approach. For instance: unbundled RECs can lead to a simple reshuffling of the pre-existing GHG emission quotas.	

II.1.2.2.1.2 Pros and Cons as found in WP2

Adding to the findings of the WP1, here is an extensive review of the pros and cons related to the location-based and market-based approaches.

II.1.2.2.1.2.1 Main concerns for location-based

The market-based approach amounts to determining rules to allocate energy production from a specific site to a specific consumer. Because electrons are not traceable in the network, and therefore, for every process, electricity consumption cannot be differentiated, the allocation of electrons is necessarily arbitrary. LCA reports should reflect the environmental impacts caused by a product as accurately as possible, and in this respect stay as close as possible to real GHG emissions, when considering its impacts on climate change. The market-based approach presents the risk of decoupling GHG inventory emissions from real GHG emissions to the atmosphere (because a product carbon footprint can be based on somebody else's emissions). The most accurate way to assess the environmental footprint of consumed electricity is to calculate it through a geographical average.

Associated concerns from OEMs with location-based approach are the following:

- Definition of location boundary: There are strong regional differences irrespective of the criteria for defining location. For example, if a country or continent is defined as a geographic boundary there are cases where energy mix varies vastly within some geographic boundaries. An ideal solution would be to define dynamic location boundary based on the congestion zones. However, this is not possible in the current energy market.
- It is not possible to reduce electricity-related emissions via the active acquisition of electricity from specific energy sources, such as fossil-free energy.
- Potential time disconnection: electricity datasets refer to past electricity production that is used for present electricity consumption.
- Secondary datasets used in the modelling of LCAs are compiled using location-based consumption mixes, but depending on the source of data these mixes can be referenced to different years or regions. E.g. datasets from associations such as Worldsteel or PlasticsEurope are mostly not updated yearly and not available for every region. If emission factors with different temporal and spatial resolutions are permitted, an accounting system among the different electricity mix resolutions is necessary, in order to avoid double counting. [Holzapfel *et.al.*, 2023]

Associated concerns from utilities with location-based approaches are the following:

- The location-based approach has been criticized for its lack of precision and for its lack of incentive for companies. These two limits can be mitigated first by using emission factors at a finer temporal grid, which will be practically easier to implement for the location-based approach than for the residual mix of the market-based approach. Second, by acknowledging that it is not the role of GHG inventories to incentivize, but to give an accurate picture of the physical emissions of a company.

For the time being, the Supplementing Regulation (EU) 2023/1542 of the European Parliament and of the Council by establishing the methodology for the calculation and verification of the carbon footprint of electric vehicle batteries advocates for the use of the location-based approach (the text is not finalized yet):

"The PEF method contains rules for accounting for electricity from the grid, including the use of contractual instruments to demonstrate that a particular electricity product was used. It stipulates that such contractual instruments may only be used if it is ensured, inter alia, that they are the only instrument that carries the environmental attribute claim associated with the quantity of electricity generated. However, in many jurisdictions outside the Union currently this cannot be ensured, entailing a risk of not well-substantiated environmental claims. Therefore, it is appropriate not to allow for the use of contractual instruments in the carbon footprint methodology for batteries."

II.1.2.2.1.2.2 Main concerns for market-based

The market-based approach is designed to allow an energy consumer to declare it has made the choice of supporting the production of a renewable or low-carbon source by creating a direct link to a producer. This is explicit in the Renewable Energy Directive (RED II): « Guarantees of origin issued for the purposes of this Directive have the sole function of showing to a final customer that a given share or quantity of energy was produced from renewable sources. »

Associated concerns from OEMs with market-based approaches are the following:

- There is a large number of EAC tracking systems (e.g. RECs (US, Canada), GoOs (Europe), GECCs (China), iRECs (Global)) with different methodological requirements, e.g. regarding different criterion for allocation of EAC to location or time expiry.
- Most life cycle inventory (LCI) datasets in common LCA databases include location-based electricity mixes. Using these LCI datasets in combination with market-based electricity accounting, for production sites within the same electricity market, leads to double counting of electricity from specific sources, such as renewable energy, in LCAs. [Holzapfel *et.al.*, 2024]
- Potential disconnection between sourcing of EACs in location and time: geographical disconnection can be solved by defining safeguards for the use of EACs; Time disconnection can be solved by a more precise tracking of renewable electricity production.

Associated concerns from academics with market-based approaches are cited in a bibliographical section (Chapter II.1.2.2.1.4).

Associated concerns from utilities with market-based approaches are the following:

- In its current form, the market-based approach for scope 2 has not proved efficient in driving real-world decarbonization.
- Contractual instruments used in the context of the Scope 2 market-based method have proved inefficient in that they are very unlikely to lead to additional renewable electricity generation, because their price is currently too low to provide additionality.
- Contractual instruments do not reflect the real cost of technology. This low price doesn't incentivize lowering energy consumption and creates a competitive bias which can point towards the wrong decarbonization solution. Indeed, if a company A invests in a heat pump to decarbonize its scope 2 while an identical company B decides to uses natural gas combined with a GO, that company B will pay less (because the GOs currently do not reflect the real price of biogas) and will be perceived greener via the GHG inventory prism, although the first solution makes more sense from an economic and a climate point of view.
- Companies have many levers to act on all three scopes, including scope 2 with permanent measures that do not depend on market laws (such as energy efficiency, change of technology / process, etc.) and drive the transition, without having to rely on contractual instruments.
- Regarding electricity GOs, although the energy price crisis and the low hydraulic production has led to an increase in price, it is expected that prices will decrease by 2025-2026 due to the expected development of the renewable electricity park necessary for States to meet their goals.
- Furthermore, the generalization of contractual instruments will fragment the electricity market, which could lead to deoptimization of the system.

II.1.2.2.1.2.3 Effects on decarbonization

Both the location-based and the market-based approach are facing accusations of not decarbonizing, either the electricity from the grid or the product itself:

Table II-2 : Accusations of market-based and the location-based approaches

Location based approach	Market-based approach
By using national or regional electricity mixes, the location-based approach is accused of not helping to decarbonize the national or regional electricity grid mixes because it does not incentivize investments in renewables.	By using GOs with no safeguards, the market-based approach is accused of not decarbonizing the national / regional electricity grid mixes because the overall emissions of a country / region would be the same with and without the use of GOs.
	The market-based approach is accused of not decarbonizing products, but of showing decarbonization for

Location based approach	Market-based approach
	given products while attributing all the "bad" emissions to other products for which there is little or no reporting that is done.

There is no clear evidence of a tangible impact of mainstream market-based approaches as a driver of decarbonization of the electric grid. Multiple studies have shown that in current state contractual instruments used in the context of the Scope 2 market-based method have proved inefficient in that they are very unlikely to lead to additional renewable electricity generation, whose price is currently too low to provide additionality. The lack of impact stems from the low prices due in part to the flexibility of current spatial, temporal and additionality criteria: GOs from old renewable installations such as Norwegian dams can be used to decarbonate an installation in southern Europe during a winter night. Furthermore, [Bjørn *et al.*, 2022] have shown that GOs represent a major part of mitigation efforts made by companies validated by SBTi (Science Based Target initiative). Because of their embedded additionality, PPAs can have a positive impact on the grid decarbonization. Nevertheless, the main contribution to additional generation has always been State subsidies. The need for privately funded renewable generation, when they exist, can be challenged, considering that the States are responsible for reaching decarbonization targets and would therefore most likely have funded the additional generation had they had to.

II.1.2.2.1.2.4 Double counting

There is no risk of double counting with a systematic and consistent approach, using either a location-based electricity modelling or a 100% market-based electricity modelling.

Double counting arises when within a given value chain, some electricity consumptions are modelled using EAC while others are modelled using a national or regional electricity mix, as shown in figure 3 of the article from [Holzapfel *et al.*, 2023].

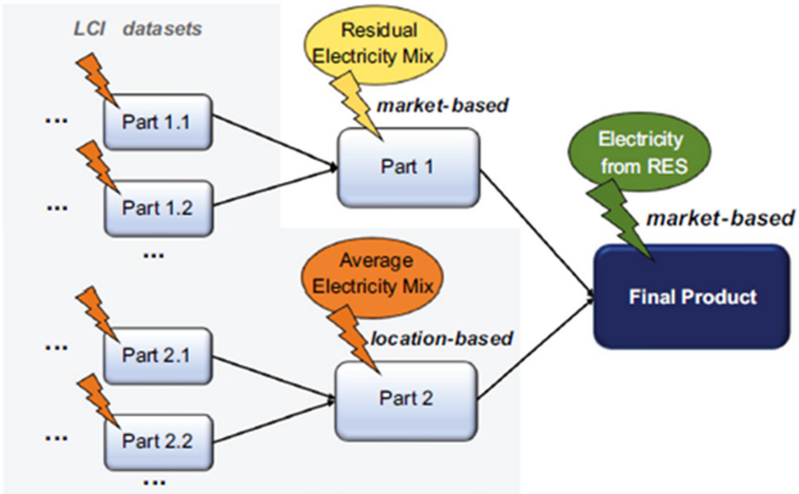


Figure II-9: Overview of simplified example illustrating the parallel use of location- and market-based electricity mixes in one LCA and GHG accounting, when including both market-based electricity and average LCI datasets with location-based electricity inputs

With the choice of the market-based method, the risk of double counting can be limited to zero if residual mixes are systematically used when no information is available about the origin of the electricity consumed.

Let's illustrate the issue of double counting through the example of a country, with a total production of 125 MWh and with only 2 electricity consumers, one using EAC while the other one is using the national grid mix, which is 20% renewable and 80% fossil:

Table II-3: Illustration of double counting

	Consumer A	Consumer B
National production	125 MWh	
National mix composition	25 MWh from renewables + 100 MWh from fossil = 20% renewable + 80% fossil	
Energy consumed	25 MWh from EAC	100 MWh from the grid = 20 MWh from renewables + 80 MWh from fossil
Total accounted energy mix	45 MWh from renewables + 80 MWh from fossil 36% renewable + 64% fossil	
Double counted energy	25 MWh from renewables is "consumed" by A and B!	

To avoid double counting Consumer B should use its national residual mix (100 MWh fossil) and not its national average mix (20 MWh from renewables + 80 MWh from fossil).

To be noted: the same mechanism will occur when within a given LCA a process uses an EAC while another process, occurring in the same country, uses the national grid mix (just replace consumer A by process A and consumer B by process B in the above example).

This mechanism is illustrated by Peter Holzapfel, Vanessa Bach and Matthias Finkbeiner in the figure 2 of their article (situation highlighted with a red dotted line):

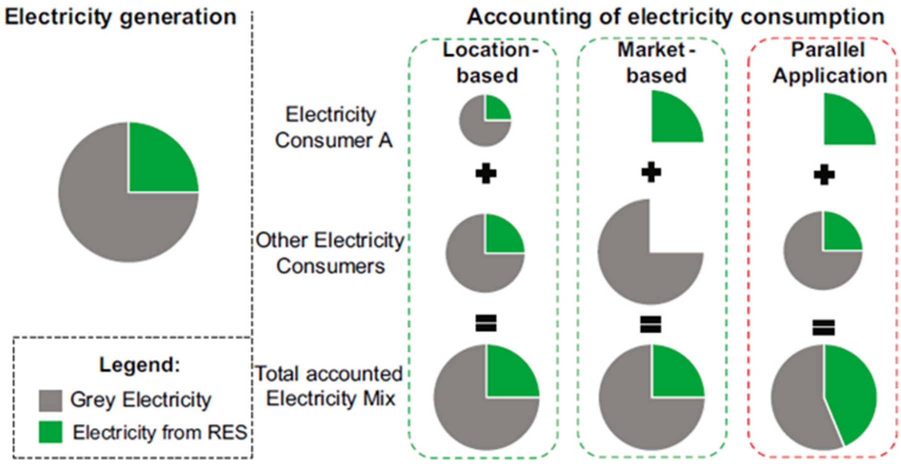


Figure II-10: Illustration of challenges of double accounting electricity from specific energy sources due to parallel application of location- and market-based electricity accounting method, based on a hypothetical region

II.1.2.2.1.2.5 Resource shuffling

A definition of resource shuffling is proposed by the European Roundtable on Climate Change and Sustainable Transition (Marcu *et al.*, 2021): Resource shuffling occurs when clean foreign production is re-routed toward export to the EU, and dirty foreign production is sold elsewhere, leaving foreign production patterns ultimately unchanged.

Why it is a risk for now:

- There is a large difference between the carbon intensity of high carbon and low carbon electricity (factor 10),
- It is very easy to switch from high carbon to low carbon (just purchase the right certificates or PPA without any physical change in the factory nor in the supply chain),
- Only a small fraction of any country electricity production will be dedicated to products subject to EU regulation, therefore it is very easy to direct the clean electricity towards this product production and dirty electricity to other consumers not subject to similar regulation, without any effect on the total country emissions.

- The price of these certificates is around 5€/MWh, this indirectly shows that their effect is limited. Indeed, if these certificates were inducing real efforts towards more low-carbon electricity production instead of only inducing resource shuffling, they would be more expensive.

The components that are mostly at risk are the electricity and electricity-intensive materials such as aluminium and steel.

As resource shuffling is a way to circumvent carbon regulations that is inherently linked to the use of specific emission values, one solution may be to enforce the use of generic national or regional consumption mixes.

<u>Impacts of the generalization of contractual instruments on the electricity grid</u>

The generalization of contractual instruments will fragment the electricity market, which could lead to deoptimization of the system. Nonsensical situations could arise, typically, if the consumer has no need for the electricity for any given reason (for example breakdown of a factory), does this mean the renewable production should stop, or be stored for the specific consumer site? The production asset could be forced to accommodate the needs of the client and not those of the system in its production schedule, which may endanger the equilibrium of the grid.

<u>Contractual instruments evolution</u>

In the longer term, other instruments may allow a higher degree of confidence, such as PPA contracts, however, under the following conditions:

- Seller and buyer identities are disclosed,
- The quantity of electricity and the contract duration are disclosed,
- Any type of electricity generator is allowed, as long as it is identified together with the associated carbon content,
- A mechanism ensures that the electricity is consumed by the factory during the same 1h timestep as it is produced by the generator (temporal consistency),
- The factory and the generator are located in the same bidding zone (geographical consistency)

However, such contracts do not cancel the risk of resource shuffling.

II.1.2.2.1.3 Pros and cons of the 3 electricity modelling approaches.

The PROs of the 3 approaches are summarized in the table below:

Table II-4: Pros of the 3 electricity consumption modelling methods for the production stage

Location-based approach	100% Market-based approach	Mixed modelling approach
- Easy to use method because national and regional location-based mixes are available from most LCA databases. Location-based mixes are incorporated in many background processes such as the production of steel, copper, aluminium, plastics... - Relies on a physical approach of electricity production and consumption. Close to real-world representativeness (geographically speaking) and reflects real impacts linked to global electricity production and consumption. The average national or regional electricity mixes of the location-based approach are a way to have a simple and consistent accounting of electricity environmental impacts in a given country or region. There is no "leakage" of electricity environmental impacts towards entities that do not report their environmental impacts (like residential households for instance). - Very few accusations of greenwashing.	- Electricity consumers from anywhere in the upstream ZEV value chain can actively choose to buy RECs and take credit for the electricity they sign up for. - By increasing the demand for contractual instruments that can prove the additionality of their production, electricity consumers would give additional incentives for building new renewable power plants. - Contractual instruments (Guarantee of Origin in Europe or other EAC such as REC in other parts of the world) are accessible to large and small companies alike. - There exists some open access Python script (by Holzapfel) that replaces all background processes using European location-based mixes by processes using the corresponding residual mixes. - Encourages energy efficiency and/or energy savings measures throughout the ZEV upstream value chain within companies that want to do more than buying EACs (going neutral for instance), although the impact of energy consumption on the ZEV upstream footprint is already decreased because of the use of EACs.	- Electricity consumers from anywhere in the upstream ZEV value chain can actively choose to buy RECs and take credit for the electricity they sign up for. - By increasing the demand for contractual instruments that can prove the additionality of their production, electricity consumers would give additional incentives for building new renewable power plants. - Contractual instruments (Guarantee of Origin in Europe or other EAC such as REC in other parts of the world) are accessible to large and small companies alike. - There exists some open access Python script (by Holzapfel) that replaces all background processes using European location-based mixes by processes using the corresponding residual mixes. - Currently, simple and pragmatic approach to implement a Market-based approach. - Makes it possible for OEMs to track their decarbonisation process while being transparent about the insufficient data availability and risk of double counting.

Location-based approach	100% Market-based approach	Mixed modelling approach
		- Encourages energy efficiency and/or energy savings measures throughout the ZEV upstream value chain within companies that want to do more than buying EACs (going neutral for instance), although the impact of energy consumption on the ZEV upstream footprint is already decreased because of the use of EACs.

The CONs of the 3 approaches are summarized in the table below:

Table II-5 : Cons of 3 electricity consumption modelling methods for the production stage

Location-based approach	Market-based approach	mixed modelling approach
- Not considering the reality of the electricity market that is already using EAC and is anticipated to do even more so in the future. - As location-based modelling results are, in average, attributed uniformly to all actors in the same geographical area, actors engaged in a voluntary individual approach to purchasing electricity from renewable energy producers, and who seek to promote their development, do not derive any credit from it. - No impact on the grid electricity decarbonization. - No incentive for companies to support renewable electricity projects. - Electricity datasets most of the time refer to electricity production periods that do not match the time	- Many accusations related to greenwashing in the scientific literature (see bibliography section). - Lower credibility to the LCA results if not done with safeguards (see following questions). Potential accusations of greenwashing will be motivated by: potential accusations of resource shuffling (see definition above) and potential accusations of double counting if not done properly (by using in the same LCA location grid mixes and EAC mixes). - There is a large number of EAC tracking systems (e.g. RECs (US, Canada), GoOs (Europe), GECCs (China), iRECs (Global)) with different methodological requirements, e.g. regarding different criterion for allocation of EAC to location or time expiry. - Additional workload for modelling the specific mixes and potentially the residual mixes and including these residual mixes in the background processes when needed.	- Robust accusations of greenwashing (double counting is scientifically acknowledged - see "Recommended approach/possible options description and justification" paragraph above). - Lower credibility to the LCA results if not done with safeguards (see following questions). - There is a large number of EAC tracking systems (e.g. RECs (US, Canada), GoOs (Europe), GECCs (China), iRECs (Global)) with different methodological requirements, e.g. regarding different criterion for allocation of EAC to location or time expiry. - Additional workload for modeling the specific mixes and potentially the residual mixes and including these residual mixes in the background processes when needed. - Relies on financial instruments related to electricity production and consumption that open the way to decoupling reported GHG emissions from real GHG emissions associated with the product under study. For instance, in the case of

Location-based approach	Market-based approach	mixed modelling approach
period related to the Product production stage.	- Relies on financial instruments related to electricity production and consumption that open the way to decoupling reported GHG emissions from real GHG emissions associated with the product under study. For instance, in the case of unbundled EAC, reported GHG emissions using EAC not linked to the electricity consumed during the production stage will be different from the real GHG emissions related to the production stage of the product, since the electricity that has been produced for the used EAC is not consumed during the production stage of the product. - Market based instruments break physical constraints: with EAC, electricity can be transmitted over distances longer that a few hundreds of kilometres (which cannot be physically the case) and can even be consumed when no physical connexion exist between the producer and the consumer (i.e. GO from Iceland can be used in continental Europe). - Impacts on the grid electricity decarbonization is not proven. - The RECs system is not meant as a lever for the development of RES, at least in Europe. The development of RES is carried out through other mechanisms: voluntarism of governments who organize calls for tenders to achieve international production mix objectives, taxes on carbon energies, etc. - Nowadays, in Europe, the price of GOs is too low to reflect the real cost of building power plants and producing the electricity. Prices may increase according to the balance between the number of companies that will want to use GOs and the GOs available.	unbundled EAC, reported GHG emissions using EAC not linked to the electricity consumed during the production stage will be different from the real GHG emissions related to the production stage of the product, since the electricity that has been produced for the used EAC is not consumed during the production stage of the product. - Market based instruments break physical constraints: with EAC, electricity can be transmitted over distances longer that a few hundreds of kilometres (which cannot be physically the case), and can even be consumed when no physical connexion exist between the producer and the consumer (i.e. GO from Iceland can be used in continental Europe). - Impacts on the grid electricity decarbonization is not proven. - The RECs system is not meant as a lever for the development of RES, at least in Europe. The development of RES is carried out through other mechanisms: voluntarism of governments who organize calls for tenders to achieve international production mix objectives, taxes on carbon energies, etc. - Nowadays, in Europe, the price of GOs is too low to reflect the real cost of building power plants and producing the electricity. Prices may increase according to the balance between the number of companies that will want to use GOs and the GOs available. - As not all players are obliged to buy AECs, it is important that the consumers in the same bidding zone where the EACs are bought, and who do not buy those EACs use the residual grid mix in their LCAs as prescribed by the market-based approach. This is especially crucial in

Location-based approach	Market-based approach	mixed modelling approach
	- As not all players are obliged to buy AECs, it is important that the consumers in the same bidding zone where the EACs are used, and who do not buy those EACs use the residual grid mix in their LCAs as prescribed by the market-based approach. This is especially crucial in countries with a big difference between the location-based and the market-based electricity emission factor (for example Norway). - Country residual mixes, since they depend on market mechanisms and not on technical issues, can have large variations from one year to another. - In practice, it may be difficult to know every amount of contracted electricity all along the ZEV upstream value chain. - Potential accusations of favouring the existence of "free riders", who either do not report their emissions (like residential households for instance), or report them using a location-based method, therefore allowing others to take credit for the renewable electricity they physically consume (e.g. Iceland electricity consumers whereas others can take credit for GOs related to Iceland electricity production).	countries with a big difference between the location-based and the market-based electricity emission factor (for example Norway). - Country residual mixes, since they depend on market mechanisms and not on technical issues, can have large variations from one year to another. - In practice, it may be difficult to know every amount of contracted electricity all along the ZEV upstream value chain. - Potential accusations of favouring the existence of "free riders", who either do not report their emissions (like residential households for instance), or report them using a location-based method, therefore allowing others to take credit for the renewable electricity they physically consume (e.g. Iceland electricity consumers whereas others can take credit for GOs related to Iceland electricity production).

II.1.2.2.1.4 Bibliography

"It is worth emphasizing that these contractual arrangements do not entail any changes to how electricity from a renewable facility is physically delivered or consumed. The only thing transacted is a claimed right to use the emission factor associated with a certain amount of generation from a particular renewable energy facility." (Brander *et al.*, 2018)

"The market-based accounting method fails to provide accurate or relevant information in GHG reports." (Brander *et al.*, 2018)

"We also distinguish here between RECs and power purchase agreements (PPAs), which represent a long-term commitment by a company to purchase power from a particular renewable energy project. Although empirical evidence is still needed, we have adopted here the common assumption that PPAs do lead to additional renewable energy production and real emission reductions, as the long-term power price de-risks new projects and allows access to project finance (references 14,15,17,18)." (Bjørn *et al.*, 2022)

"When removing the emission reductions claimed through RECs, companies' combined 2015–2019 scope 2 emission trajectories are no longer aligned with the 1.5 °C goal, and only barely with the well below 2 °C goal of the Paris Agreement. If this trend continues, 42% of committed scope 2 emission reductions will not result in real-world mitigation." (Bjørn *et al.*, 2022)

"The use of market-based accounting undermines the accuracy of GHG inventories (Brander *et al.* 2018b; Monyei and Jenkins 2018)." (Brander and Bjørn, 2023)

"Market-based accounting allows companies to report that they have fulfilled reduction targets without reducing emissions (Bjørn *et al.* 2022)." (Brander and Bjørn, 2023)

"A benefit of the exclusive application of the location-based method is that it representatively evaluates the environmental impacts of the physically consumed electricity." (Holzapfel *et al.*, 2023)

"The contribution of the market-based method and accompanying EAC systems to emission reductions and the expansion of RES is critically discussed in the literature. Central discussion points are missing incentives for the expansion of electricity from RES, due to low EAC prices and reduced necessity for energy efficiency measures (Bjorn *et al.* 2022; Brander *et al.* 2018; Hulshof *et al.* 2019)." (Holzapfel *et al.*, 2023)

"However, a price elevation, sufficient to incentivize the construction and operation of additional RES-based power plants, is by no means certain. Thus, an agreement on stricter quality criteria for accountable electricity from RES might be necessary, to ensure the contribution of the market-based method to the energy transition." (Holzapfel *et al.*, 2023)

See also: (Hamburger, 2019; Holzapfel *et al.*, 2024). More extensive sources can be found here:

Renewable Energy Purchasing and the Market-based (Scope 2) Method | B-CCaS

II.1.2.2.2 Overview on criticism on market-based energy accounting and EACs

"The effect of Energy Attribute Certificates (EAC), such as Guarantees of Origin (GOs), and market-based (renewable) energy accounting on corporate emission reduction targets and the energy transition is critically discussed (Bjørn *et al.* 2022). In a performance analysis of the European GO system Hulshof *et al.* (2019) conclude that the GO market has a low market liquidity, as well as a high and in transparent price volatility. Additionally, they state that the GO market has been in a constant state of oversupply, leading to low GO prices.

Bogensperger and Zeiselmair (2020) state that market-based energy accounting does not provide incentives for the expansion of renewable energy sources (RES), due to the low GO prices and the low share of newly build RES among all GOs. Despite a slight price increase in recent years, GO prices still account for a very small part of the total revenues renewable power plant operators (Hauser *et al.* 2019). The GO related income therefore currently has more the status of a "take-home effect", which does not represent a decisive investment incentive. Additionally, the GO system is accompanied by technical challenges. The expansion of decentralized photovoltaics will lead to an increasing number of small RES based power plants with an annual power output below 1 MWh, which is the size of one GO (EU 2018; Weckmann *et al.* 2017). The inclusion of these small scale RES based power plants would require a general revision of the GO system design. Furthermore, the system does not generate a significant control effect for customer behavior, due to the low temporal resolution, and there is currently no integration of smart meters. Currently GOs can be issued and cancelled within an annual time period (Kuronen *et al.* 2020). However, recently the introduction of GOs with a higher temporal granularity of one hour is discussed (Kuronen 2021).

Furthermore, the possibility to account for 100% renewable energy might undermine the recognition of energy efficiency measures. This is due to the fact that money spend to purchase GOs from RES can lower scope 2 GHG emissions much more effectively than the same money spend in energy efficiency. Brander *et al.* (2018) question whether the market-based scope 2 accounting methodology is useful as a GHG emission reductions tool. They illustrate this statement using the following example.

Following the market-based GHG Protocol Scope 2 Guidance (WRI & WBCSD 2015), Company A purchases RES based GOs for all of its grid electricity consumption and reports electricity related scope 2 emissions of 0 t CO_2 eq, resulting to a 30 % reduction in its total corporate emissions (Brander *et al.* 2018). In contrast, the otherwise identical Company B does not purchase contractual agreements for its grid electricity consumption, but invests the equivalent money in an energy efficiency program. These measures reduce its electricity consumption and scope 2 emissions by 10 %.

Consumers and investors use the GHG reports of the two companies to make their purchasing and investment decisions (Brander *et al.* 2018). They prefer Company A, since it seems to have a better environmental performance. However, Company A's consumption of grid electricity remains unchanged. Assuming that the purchase of RES based GOs does not sufficiently incentivise the construction of new RES based power plants, no physical emission reduction takes place. In contrast, Company B has reduced its demand for grid electricity, some of which is supplied by fossil fuel power plants. As a result, emissions are actually reduced.

In addition, to prevent that the exclusive claiming of grid electricity from specific energy sources leads to double counting, the market-based methodology requires the application of residual electricity mixes, in case no valid contractual agreements are acquired (WRI & WBCSD 2015). As this residual mix emission factor is higher than the average grid emission factor, Company B's performance is again represented worse (Brander *et al.* 2018)."

II.1.2.2.2.1 Additionality

Some Energy Attribute Certificate (EAC) rely on electricity producing assets that were built some time ago. Some, like in France, can be rather old. Using such old assets, has no influence on the decarbonization of electricity mixes nor on the production stage real emissions.

The whole purpose of Energy Attribute Certificate (EAC) is to promote decarbonization through the construction of new low carbon electricity production plants. If the EAC that are used for TranSensus-LCAs are coming from old power plants, then their decarbonization effect can be questioned (the GHG emissions of the consumed electricity will be the same, whether or not the product under study uses such EAC, since the plants are already there since a long time).

Recent (below 5 years) important retrofit / repowering should also be considered because these actions can be cost effective and therefore could benefit from additional revenues.

A safeguard on additionality will help avoid accusations of resource shuffling.

II.1.2.2.2.2 Time consistency

At every moment, electricity consumption and production should be at an equilibrium through the grid, otherwise the grid would collapse.

As power produced by renewables depends on the weather, and not on manufacturing schedules, it is possible that there is not a perfect match between electricity production and consumption, as illustrated by the following figure, which is Figure II-11: "Typical daily solar generation curve and load curve" from the GBA GHG Rulebook:

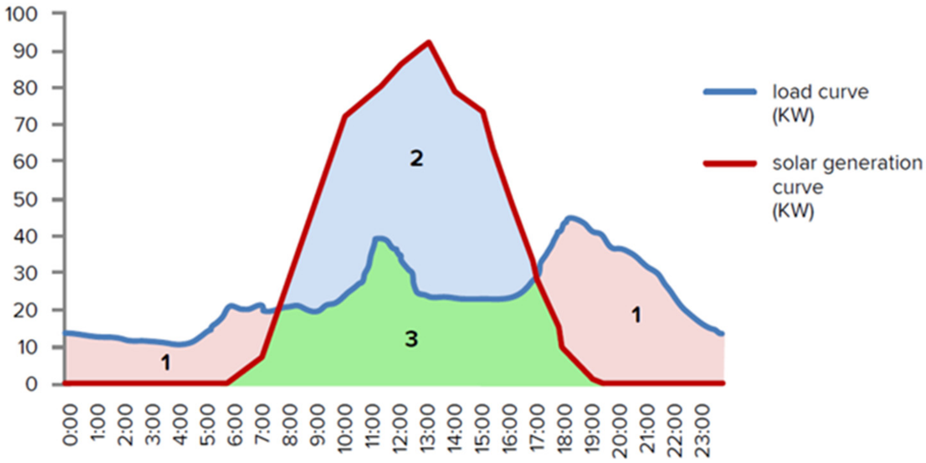


Figure II-11: Typical daily solar generation curve and load curve from the GBA GHG Rulebook

In this chart, only the electricity from area #3 (in green) can be counted as consumed during the production stage. The energy of area #2 cannot physically be consumed during the production stage.

It is not physically correct to attribute the electricity production of both areas 2 and 3 of the above figure to the product production stage.

The best possible option would be an hourly production/consumption time synchronization. Some projects are being developed for that purpose (see https://energytag.org/ for hourly disclosure projects and see Trader (certigy.net) for a software solution for Granular Certificates, up to the hour).

Nevertheless, such an option may not be always possible, therefore the need to have less granular certificates. Monthly production/consumption time synchronization are possible in some countries such as France and Sweden.

When neither hourly nor monthly production/consumption time synchronization are available, then the last resort solution will be an annual production/consumption time synchronization, which is already available.

II.1.2.2.2.3 On-site electricity production

There may be some electricity production systems (e.g., solar panels, wind turbines) within the boundaries of the LCA. This would be the case for instance for an electricity production system that is located within the premises of any manufacturing or operating site that is part of the vehicle value chain and/or directly connected to such sites but not connected to the grid.

To be characterised as an on-site electricity production system, it should be owned by the company manufacturing or operating the vehicles. In such a case the produced electricity is part of the system, there is no need to buy it, it can be considered as a "co-product" that is meant to be consumed within the system.

To be noted: this case is in nature different from the case where the consumed electricity is bought from an external entity (with or without an Energy Attribute Certificate) to fulfil the needs of the vehicle life cycle. For instance, if an external company owns and operates a photovoltaic system installed on a company manufacturing premises, and sells the generated electricity to the manufacturing company, the photovoltaic system shall be considered as an external system (outside of the boundaries of the LCA). Whereas the same photovoltaic system, being owned by the manufacturing company, and operated by an external entity (which is paid for that), in the name of the manufacturing company, shall be considered an on-site production system.

For all on-site electricity production systems, part of the produced electricity can be consumed by the product system under study and part of it can be fed into the grid (excess of production).

There may be some electricity production systems within the boundaries of the study. These will be called on-site electricity production systems if they are owned by the entity that owns and operates the premises. Such systems may exist on manufacturing sites.

Since, in most cases, part of the on-site electricity production will be consumed during the production stage and part will be fed to the grid, part of the on-site electricity production system inventory should be allocated to the production stage (the inventory should be prorated according to the amount of electricity consumed by the manufacturing sites and produced by the considered on-site electricity production system). This recommendation is derived from usual boundaries and allocation rules.

The way on-site electricity production is handled for the production stage does not depend on whether the location-based or the market-based approach is chosen for the production stage electricity consumption modelling.

For harmony and comparability, we decided to neglect exceptions (e.g. home chargers fed by solar panels for instance) and therefore not to consider / model on-site electricity production for the use stage for Product LCA.

For both Prospective and Fleet LCA we decided to consider and model on-site electricity production for the use stage, to allow the analysis of situations that can occur today (charging stations equipped with solar panels for instance) and in the future, as long as these situations are clearly described and documented.

For simplicity and robustness (it would be very difficult to make robust assumptions for on-site electricity production during the EoL stage), we decided not to consider / model on-site electricity production systems for the EoL stage for all types of LCA.

Negative emissions/impacts is a very controversial topic. TranSensus-LCA methodology, to be as robust as possible, should not allow to consider negative emissions/impacts to avoid raising doubts and criticism. This recommendation is in line with the one related to the safeguards for the use of Energy Attribute Certificate (EAC) related to the excess of production that is not consumed during the product LCA production stage.

II.2 Use stage modelling

II.2.1 Estimating the energy requirements of vehicles

There is a gap between regulatory testing results (i.e. WLTP) and real-world energy consumption performance of light duty vehicles, which is well documented and significant. There are also efficiency degradation effects anticipated over the vehicle lifetime in some cases for all vehicle categories. These differences can be defined through two separate effects (i) differences due to energy demands not captured during regulatory testing and due to user behavior and real-world environmental/operational conditions, (ii) degradation in vehicle efficiency over the life of the vehicle (mainly affecting fuel cell electric vehicles).

For light-duty vehicles, it has been previously agreed within TranSensus-LCA's previous voting rounds to include accounting for impacts on the gap to real-world energy consumption either by default, or as a mandatory sensitivity (depending on the requirements set out at the UNECE-level, or the methodology to be developed by the EC for voluntary LCA reporting under the LDV CO_2 regulations). There is now a need to define the specific methodological basis and data prioritization recommended for this, so that such calculations can be performed in a consistent and harmonized way.

In addition to differences in performance in real-world conditions compared to regulatory testing for new vehicles, there is a need to account for loss in vehicle efficiency over its lifetime in some cases (for light-duty, heavy-duty and other vehicle categories). For batteries used in electric vehicles, the reduction in round-trip charge/discharge efficiency is reportedly very low (unlike energy storage capacity loss, is significant). However, for fuel cells there is a more significant loss in overall efficiency due to a reduction in the peak power/voltage over the life of the fuel cell (with fuel cell durability defined as the number of operational hours until 10% peak power degradation). This loss in efficiency over the lifetime of the use of the vehicle also needs to be taken into account in the calculations, where it is anticipated to be significant. Such calculations can be performed in a consistent / harmonized way.

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 recommend including this. However, the situation for fuel cells is different, where efficiency degradation is expected to be significant, particularly for HDVs.

For fuel cells, efficiency losses occur over the operational life of the vehicle. It is proposed that the average loss of efficiency (used to calculate an amended lifetime average energy consumption in MJ/km) to be calculated based on the fuel cell durability assumptions and operational lifetime km, as outlined below. Fuel cell durability is defined as the number of operational hours to reach 10% degradation of the original fuel cell rated power (in kW)[3]. 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.)

II.2.2 The Well to Tank (WTT) modelling

II.2.2.1 Electricity

Within BEVs, the electricity consumption associated with the use phase accounts for a substantial share of the total life cycle impacts. Therefore, the modelling method for calculating the impact of the electricity is significant. The following four-step process should be followed:

1. Select a scenario for default conservative dynamic grid mix projections,
2. Calculate the grid mix composition for each year over the assumed service life of the vehicle,
3. Determine assumptions,
4. Build the bespoke grid mix model developed at STEP 3 for 'specific vehicle use phase' into the LCA software of choice.

[3] FCH 2 JU - MAWP Key Performance Indicators (KPIs) - European Commission (europa.eu)

STEP 1: Selecting a scenario for default conservative dynamic grid mix projections

When selecting a scenario for the default conservative dynamic grid mix projections, the following scenario hierarchy should be used for the specific location of interest:

- Where possible, an official national or regional supply mix scenario should be used.
  - For example, the HM Treasury Green Book can be used for modelling electricity use in the UK, or other country or regional equivalents can be used.
  - **Conditions:** If available, the official national or regional supply mix scenario should be used as the default, though additional alternative scenarios may be adopted for sensitivity analysis.
- If official national or regional supply mix scenarios are unavailable, then unofficial national or regional supply mix scenarios, based on currently implemented policy, should be used.
  - For example, the EU Reference Scenario 2020, or other unofficial scenarios and projections from national / regional governmental bodies provided for indicative purposes.
  - **Conditions:** Ensure that the scenario is updated within < 3 years after publication. If available, the unofficial national or regional supply mix scenario should be used as the default, though additional alternative scenarios may be adopted for sensitivity analysis.
- If official or unofficial national or regional supply mix scenarios are unavailable, then the International Energy Agency's Stated Policies Scenarios (STEPS) for a specific location should be used.
  - **Conditions:** If datasets for specific locations are unavailable, then regionally-representative datasets can be used. Additional alternative scenarios may be adopted for sensitivity analysis, e.g. SDS or others published within the World Energy Outlook (WEO) report).
- If the above are unavailable, then a 'static' grid mix projections for the specific country or region should be used.
  - In the absence of datasets for a specific location for scenarios 1-3, or if specific provisions apply*, a static mix projections may be used. When static mix modelling is the only possible approach for a given location, it is recommended that alternative assessment using 100% renewable electricity mix be undertaken. When special provision applies, and a sensitivity is conducted on dynamic future mix projections, one of the applicable scenarios from 1-3 shall be adopted.

*Special provision to deviate from this consideration for 'default' scenario, allowing the use of 'static' electricity mix projections, to overcome legal concerns associated with corporate reporting requirements; Dynamic mix modelling must be undertaken as a part of sensitivity analyses.

STEP 2: Calculating the grid mix composition for each year over the assumed service life of the vehicle

A dynamic mix composition for a given location should be calculated for each year through linear regression, using pre-defined time horizons (e.g., 2030, 2035, 2040, 2050), as a percentage (%) share of electricity supplied $S_{I,N}$, by each technology I in the year N.

Table II-6: Example with dummy figures from IEA Stated Policies Scenario (STEPS), energy generation from different types of technology (generation capacity in % shares)

Grid Mix Projections	2030	2035	2040	2050
Solar PV	15%	21%	26%	32%
Wind	15%	19%	20%	22%
Nuclear	9%	9%	9%	9%
Other technologies	…%	…%	…%	…%

STEP 3: Determining assumptions

There are two approaches available for calculating the vehicle lifetime activity for each year:

I. **Approach employing 'uniform' vehicle use intensity:** Assume a simplified homogenous distributed vehicle activity (km travelled per year as percentage (%) share of annual vehicle activity) over the vehicle lifetime based on L/N km. L = total vehicle lifetime activity and N years of vehicle operation; NOTE: This assumption could oversimplify the demonstration of a vehicle's operational impact over its lifetime.

II. **Approach employing 'variable' vehicle use intensity:** For a more representative scenario, and with the availability of relevant statistical evidence, assume a weighted distribution of vehicle use intensity (percentage (%) share of annual vehicle activity), over the vehicle lifetime, through this expression:

$$W_n = A_N/L$$

AN = annual vehicle activity in year N; L = total lifetime activity

Example: Assuming vehicle lifetime activity of 250,000 v.km in 20 years, data available to suggest vehicle does 25,000 miles per year between 2025-2030; 20,000 miles per year between 2030-2035 and then only 5,000 miles between 2035 and 2045, weighted share of vehicle activity is calculated over its use-phase as below:

Table II-7: Example weighted share of vehicle activity with dummy figures

Years of vehicle operation	2025	2030	2035	2040	2050
Example weighted share of vehicle activity (1-W_N)	50%	40%	5%	5%	0%

There are two approaches available for calculating the average representative grid mix composition over full service life of the vehicle:

I. **Approach employing 'uniform' vehicle use intensity:** By default, as the arithmetic average of individual shares of electricity supplied from STEP 2.

II. **Approach employing 'variable' vehicle use intensity:** If vehicle intensity is anticipated to change over time and if year-specific activities are estimated with sufficient confidence, then a more detailed, accurate modelling approach may be adopted. To calculate a weighted average of individual shares of electricity supplied using:

$$wS_{LN} = \sum_N W_N S_{LN}$$

Example: $_{w}S_{solarPV,2025\text{-}2045}$ = [(10% * 6%) + (10% * 8%) + (10% * 10%) + (10% * 11%) + (10% * 13%) + (8% * 15%)...]

Repeat the steps for each electricity generation share, over the entire vehicle lifetime and sum up the outputs to get a weighted grid mix composition.

Table II-8: Example assumptions for vehicle activity and grid mix composition over the full service life of the vehicle using approach I

Parameters	2025	2026	2027	2028	2029	2030	2031	2032
Vehicle activity share	10%	10%	10%	10%	10%	8%	8%	8%
Solar PV	6%	8%	10%	11%	13%	15%	16%	17%
Wind	9%	10%	11%	12%	14%	15%	16%	17%
Nuclear	9%	9%	9%	9%	9%	9%	9%	9%
…	…%	…%	…%	…%	…%	…%	…%	…%
Total grid mix composition (as a weighted % share)	…	…	…	…	…	…	…	…

Table II-9: Example assumptions for vehicle activity and grid mix composition over the full service life of the vehicle calculate using approach II

Generation technologies	Generation share (%)					Vehicle use intensity (%)					wS_{LN} (%)
Renewables	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045	-
Solar PV	4	15	21	26	32	50	40	5	5	0	10
Wind	7	15	19	20	22	50	40	5	5	0	11

Generation tech-nologies	Generation share (%)					Vehicle use intensity (%)					wS_{LN} (%)
Hydro	15	14	13	12	12	50	40	5	5	0	14
Bioenergy	2	3	3	3	3	50	40	5	5	0	3
Of which BECCS	0	0	0	0	0	50	40	5	5	0	0
CSP	0	0	0	0	1	50	40	5	5	0	0
Geothermal	0	0	1	1	1	50	40	5	5	0	0
Marine	0	0	0	0	0	50	40	5	5	0	0
Nuclear	9	9	9	9	8	50	40	5	5	0	9
Hydrogen and Ammonia	0	0	0	0	0	50	40	5	5	0	0
Fossil fuels with CCUS						50	40	5	5	0	0
Coal with CCUS	0	0	0	0	0	50	40	5	5	0	0
Natural gas with CCUS	0	0	0	0	0	50	40	5	5	0	0
Unabated fossil fuels						50	40	5	5	0	0
Coal	36	23	17	14	9	50	40	5	5	0	29
Natural gas	22	18	15	13	11	50	40	5	5	0	20
Oil	2	1	1	1	1	50	40	5	5	0	2

STEP 4: Build the bespoke grid mix model developed at STEP 3 for 'specific vehicle use phase' into the LCA software of choice.

Build the bespoke grid mix model developed at STEP 3 for 'specific vehicle use phase' into the LCA software of choice. The way to do this can vary a lot even within the same software. Therefore, no snapshots are provided here. Please ensure the most up-to-date database processes for individual energy generation technologies are employed.

II.2.2.2 Hydrogen

Similarly as for BEVs and their use of electricity, the environmental impacts arising from the use stage of ZEV powertrains using hydrogen (i.e. FCEVs, FC-REEVs and H_2 ICEVs) represent a significant share of the total life cycle impacts of such vehicles. They are strongly dependent on the hydrogen fuel production and supply chain. Hydrogen can be supplied from a limited number of different sources and processes (currently steam reforming natural gas, or electrolysis of water, e.g. using grid electricity or renewable electricity). And compared to electricity, there is relatively much greater uncertainty on what the actual supply mix will be for future hydrogen fuelled vehicles, and how this is likely to change over time. This is important particularly for comparative LCAs, where the environmental impacts of different ZEV powertrains are likely to be compared to each other, and to those of ICEVs, and different assumptions can make a significant impact on comparisons.

In TranSensus-LCA, a decision has already been reached that a conservative dynamic electricity mix projection approach shall be used by default to model the electricity modelling input to the use stage of BEVs (with some exceptions, e.g. for OEMs where a static grid mix may be allowed). A similar approach is also proposed for hydrogen, however this is currently limited by the comparative lack of availability of robust future projections, compared to the availability of projections for future electricity supply mixes produced by the IEA. However, should official projections become available in the future, it is desirable to already have a proposed methodology that can account for this (similarly as for electricity).

II.2.3 Non-exhaust emissions

II.2.3.1 Hydrogen leakage

Hydrogen is used in several ZEV powertrains. It has a significant impact on their overall lifecycle emissions even with actual practices to consider only hydrogen production and supply without the impact of hydrogen itself. Hydrogen has been previously characterised as an indirect greenhouse gas, and recent scientific evidence suggests that these impacts are more than double that previously estimated. As part of the Impact Assessment, it has been recommended that until an official GWP value is agreed upon for hydrogen, a hydrogen emission flow indicator should be provided (see separate voting question under Task 2.4). Hydrogen emissions are not commonly captured in LCI datasets, and there is a need to define an approach to estimate the hydrogen leakage rate for consistency in modelling this.

Emissions of hydrogen can occur mainly during the hydrogen production and distribution stage (predominantly due to fugitive leakage) – see

Table II-10. Emissions are also anticipated to a lesser extent directly from hydrogen fuelled vehicles though no standardised test methods currently exist for this. H_2 can slip from combustion vehicles and potentially fugitive emissions from H_2 storage systems (particularly for liquefied hydrogen). Recent research has found emission rates of hydrogen from the supply chain are likely to be similar to those of methane from the natural gas supply chain, with net leakage rates estimated to be 2.6%-6.9% for green hydrogen supply chains by (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022) [4].

[4] Hydrogen emissions from the hydrogen value chain-emissions profile and impact to global warming - ScienceDirect - https://doi.org/10.1016/j.scitotenv.2022.154624

Table II-10: Estimated H2 supply chain emission rates from (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022)

	Production and processing	Compression	Storage and transport	Liquefaction	Haber-Bosch	Shipping	Regasification	NH_3 cracking	Transmission and storage	Distribution
USA biomass gasification for local use	0.55% (0.10–1.00%)									0.08% (0.05–0.12%)
Australian blue H_2 from coal for export to Japan	0.55% (0.10–1.00%)	0.18% (0.15–0.27%)	0.31% (0.06–0.53%)	0.34% (0.15–2.21%)		0.03% (0.00–0.10%)	0.00%		0.03% (0.02–0.05%)	0.08% (0.05–0.16%)
Qatar blue H_2 from natural gas for export to Japan	0.55% (0.10–1.00%)			0.33% (0.14–0.98%)		0.06% (0.01–0.17%)	0.00%		0.03% (0.02–0.05%)	0.08% (0.05–0.16%)
North Sea green H_2 for local use	2.05% (0.10–4.00%)								0.05% (0.04–0.06%)	0.02% (0.0003–0.03%)
Australian green H_2 for export to Japan	2.05% (0.10–4.00%)			0.32% (0.14–0.95%)		0.03% (0.003–0.10%)	0.00%		0.03% (0.02–0.05%)	0.08% (0.05–0.16%)
Saudi Arabian green H_2 for export to Japan- as LH2	2.05% (0.10–4.00%)	0.17% (0.14–0.26%)	0.31% (0.05–0.54%)	0.33% (0.01–2.04%)		0.06% (0.01–0.17%)	0.00%		0.03% (0.02–0.05%)	0.08% (0.05–0.16%)
Saudi Arabian green H2 for export to Japan- as NH3a	2.05% (0.10–4.00%)				0%	0%		0%	0.03% (0.02–0.05%)	0.08% (0.05–0.16%)

Notes: Engine slip of H_2 is reported to range from 0 to 12%, and a value of 0.5% was assumed in (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022).

II.2.3.2 Refrigerants

Leakage of refrigerants can have a direct impact on the environment. These refrigerants are typically a group of synthetic gases called hydrofluorocarbons (HFCs) that substituted their predecessor hydrochlorofluorocarbons, or HCFCs that contained chlorine due to the latter destructive impact on the ozone layer. Although HFCs are short-lived pollutants (≈15 years) (Climate and Clean air Coalition, n.d.) and do not pose a significant risk on the ozone layer, most of them have an extremely potent impact on climate in terms of global warming. The most concerning and historically used refrigerant is HFC-134a which has a global warming potential (GWP100) of 1300 (European Parliament, 2006).

The leakage of HFCs from vehicles is almost unavoidable. There are five different categories of HFCs emissions: emissions before vehicle becomes in use (in the supply chain of production for example), regular (steady) loss, irregular loss due to system failure, and emissions during service of the mobile air conditioners (MACs), and the end of life of the vehicle. (Schwarz & Harnisch, 2003)

According to (Schwarz & Harnisch, 2003), the amount of leakage from the first category is negligible, and the leakage from service and EoL can be assumed to be also negligible as long as service and dismantling facilities follow the set measures in the European context. For example, The ELV Directive (Directive 2000/53/EC (The European Parliament, 2000) requires the recovery of all fluids from old cars before scrapping. The irregular leakages due to system failures are arbitrary as the name implies. Similarly, this is unlikely to happen in the European context since vehicles are generally expected to follow strict maintenance schedule. Lastly, the regular or steady leakage is usually minimal according to some OEMs internal research. According to (Schwarz & Harnisch, 2003), this can be around 15 grams/year).

Furthermore, according to (European Parliament, 2006) in its phase 3, the use of fluorinated greenhouse gases with a GWP100 higher than 150 was totally banned for all new passenger cars and LDVs put on the EU market since January 2017. New vehicles with MAC systems using these gases are not registered, sold, or able to enter into service in the EU. One the other hand, for HDVs and temperature controlled commercial freight vehicles, there is no similar regulation as to our knowledge (European Parliament, 2024), but rather individual voluntary steps taken by some HDV OEMs to use low GWP refrigerants in their vehicles.

Based on these facts, and as a conservative approach it was agreed to set a threshold at 150 GWP100 or above as a general threshold for mandatory inclusion of refrigerants emissions.

How to estimate the amount of leakage is left to the practitioner, however we can suggest (Schwarz & Harnisch, 2003) as a useful reference to do so. In any case, proper documentation and transparency on how it was estimated should be provided.

II.2.3.1 Tyres and Brake wearing

Current official data are available from EMEP guidebook: EMEP/EEA air pollutant emission inventory guidebook 2023. Chapter *NFR code 1.A.3.b.vi* from *EMEP/EEA emission inventory guidebook 2013* provides the methodology for emission factors estimation (see below).

The following decision tree helps to select between Tier1 or Tier 2 emission factors:

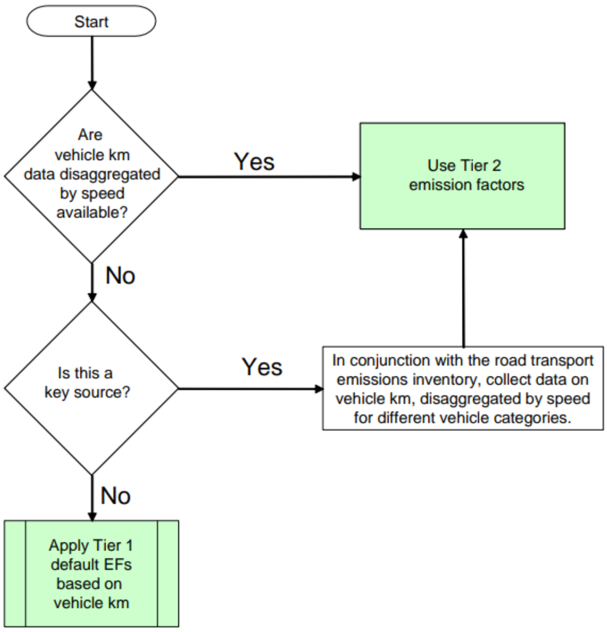


Figure II-12: Decision tree for vehicle tyre and brake wear and road surface wear

Brake and tyre particles emissions can be estimated combined or separately. Only separated emission factor estimation is presented below.

1) Tier 1 emission factors

Table II-11: Tier 1 emission factors for tyre and brake wear combined per vehicle type (according to source category defined in EMEP 1.A.3.b.vi document)

Tier 1 emission factors							
		Code	Name				
NFR Source Category		1.A.3.b.vi	Road vehicle tyre and brake wear				
Fuel		N/A					
Not estimated		PAHs, POPs, HCB, PCBs, dioxins and furans					
Pollutant	Vehicle type	Value	Unit	95% confidence interval		Reference	
				Lower	Upper		
TSP	Two-wheelers	0.0083	$g\ km^{-1}\ vehicle^{-1}$	0.0064	0.0103	EMEP-Corinair B770 v1.0	
PM10		0.0064	$g\ km^{-1}\ vehicle^{-1}$	0.0047	0.0081	EMEP-Corinair B770 v1.0	
PM2.5		0.0034	$g\ km^{-1}\ vehicle^{-1}$	0.0026	0.0042	EMEP-Corinair B770 v1.0	
TSP	Passenger cars	0.0229	$g\ km^{-1}\ vehicle^{-1}$	0.0083	0.0369	EMEP-Corinair B770 v1.0	
PM10		0.0184	$g\ km^{-1}\ vehicle^{-1}$	0.0067	0.0297	EMEP-Corinair B770 v1.0	
PM2.5		0.0093	$g\ km^{-1}\ vehicle^{-1}$	0.0034	0.0150	EMEP-Corinair B770 v1.0	
TSP	Light duty trucks	0.03427	$g\ km^{-1}\ vehicle^{-1}$	0.0190	0.0450	EMEP-Corinair B770 v1.0	
PM10		0.0271	$g\ km^{-1}\ vehicle^{-1}$	0.0148	0.0351	EMEP-Corinair B770 v1.0	
PM2.5		0.0139	$g\ km^{-1}\ vehicle^{-1}$	0.0076	0.0180	EMEP-Corinair B770 v1.0	
TSP	Heavy duty trucks	0.0777	$g\ km^{-1}\ vehicle^{-1}$	0.0462	0.1318	EMEP-Corinair B770 v1.0	
PM10		0.0590	$g\ km^{-1}\ vehicle^{-1}$	0.0500	0.0950	EMEP-Corinair B770 v1.0	
PM2.5		0.0316	$g\ km^{-1}\ vehicle^{-1}$	0.0281	0.0541	EMEP-Corinair B770 v1.0	

2) Tier 2 emission factors

The Tier 2 methodology expands upon the Tier 1 methodology to take account of the speed dependency of tyre and brake wear, and is based on the ‘Detailed Methodology’ in the previous version of the Guidebook.

$$TE = \sum_{j} N_j \times M_j \times EF_{TSP,s,j} \times f_{s,i} \times S_s(V) \qquad (2)$$

Where:

- TE = total emission for the defined time period and spatial boundary [g],
- N_j = number of vehicles in category *j* within the defined spatial boundary,
- M_j = mileage [km] driven by each vehicle in category *j* during the defined time period,
- $EF_{TSP,s,j}$ = TSP mass emission factor for vehicles in category *j* [g/km],
- $F_{s,i}$ = mass fraction of TSP that can be attributed to particle size class *i*,
- $S_s(V)$ = correction factor for a mean vehicle travelling speed *V*.

The index *j* relates to the vehicle category (similar to eq.1). The index *s* refers to the source of PM, i.e. tyre (*T*) or brake (*B*) wear. The particle size classes *i* are TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$.

2.1) Emission factors for tyre wear

According to vehicle category concerned, total suspended particles emissions from tyre wear can be estimated, as described in the following tables:

Table II-12: Total Suspended Particles (TSP) emission factors from tyre wear for vehicle category (EMEP-Guidebook)

Vehicle class (j)	TSP emission factor (g/km)	Uncertainty range (g/km)	Quality code
Two-wheel vehicles	0.0046	0.0042–0.0053	B
Passenger cars – ICE – Mini	0.0085	0.0053–0.0128	D
Passenger cars – ICE – Small	0.0096	0.0060–0.0145	C
Passenger cars – ICE – Medium	0.0107	0.0067–0.0162	B
Passenger cars – ICE – Large	0.0118	0.0074–0.0179	C
Passenger cars – Hybrid – Mini	0.0089	0.0056–0.0134	D
Passenger cars – Hybrid – Small	0.0100	0.0063–0.0151	D
Passenger Cars – Hybrid – Medium	0.0111	0.0070 - 0.0168	D
Passenger Cars – Hybrid – Large	0.0123	0.0077 - 0.0186	D
Passenger Cars – PHEV – Small	0.0101	0.0064–0.0153	D
Passenger Cars – PHEV – Medium	0.0112	0.0071 - 0.0170	D
Passenger Cars – PHEV – Large	0.0124	0.0078 - 0.0188	D
Passenger Cars – BEV – Small	0.0105	0.0066 – 0.0161	C
Passenger Cars – BEV - Medium	0.0116	0.0072 – 0.0178	C
Passenger Cars – BEV – Large	0.0127	0.0079 – 0.0195	C
Light-Commercial Vehicles (N1 – I)	0.0107	0.0067–0.0162	B
Light-Commercial Vehicles (N1 – II, III)	0.0169	0.0088–0.0217	B
Heavy-Duty vehicles	Equation 3	0.0227–0.0898	B–C

Note:
B: Emission factors are non-statistically significant based on a small set of measured re-evaluated data.
C: Emission factors estimated based on available literature.
D: emission factors estimated by applying similarity considerations and/or extrapolation.
For BC emission factor estimation it is proposed to use a BC fraction of TSP of 0.153, c.f. Appendix B.

Table II-13: Size distribution of tyre wear particles

Particle size class (*i*)	Mass fraction ($f_{T,i}$) of TSP
TSP	1.000
PM_{10}	0.600
$PM_{2.5}$	0.420
PM_{1}	0.060
$PM_{0.1}$	0.048

2.2) Emission factors for brake wear

According to vehicle category concerned, total suspended particles emissions from brake wear can be estimated, as described in the Table II-14:

Table II-14: Total Suspended Particles (TSP) emission factors from brake wear for vehicle category

Vehicle category (j)	TSP emission factor (g/km)	Range (g/km)	Quality code
Two-wheel vehicles	0.0037	0.0022 – 0.0050	D
Passenger cars – ICE – Mini	0.0082	0.0050 - 0.0110	D
Passenger cars – ICE – Small	0.0102	0.0061 - 0.0137	C
Passenger cars – ICE – Medium	0.0122	0.0073 - 0.0165	B
Passenger cars – ICE – Large	0.0143	0.0085 - 0.0190	C
Passenger cars – Hybrid – Mini	0.0065	0.0040 - 0.0090	D
Passenger cars – Hybrid – Small	0.0081	0.0048 - 0.0110	D
Passenger Cars – Hybrid – Medium	0.0097	0.0058 - 0.0131	D
Passenger Cars – Hybrid – Large	0.0114	0.0068 - 0.0153	D
Passenger Cars – PHEV – Small	0.0055	0.0033 - 0.0074	D
Passenger Cars – PHEV – Medium	0.0066	0.0039 - 0.0089	D
Passenger Cars – PHEV – Large	0.0077	0.0046 - 0.0104	D
Passenger Cars – BEV – Small	0.0030	0.0017 - 0.0040	C
Passenger Cars – BEV - Medium	0.0035	0.0021 - 0.0046	C
Passenger Cars – BEV – Large	0.0040	0.0025 - 0.0055	C
Light-Commercial Vehicles (N1 – I)	0.0122	0.0073 - 0.0165	B
Light-Commercial Vehicles (N1 – II, III)	0.0173	0.0104 - 0.0234	C
Heavy-Duty vehicles	Equation 6	0.0235 – 0.0420	B–C

Note

Quality codes:

- B: emission factors non statistically significant based on a small set of measured re-evaluated data;
- C: emission factors estimated on the basis of available literature;
- D: emission factors estimated by applying similarity considerations and/or extrapolation.

For BC emission factor estimation it is proposed to use a BC fraction of TSP of 0.0261, c.f. Appendix B.

Then, in order to estimate PM_{10} or $PM_{2.5}$ emissions from brake wear, the following size distribution can be applied:

Table II-15: Size distribution of brake wear particles

Particle size class (*i*)	Mass fraction ($f_{B,i}$) of TSP
TSP	1.000
PM_{10}	0.980
$PM_{2.5}$	0.390
PM_1	0.100
$PM_{0.1}$	0.080

II.2.4 Maintenance

For most known applications like passengers cars, batteries and fuel cells do not need to be replaced during the vehicle lifetime. Nevertheless, it may not always be the case when considering specific applications or usages. Then, because battery or fuel cell replacement have important consequences on LCA results, specific guidance is provided.

Especially, it is known that batteries and fuel cell ageing depend on many complex parameters. Additionally, the way the vehicle is used (and consequently, the way the battery or fuel cell of the vehicle is used), varies. It is therefore relevant to use, when available, the ageing model that is the most representative of the system under study, associated to a mission profile that is correctly defined accordingly to the usage under study (Lavisse *et al.*, 2023)

Note that, even if the ageing model is not easily available and highly specific to a system reference, vehicle OEM generally have it (from tests results or, when these long tests are not completed at the time of the study, from extrapolation), because of the importance of the system ageing prediction for the vehicle design and also for related warranty considerations. Battery or fuel cell systems manufacturers, who qualify their systems, also have this.

In case it is not possible to use an ageing model, then simplified methods to calculate the battery or fuel cell ageing are described in the methodology, based on a number of charge/discharge cycles (as also previously implemented in (Ricardo *et al.*, 2020) from consultation with stakeholders). Note that this approach is simplified since, for batteries, the ageing model depends both on the cycling but also on the calendar ageing (Redondo-Iglesias *et al.*, 2018). The last possibility, when previous solutions cannot be applied, rely on default values. Figures that are provided in the methodology are expert values defined by the working group, some of them being also based on Ricardo's review of publicly available information (for instance as previously used in modelling for the European Commission - (Ricardo *et al.*, 2020), Appendix A4, Table A35).

Further insights into the battery and fuel cell replacement assumptions:

For traction batteries and fuel cells systems, the frequency of replacement is directly related to the ageing model of the system and its mission profile. The ageing model will help to determine how many years the system will last, in relation to a mission profile, which defines (among other parameters) the driven distance per year. It depends on many parameters such as the battery chemistry, the thermal management, the environmental conditions, the parking stages, the usage (and especially operational power for fuel cells) during driving, the type of recharge, etc.

The ageing model gives the system degradation and therefore whether the system is still good for operation or if it must be changed. It is specific to a system reference (ex: battery chemistry, cell's reference, thermal management system, etc.). For batteries, the ageing includes both: cycling ageing (= battery charge and discharge cycles) and calendar ageing (= battery ageing with time when it does not deliver or receive current, for instance when the vehicle is parked without charging, that is to say not in operation). For standard usage of passenger cars, which are most of their time driven during a very limited time each day, then the calendar ageing should not be neglected. For fuel cell systems, the ageing mainly depends on the ageing due to hours of operation and average power level.

The mission profile is the way the system is used. It depends on the vehicle's mission profile. For the vehicle, the mission profile is created as follows:

a. List the different typical trips performed by the user (e.g., work commute, weekend excursion, holidays)

Then for each kind of trip:

b. Define its typical length in km

c. Define the number of times this trip is performed per year

d. Define a typical speed profile (can look like a WLTP cycle, but on the full length of the trip)

e. Define the type of charging after the trip (charging power, charged once every x trips, state of charge (SOC) limit)

f. For long trips, define the type of charging during the trip (charging power, SOC limits)

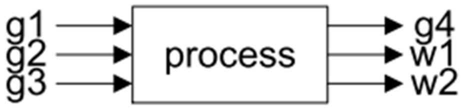
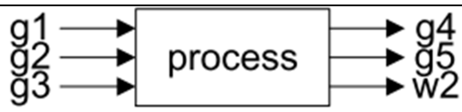
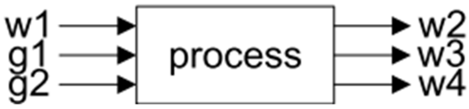
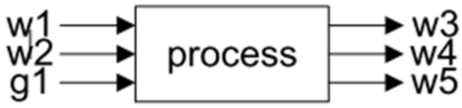
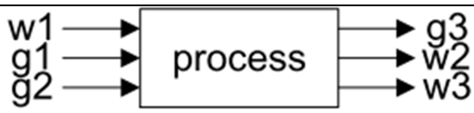
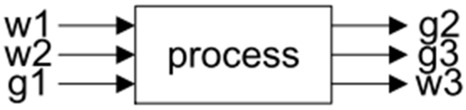
g. Consider the climate where the car operates, define the external temperatures at which the trip is performed (e.g., x times at 0°C, y times at 10°C, z times at 20°C,...).

For the battery system, the mission profile is defined from the mission profile of the vehicle using the vehicle model. The vehicle speed profile is transformed into the battery system power profile, and the vehicle external climate temperature profile is transformed into the battery system temperature.

II.3 Multifunctionality problems

Table II-16 summarizes the different Typologies of mono- and multi-functional processes. It includes a mono-functional production process as well as a mono-functional waste process as references and one example of a combination of the three basic typologies.

Table II-16 : Typologies of mono- and multi-functional processes

Typol-ogy #	**Typology**	**Example***	**Functional Flow(s)**	**#Functions**
1	Mono-functional production process		g4	1
2	**Co-production process**		**g4;g5**	**2**
3	Mono-functional waste process		w1	1
4	**Combined waste processing**		**w1;w2**	**2**
5	**Recycling**		**w1;g3**	**2**
6	**Combined waste processing and recycling**		**w1;w2;g2;g3**	**4**

II.3.1 Multifunctionality in the end of life

Multifunctionality in the end of life of a vehicle or battery typically arises from open-loop recycling producing secondary materials, and/or open-loop energy recovery from incineration (electric or heat energy) and landfilling (via biogas collection), and/or open-loop reuse (second use in another system or life cycle). This means that in addition to the function identified in the functional unit, there are additional functions delivered to another subsequent system[5], therefore

[5] This is not the case for 100% closed loop reuse, recycling or energy recovery where secondary commodities generated are explicitly consumed within the system boundary of the same system generating it, hence no multifunctionality problem to start with because these flows never cross its system boundary to another system or to the market.

there is a need to allocate burdens and benefits between the system understudy and any subsequent systems that will use these secondary commodities.

The cut-off approach which is also referred to as "recycled content" or "100:0" approach (Frischknecht, 2010; Schrijvers *et al.*, 2016b, 2016a) excludes any additional functions that might arise from waste treatment from the first life cycle, hence attributing the impact of obtaining these co-functions entirely to the function of the system understudy (i.e. the waste-generating system) until what is known as the "cut-off point", after which the resulting co-functions (i.e. recyclable materials or recovered energy) come "burden-free" for a subsequent system to use as input (Nordelöf *et al.*, 2019; Schrijvers *et al.*, 2016a; Zackrisson *et al.*, 2010). Consequently, this approach follows the polluter pay principle as indicated in the international EPD program (EPD, 2021) and modules A to C in EN 15804 (European Union, 2021). The cut-off approach is mentioned in ISO 14067 (ISO, 2018) under the name "process subdivision" which makes it also compatible with ISO 14044 (ISO, 2020) as stated by Schrijvers *et al.*, (2016b). See a simple depiction of the cut-off approach in Figure II-13.

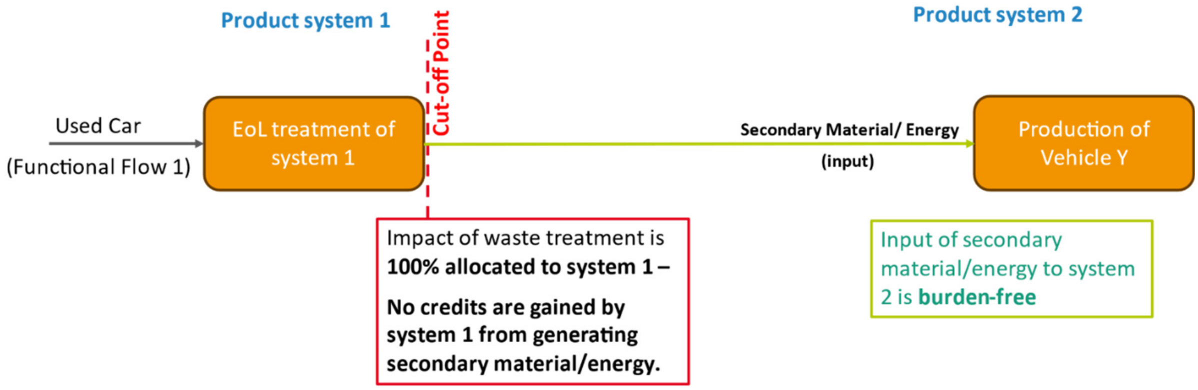


Figure II-13 : Depiction of cut-off approach

The cut-off approach is typically associated with a simple application and environmental conservativeness. As indicated by Frischknecht, (2010), it adopts a risk-averse approach as it aims not to shift any burdens into the future. Moreover, it follows what's called the "strong sustainability" concept which considers that natural capital shall be kept constant, independent of man-made capital (non-substitutability concept) (Frischknecht, 2010). The cut-off approach is a default choice when companies have control over the recycled content in their product (to balance the cycle upstream with burden-free recycled content input), when the time frame of the life cycle is very long (increased uncertainty about the future), or in a market with a higher supply than demand for the recycled material (providing a balance by encouraging the consumption of recycled material) (Schrijvers *et al.,* 2016b). At least the first two conditions apply in the case of vehicles. Moreover, it fits into an attributional LCA context (Ekvall *et al.*, 2020).

The Circular Footprint Formula (CFF) is not part of the TranSensus-LCA method in this current version, however it is to be considered in the future if improvements are carried out on the formula, especially those related to applicability and complexity concerns (Ekvall *et al.*, 2020) (See also Deliverable D1.1 and D2.2 for more information)

II.3.1.1 Cut-off point

The cut-off point is the point where the system boundary of the waste-generating system ends, and outputs come burden-free to other systems. The cut-off point can lie immediately after the use stage ceases (Frischknecht, 2010) or at any point of the waste treatment value chain after (Nordelöf *et al.*, 2019; Schrijvers *et al.*, 2016a). The former, however, aligns neither with the aspired conservativeness discussed above (because it still shifts impacts to the future), nor with the system boundary decided in TranSensus-LCA (i.e. cradle to grave). Furthermore, it is not the common choice in literature (Catena-X Automotive Network, 2023; Filière automobile & mobilités (PFA), 2022; Global Battery Alliance (GBA), 2022; Wernet *et al.*, 2016). So, TranSensus-LCA opted for the latter option.

For used ZEVs, the EoL value chain can get quite complex, so at least a handful of pre-treatment processes always exist. This typically includes at least collection, pretreatment (depollution), dismantling, shredding (ISO, 2002; The European Parliament, 2000). It was agreed in TranSensus-LCA that the impact of these activities including the transportation in between are always attributed to the EoL of the product under study (i.e. waste generating system). An obvious reason to model the EoL at least until sufficient sorting and separation[6] is to make a clear distinction between the types of resulting waste streams whether it is recyclable materials or non-recyclable materials for incineration or landfilling (Nordelöf *et al.*, 2019).

Given the variability of the subsequent activities that each waste stream goes through, we adopt the "market value" as a general reference to determine where the cut-off point should ideally be for each waste stream resulting from pretreatment, dismantling, and shredding. The market value can be perceived as a numerical translation of the End of Waste (EoW) status condition of having an existing market or demand for the substance or object (EPD, 2021; European Council, 2008). This means that the generator of the waste shall bear the full environmental impacts until the point in the product life cycle in which the waste stream no longer has negative market value. Negative market value comes from the fact that money must be paid to get rid of the waste. In other words, moving from "waste" to "good" following the terminology of Guinée *et al.*, (2004) which associates a "good" with positive market value and a "waste" with negative

[6] ecoinvent cut-off system model places the cut-off point after vehicle shredding and sufficient separation and sorting (Wernet *et al.*, 2016)

market value. In case the positive value is obtained for a waste stream immediately after pre-treatment, dismantling or shredding, then this becomes its cut-off point.

If it is impossible to follow the economic value of a certain flow, it was decided within TranSensus-LCA to provide general vehicle EoL management scheme with preset cut-off points. It was developed considering the ELV directive (The European Parliament, 2000), and ISO 22628 (annex B) (ISO, 2002) and with further input from Accardo *et al.*, (2023). For each waste stream, we provide a default cut-off point striking the balance between conservativeness and compatibility with current practices (e.g. databases). For example, for conservativeness, we mandate that incineration should always be borne by the waste-generating system, but on the other hand advanced material recycling lies within the boundary of the subsequent system which is the common practice (e.g. ecoinvent).

This reference model can be used partially (if market value of ***some*** waste streams are hard to trace) or fully (if market value of ***all*** waste streams are hard to trace).

II.3.1.2 Acknowledged risks in application

The main limitation of this approach is potential double counting or between-systems treatment processes omission. The first is expected when the subsequent system (could be other industries than automotives) accounts for impacts that were already accounted for in the first life cycle. The omission of in-between processes is the other face of the same coin, when material flows enter the next system burden-free without ensuring that all processes leading to these flows were considered (i.e. knowing where the EoL of previous system ceased). Until a global harmonization of cut-off points across sectors is realized, this problem will persist.

Currently, OEM LCA practitioners mostly use secondary datasets to model the supply chain of the recycled material (e.g. an average of EU recycling processes for a certain material). The exact source of the recycled material is often unknown as it is bought from a scrap market (in case of steel or aluminium for example). The recycled material enters the OEM's system boundary "burden-free" but the impact of necessary processing steps to produce the final recycled component must be accounted for by the OEM. Moreover, it is always recommended to read the documentation of used commercial datasets to explore what activities are already included there and what might need to be added. This practice is crucial to reduce the aforementioned risk of both double counting and omission. This will appear in the impact distribution between production and EoL stages like in Figure II-14:

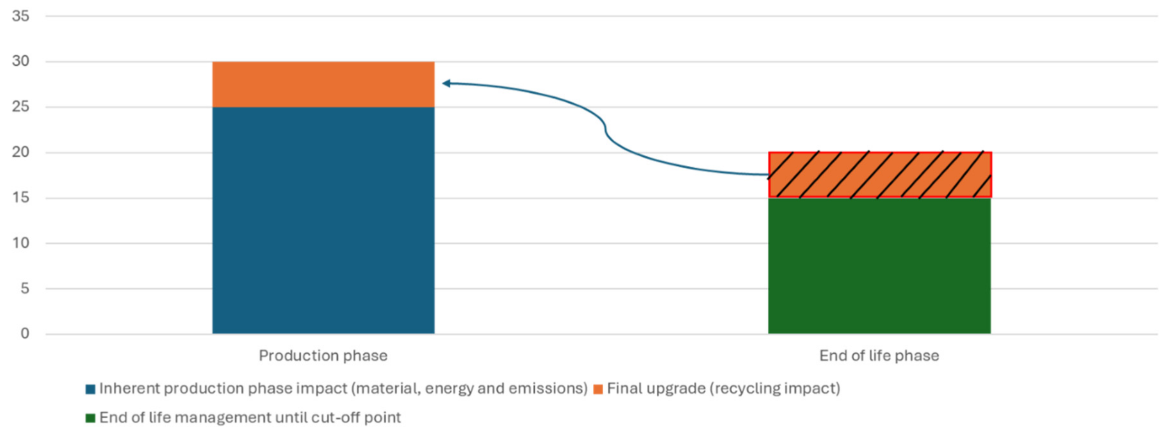


Figure II-14 : Expected effect of cut-off approach on the impact distribution between production stage and end of life stage

II.4 Data quality rating (DQR)

According to ISO 14044 (ISO, 2020), a data quality assessment must be performed. This assessment relates differently to each LCA phase. An overview on this is provided in Table II-17. Data quality assessment is emphasized further in case of third-party reporting.

Table II-17 : Data quality assessment in ISO 14044

Goal and Scope Definition	Life Cycle Inventory	Life Cycle impact assessment	Interpretation
In the scope definition, minimum data quality requirements that fulfil the goal of the study shall be defined. These include time, geography and technology coverage, precision, completeness, consistency, reproducibility, source, and uncertainty	When collecting data, further information about data quality indicators shall be referenced. If such data do not meet the data quality requirements, this shall be stated. This shall be validated whether it fulfils data quality requirements in scope definition.	Data quality analysis is mentioned as an optional step after weighting. To be done via gravity, uncertainty, or sensitivity analysis	Has an impact on mandatory interpretation components which are completeness check, sensitivity checks, and consistency checks.

ISO however doesn't provide a specific way to execute such data quality assessment. In order to tackle this issue, what is called Data Quality Rating (DQR) became a staple part of many guidelines including PEF. Nevertheless, there is no consensus on a single method to calculate it. Although all methods depart from the same concept of defining criteria for quality (mostly inspired from ISO data quality requirements in Table) and giving each criterion a qualitative or more commonly quantitative score, they differ in the criteria suggested and the scoring system. The criteria are usually related to technological, geographical, time representativeness, in addition to completeness, and reliability of each exchange (inflow/outflow of a unit process). Then each exchange within an activity is assigned a single DQR depending on the average of the scores in each of these criteria. See example from Catena X in Figure III-16 below:

Data quality rating	1 – Good	2 – Fair	3 – Poor
Technology (TeR)	Same technology	Similar technology (based on secondary data)	Different or unknown technology
Time (TiR)	Data from reporting year	Data less than 5 years old (creation date of dataset)	Data more than 5 years old (creation date of dataset)
Geography (GeR)	Same country or country subdivision	Same region or subregion	Global or unknown
Completeness (C)	All relevant sites for specified period	<50% of sites for specified period or >50% of sites for shorter period	Less than 50% of sites for shorter time period or unknown
Reliability (R)	Measured activity data	Activity data partly based on assumptions	Non-qualified estimate

The data quality rating for activity data or an emission factor shall then be calculated from the five data quality indicators as an arithmetic mean.

$$DQR = \frac{TeR + GeR + TiR + C + R}{5}$$

Figure III-16 : Catena-x proposed sample scoring criteria for performing a qualitative data quality assessment (Please note this is taken from Catena X V2, Catena X V3 has a slightly different DQR method)

Catena-x in its version 2 proposed five criteria (which they call indicators) and only 3 scores Good, Fair, Poor which are translated into numbers 1, 2, 3 respectively, with 1 indicating the best quality.

Another variation of the same concept is found in ecoinvent which is the pedigree matrix. ecoinvent applies a method for estimation of default standard deviations for flow data. Characteristics of these flows and the respective processes are turned into uncertainty factors in a pedigree matrix, starting from qualitative assessments. The uncertainty factors are aggregated to the standard deviation. This approach allows calculating uncertainties for all flows in the ecoinvent database. For more information See (Ciroth *et al.*, 2016; Muller *et al.*, 2016; Weidema *et al.*, 2013)

III. LCIA requirements: background, justification & consensus building

III.1 Calculation of LCIA results

III.1.1 Mandatory set of Impact Categories (IC)

Most OEMs regularly report a set of impact categories, mainly global warming potential (GWP), acidification potential, eutrophication potential and photochemical ozone creation potential. This restrained list is often arbitrary chosen, inspired by the review of other published product LCAs. Two opposite needs are highlighted in D1.2:

1. the need for a comprehensive set of method, including circularity and biodiversity.
2. the need for a simple and easy to use set of impact categories, based on the most relevant and reliable indicators.

TranSensus-LCA has thus analysed a list of existing LCA impact categories and evaluated the relevance of each impact for zero emission vehicles (ZEVs) life cycle assessment. This evaluation has been performed by scoring each impact regarding a set of 5 criteria:

- Science based criteria: 1) robustness of the impact, and 2) relation to planetary boundaries.
- Other criteria: 3) importance for ZEVs, 4) data availability, and 5) easy-to-use.

Based on this analysis, we have proposed a list of mandatory impacts categories meaning that this set of impacts has to be calculated. Impacts not included in the mandatory list are either optional with TranSensus-LCA recommendation of calculation or not recommended for calculation (see details below).

The scoring system used for the evaluation is designed with a range of "A" to "E", where "A" represents the highest possible score, indicating the most favourable assessment or the highest level of compliance with the criteria evaluated. Conversely, "E" denotes the lowest score, reflecting significant deficiencies or areas in need of improvement. This hierarchical system of letter grades is intuitive, as it is based on rating systems known from educational contexts and allows for quick and clear comparisons and decision-making processes.

In the context of a quantitative analysis or further statistical evaluation, these letter grades are converted into numerical values. Specifically, "A" equals a score of 5, reflecting the highest compliance or the most favourable conditions, while "E", with a score of 1, signals the lowest level of compliance. When the scores for several criteria are added together to calculate an average, the resulting figure does not always perfectly match the integer numbers. To address this problem and maintain the integrity of the assessment, a more granular rating scale was used for averages that fall between the standard letter grades. This refined rating scale introduces "+" and "-" modifiers to the basic letter grades, creating subdivisions that more accurately represent nuanced differences in performance or compliance levels.

Regarding the scoring on the relation to planetary boundaries, the Joint Research Center has worked for several years to establish a link between LCA and Planetary Boundaries (PBs) through different methods, mapping most of the EF impact categories to the planetary boundaries [1], [2]. Their papers show on two scales (global and European) the results for each impact category, some of them exceed the limit no matter the scale and the method and find themselves in the high-risk zone. In this workgroup, we considered that such impact categories are of the utmost importance to integrate into the TranSensus-LCA methodology. Thus, we provided a rating for the impact categories considering how many times they were found in the safe operating space ("E"), the zone of uncertainty ("D", "C") or the high-risk zone ("C", "B", "A").

The particulate matters (PM), climate change (CC) and land use (LU) impact categories exceed the limit by a factor 8 for PM and CC and a factor 60 for LU. That's why they were given the highest rating as they are considered urgent to address in LCA.

T2.4 has decided to propose as mandatory impact categories, those reaching a total score of A+, A, A- or B+ (see table below). Below this threshold limit, it is understood that impact considered is non-mature enough, methodology or data are not available yet. The concerned impacts may be a priority for R&D activities to include it as mandatory within a future revised TranSensus-LCA methodology for ZEV.

Table III-1: Mandatory impact categories evaluation by TranSensus-LCA

	Science based criteria		Other criteria			
Impact category	**Robustness**	**Relation to planetary boundaries**	**Importance for ZEVs**	**Easy to use**	**Data availability**	**Score**
Climate change	A+	A+	A+	A+	A+	A+
Photochemical ozone formation	B-	D+	A-	A	A+	B+
Acidification	B	D	A	A	A	B+
Freshwater eutrophication	B	B-	B-	A	A+	B+
Particulate matter	A	A+	A	A+	A	A
Depletion of abiotic resources	C-	B	A+	A+	A-	B+
CED	A-	C+	A	A-	A	A-

The results of voting sessions led to a list of 7 impact categories to be mandatory in TranSensus-LCA methodology:

- **Climate change**: Climate change impact category is considering all inputs and outputs that result in greenhouse gas (GHG) emissions. The consequences include increased average global temperatures and sudden regional climatic changes.
- **Photochemical ozone formation:** Photochemical ozone formation is an impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials, by reacting with organic materials.
- **Acidification:** Acidification contributes to the decline of coniferous forests and increased fish mortality. Acidification can be caused by SO_2, NOx and NH_3 emissions that reach the air, water and soil. The most important sources are combustion in electricity production, heating and transportation. The contribution to acidification is highest when fuels contain a high level of sulphur.
- **Particulate matter:** This Impact category assesses the Impact on human health the potential incidence of disease due to particulate matter emissions.
- **Freshwater eutrophication:** Eutrophication affects ecosystems due to substances containing nitrogen (N) or phosphorus (P). If algae grow too fast, they can leave the water without enough oxygen for fish to survive. Nitrogen emissions to the aquatic environment are largely due to fertilizers used in agriculture, but also to combustion processes. The most important sources of phosphorus emissions are urban and industrial effluent treatment plants and leaching from agricultural land.
- **Depletion of abiotic resources:** Depletion of abiotic resource addresses the use of non-renewable abiotic natural resources (minerals and metals: copper, potash, rare earths, sand, etc.) See chapter below for more details.
- **Cumulative Energy demand (CED):** see chapter below

III.1.1.1 Cumulative Energy demand

Definition of CED:

Cumulative Energy Demand (CED) is the amount of primary energy consumed during the life cycle of a product or a service. It can be differentiated between renewable (r-CED) and non-renewable energy demand (nr-CED). This is the most common and accepted approach in the scientific community, it is also already implemented that way in software which makes it easier to apply.

Renewable and non-renewable energy demand may then be further sub-divided into eight impact subcategories: non-renewable—primary forest, nuclear, and fossil fuels; renewable resources—biomass, wind, solar, geothermal, and water, like it is done in the ecoinvent database (Table III-2), where no aggregated value is presented (due to the existence of divergent concepts and the unclear basis for the characterization of the various primary energy carriers).

Table III-2: List of CED indicators

	subcategory	includes
non-renewable resources	fossil	hard coal, lignite, crude oil, natural gas, coal mining off-gas, peat
	nuclear	uranium
	primary forest	wood and biomass from primary forests
renewable resources	biomass	wood, food products, biomass from agriculture, e.g. straw
	wind,	wind energy
	solar	solar energy (used for heat & electricity),
	geothermal	geothermal energy (shallow: 100-300m)
	water	run-of-river hydro power, reservoir hydro power

CED can also be referred to as Primary Energy Consumption (PEC) or Primary Energy Demand (PED); these three names are, to the best of TranSensus-LCA knowledge, equivalent and refer to the same indicator. CED being the most known and used in the LCA community, it will be the name used hereafter. In case this assumption proves to be wrong and for future revision of this methodology, definitions and conversion factors among software shall be harmonized. What's more, discrepancies in definition and conversion factors between software is not an issue specific to CED but to other indicators too.

There is still a debate on whether CED is a life cycle inventory indicator (driver indicator) or a life cycle impact assessment indicator. However, TranSensus-LCA shall evaluate CED by following the energy harvested approach defended by Frischknecht *et al.* [3], and in this paper the authors refer to CED as an LCA impact category with equal[7] weighting between Renewable and Non-Renewable indicators. To be consistent, CED will be considered as an LCA impact category in the TranSensus-LCA methodology. For monitoring energy efficiency of product systems, like ZEV's, the CED is considered a relevant additional indicator. However, while presenting and interpreting results of the LCAs for different impact categories, one should keep in mind that CED indicators and other impact category indicators are defined on different stages

[7] Frischknecht *et al.* (2015) does not mention explicitly which weighting factor is proposed. It is mentioned that aggregation without weighting (that is, equal weights) is the method which is most often used. However, the paper also mentions that it's better to report different indicators separately, or at least renewables and non-renewables separately.

of the DPSIR cause-effect chain[8]. Therefore, the different indicators measure effects of economic activities on different stages (namely driver (energy consumption) and pressure (i.e. extractions and emissions). Now, combining indicators on different stages of the DPSIR, might lead to redundant information and has the danger of introducing overlap, when not presented and interpreted with caution (e.g. 'depletion of abiotic resources-fossil fuels (of EF3.1)' is part of CED). Therefore, CED **shall** be discussed in relation to other impact categories to avoid the risk of double counting.

Frischknecht *et al.* define the energy-harvested approach as a quantification of "the amount of energy resources made available for human use. Following this approach, the intrinsic value and the depletion aspect of resource protection are combined and the following definition of the indicator proposed:

- Energy deposits, stocks of funds and flows do have an intrinsic value.
- The harvested amount of energy resources qualifies for accounting the cumulative energy demand based on the intrinsic value of the energy resources.
- The intrinsic value is determined by the amount of energy extractable from the harvested energy resources.
- All other aspects like abundance, societal demand, possibilities for substitution etc. add nothing to the value of energy resources".

Background

In the policy framework and decarbonation targets, energy efficiency is one of the key drivers to reduce environmental impacts. That is why, including the CED as a mandatory indicator (both renewable and non-renewable) is essential in LCAs. It is already mandatory to calculate for some product declaration programs (The International EPD System [4], Green NCAP [5], 'and included in most LCAs performed reflecting the global scientific consensus of its relevance. Including CED as a mandatory indicator is even more important in the case of ZEVs as their production and overall life cycle is energy intensive. Especially, when studying the effects of using renewables for the use stage of ZEV, and how it affects the energy demand according to different vehicle types.

[8] When indicators are used that represent different stages of the DPSIR cause-effect chain, one should be very cautious! On all levels useful indicators can be defined. And for measuring energy efficiency the use of CED is a useful indicator. But there are good arguments to define CED as a driver indicator. The consumption of energy, as a driver, leads to emissions (e.g. CO2, NOx etcetera) and extractions (fossil fuels), which are both pressure indicators, that may lead to effects on midpoint impact categories (e.g. depletion of fossil fuels, climate change, acidification, eutrophication, etcetera) using indicators on the state level.

Table III-3: Proposal of new mandatory impact categories evaluation by TranSensus-LCA – Results for CED

	Science based criteria		Other criteria			
Impact category	**Robustness**	**Relation to planetary boundaries**	**Importance for ZEVs**	**Easy to use**	**Data availa-bility**	**Score**
CED	A-	C+	A	A-	A	A-

The analysis performed in the project and provided in the table above shows that, according to the partners, this indicator is robust, easy to use, and data is easily available. However, the grade regarding the relation to the planetary boundaries is low. This is due to the fact that this relation has not been assessed in scientific papers yet. Moreover, CED is an indicator that is quite transversal and would have an influence on most of the planetary boundaries, as such, it is still relevant to consider as a mandatory indicator in TranSensus-LCA.

TranSensus-LCA acknowledges that there could be a bias while using the CED indicator that does, under some circumstances, under-estimate the impact on natural ecosystems due to human-induced degradation of high-quality forms of renewable energy resources (e.g., visible sunlight) into lower-quality heat. However, all LCA impact indicators only estimate a "potential" impact and only provide an estimation, there will always be uncertainties while calculating environmental impacts, and the uncertainties for CED seem no greater than for many other impact categories. Thus, TranSensus-LCA recommends using CED indicator with care and taking into account the uncertainties that come with. The assumptions taken while using CED **should** be clearly stated as it can influence the results.

III.1.1.2 Depletion of abiotic resources

Depletion of abiotic resource addresses the use of non-renewable abiotic natural resources (minerals and metals: copper, potash, rare earths, sand, etc.). It focuses on the contribution of product systems to the exhaust of primary stocks of a non-renewable resource. Efforts for a better understanding of the impacts associated to non-renewable resources highlight barriers other than depletion; notably criticality and dissipation. Criticality is already part of the optional list of impact categories in TranSensus-LCA. The method testing conducted since the last voting session reveals the relevance to include "dissipation of abiotic resources" as an optional impact category that also serves as a complement to depletion.

Background

Table III-4: Proposal of new mandatory impact categories evaluation by TranSensus-LCA – Results for depletion of abiotic resources

	Science based criteria		Other criteria			
Impact category	Robustness	Relation to planetary boundaries	Importance for ZEVs	Easy to use	Data availability	Score
Depletion of abiotic resources	C-	B	A+	A+	A-	B+

The depletion of abiotic resources impact received a B+ score reflecting its importance in the broader context of environmental science and policy. Its ease to use is highlighted by a A+ score. It should be noted that data are relatively available, which led to a A- grade.

III.1.1.3 Mandatory H2 emissions flow indicator and a sensitivity on GWP impacts of H_2 emissions

The lifecycle impacts of hydrogen fuelled ZEVs (i.e. FCEV, FC-REEV and H_2 ICEV) are particularly influenced by the impacts from production, supply and use of hydrogen fuel. Whilst most LCA studies address impacts resulting from hydrogen production, impacts from fugitive hydrogen emissions are not generally included. There is some uncertainty on the GWP100 value of hydrogen itself, and it was not included in IPPC AR6 (and consequently also not in relevant LCI and impact methodologies). However, recent scientific evidence from (Sand, *et al.*, 2023) [6] suggests these impacts double those previously estimated, making lifecycle GWP impacts of hydrogen emissions potentially significant for vehicles using it as a fuel.

Without formalisation of the GWP of hydrogen (e.g. in the next IPCC Assessment Report, or UNECE IWG A-LCA methodology) it is difficult to recommend mandating its inclusion by default in the TranSensus-LCA's methodology. Until this is the case, because of the potential significance of hydrogen emissions, and to future-proof analyses using the TranSensus-LCA recommended method, it is proposed for LCA of vehicles using hydrogen as a fuel:

1. To include a **mandatory** hydrogen emission flow indicator (corresponding to the mass of hydrogen emitted into the atmospheric environment (in kg H_2).
2. To include a **mandatory** sensitivity analysis

Further, following requirements **shall** be followed by default:

i. In the absence of supplier-specific information on fugitive hydrogen emissions from the supply chain, to include estimated H_2 supply chain emission rates based on (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022) [7].

ii. The use of GWP100 of 11.6 for characterising the impacts of hydrogen emissions for the sensitivity analysis (unless this is superseded by a formally agreed figure).

Background

Hydrogen is used in several ZEV powertrains and has a significant impact on their overall lifecycle emissions though previous analysis has been limited to impacts from hydrogen production and supply only and not from emissions of hydrogen itself. Hydrogen has been previously characterised as an indirect greenhouse gas and has previously been included in the IPPC AR5 (2007) with a GWP100 value of 5.8 [8], but an updated value was not provided in AR6 (2021). However, recent scientific research has found hydrogen's climate impact to be significantly higher – around double the previous figure – with the most recent authoritative research estimating a value of a hydrogen of GWP100 of 11.6 ± 2.8 (one standard deviation) [9].

Emissions of hydrogen can occur mainly during the hydrogen production and distribution stage (mainly due to fugitive leakage) – see Table III-5. But also emissions are anticipated to a lesser extent directly from hydrogen fuelled vehicles, though no standardised test methods currently exist for this, through H_2 slip from combustion vehicles and potentially fugitive emissions from H_2 storage systems ;(particularly for liquefied hydrogen. Recent research has found emission rates of **hydrogen** from the supply chain are likely to be similar to those of methane from the natural gas supply chain, with net leakage rates estimated to be 2.6%-6.9% for green hydrogen supply chains [10]. Together with the higher estimated values for GWP100, accounting for these emissions would likely to result in a significant impact on the full LCA for hydrogen fuelled ZEVs (i.e. FCEV, FC-REEV and H2 ICEV).

Hydrogen emissions are not commonly captured in LCI datasets, and a characterisation factor for hydrogen is currently not included (e.g. in the EF method) due to its exclusion from the explicit list of greenhouse gases in AR6. There is currently mixed support for including hydrogen as a greenhouse gas (with GWP based on the best current scientific evidence) at the UNECE Informal Working Group on Automotive LCA. Therefore, it is recommended that accounting for hydrogen as a greenhouse gas **should** be included by default in the future only once consensus has been reached formally on the GWP value, and/or its inclusion within the EF method.

However, in order to future-proof the TranSensus-LCA methodology, users **shall** for now (until hydrogen's GWP is formalised/agreed) assess the total lifecycle emissions of hydrogen as a mandatory flow indicator and additionally conduct a sensitivity on the potential GWP impacts of these.

Further information on the potential significance of emissions from different hydrogen production and supply chains has been recently assessed by (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022) [11], with estimated H_2 supply chain emission rates derived and simplified from this source provided in Table III-5.

Table III-5: For hydrogen produced from (i) steam reforming of natural gas, (ii) electrolysis of water, derived and simplified from (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022)

	Production and processing	Compression	Storage and transport	Liquefaction	Shipping	Regasification	Transmission and storage	Distribution	Use in H2 ICEV, FCEV and FC-REEV*	Total
H_2 from natural gas (production in same region as use)	0.55%	0.17%	0.31%				0.05%	0.02%	0.50%	**1.61%**
H_2 from natural gas (imported to region of use - as LH2)	0.55%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	**2.05%**
H_2 from electrolysis (production in same region as use)	2.05%	0.17%	0.31%				0.05%	0.02%	0.50%	**3.13%**
H_2 from electrolysis (imported to region of use - as LH2)	2.05%	0.17%	0.31%	0.33%	0.06%	0.00%	0.03%	0.08%	0.50%	**3.57%**

Notes: Hydrogen has a high tendency to leak, which makes it difficult to be contained; primarily due to safety concerns, many studies have assessed the potential for hydrogen leakage from fuel cell electric vehicles, both in stationary conditions and from operation. However, such studies generally do not contextualise hydrogen leakage rates in terms of the overall supply of hydrogen to the vehicle. Engine slip of H_2 in ICEVs fuelled by hydrogen is reported to range from 0 to 12%, and a value of 0.5% is assumed by (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022) (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022). In the absence of other information, a similar rate is assumed also for hydrogen vehicles using fuel cells.

III.1.2 Optional set of impact indicators

The results of voting sessions led to a list of 11 impact categories to be optional in TranSensus-LCA methodology.

Table III-6: Optional impact categories evaluation by TranSensus-LCA

	Science based criteria		Other criteria			
Impact category	**Robustness**	**Relation to planetary boundaries**	**Importance for ZEVs**	**Easy to use**	**Data availability**	**Score**
Ozone depletion	A-	D	C	A	A	B
Human toxicity	D+	C+	B+	B+	B+	B
Marine eutrophication	B	C-	C+	A	A+	B
Ecotoxicity	C-	D	B+	B	B+	B-
Acidification	B	D	A	A	A	B
Land use	D+	A+	C+	B	B	B
Water use	C-	D	B+	A-	A	B-
Criticality	D-	E+	B+	C	C	C-

- **Ozone depletion**: Ozone depletion is an impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e. g. chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs), halons).
- **Human toxicity, cancer:** is an impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – insofar as they are related to cancer.
- **Human toxicity, non-cancer**: is an impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

- **Ionising radiation, human health**: Ionising radiation is an LCA impact category that quantifies the potential radiological impact on human health due to radionuclide emissions throughout a product's lifecycle. The category incorporates detailed nuclear physics models to assess the emissions of α, β, γ rays, and neutrons, and to calculate their subsequent radiation exposure and associated health risks. The impact is expressed in units of kg of uranium-235 (U^{235}) equivalent.
- **Eutrophication, terrestrial**: Eutrophication occurs when excess nitrogen (N) or phosphorus (P) enters ecosystems, leading to excessive plant and algae growth. This disrupts the ecosystem's balance and limits growth of other organisms. To assess the impact of substances causing terrestrial eutrophication, their potential effect is quantified in terms of equivalent moles of nitrogen (mol N eq).
- **Eutrophication, marine**: Marine eutrophication is caused by an excess of nutrients, particularly nitrogen (N). This nutrient overload, often from agricultural runoff and combustion emissions, fuels excessive algal growth. To assess the severity of marine eutrophication, the impact of different pollutants is standardized to nitrogen equivalents (kg N eq).
- **Ecotoxicity, freshwater**: Freshwater ecotoxicity addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.
- **Land use:** Land use impact category is related to the use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in soil quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in soil quality multiplied by the area).
- **Water use:** Water abstraction from surface and groundwater sources can contribute to water resource depletion. This impact category considers the water stress level in the regions of operation, if known. The potential impact is quantified in cubic meters (m^3) of water used, adjusted for local water scarcity conditions.
- **Criticality**: Material criticality generally includes dimensions such as supply risks and vulnerability to supply disruptions which are influenced by geopolitical factors, trade barriers and environmental regulations. For more details see chapter below.
- **Dissipation**: Resource dissipation represents a loss or degradation of resources in the technosphere, preventing their further use in the economy. For further information, see chapter below.

III.1.3 Criticality

Raw material criticality refers to the dependency on a certain material, as well as the probability of supply disruptions from the perspective of an economic actor over a determined period of time. Criticality indicators in LCA primarily focus on supply risks rather than resource depletion, their inclusion provides valuable complementary information for understanding material criticality.

While scientific consensus is lacking on the optimal methodology for evaluating criticality, either generally or within a product life cycle context, there is a pressing need for guidelines like those recommended by the Joint Research Centre (JRC) for Product Environmental Footprint (PEF)/ Organization Environmental Footprint (OEF) assessments. Criticality adds layers of economic and social assessment through the inclusion of supply risks. Table III-7 summarizes the considerations for the inclusion of criticality as part of the Transensus-LCA methodology.

Advantages and limitations of the inclusion of criticality indicators in the Transensus-LCA methodology are described in the table below.

Table III-7: Advantages and Limitation of Criticality Analysis

Advantages	• Criticality analysis highlights the scarcity of crucial materials such as lithium and cobalt, which are essential for battery production, and the geopolitical and supply chain risks associated with these materials. • By understanding the criticality, policymakers and industry stakeholders can make informed decisions and strategies regarding resource management, recycling, and sourcing. • Awareness of the criticality of materials can stimulate innovation in the sector, encouraging the development of alternative materials and technologies that are less dependent on scarce or geopolitically sensitive re-sources.
Limitations	• The criticality of materials may change over time due to geopolitical changes, new reserve discoveries or changes in technology, which can quickly make the analysis obsolete. • It requires extensive data collection, expertise and resources to conduct a thorough analysis. • There may be limitations in the availability and accuracy of data relating to material reserves, mining impacts and recycling rates that may affect the accuracy and reliability of the criticality analysis.

Based on the evaluation conducted by the ORIENTING project, which used the RACER methodology to rank criticality assessment methodologies, TranSensus-LCA includes criticality in the recommended set of Impact categories and recommends using the GeoPolRisk method based on its robustness, acceptance, credibility, ease of use, and relevance. Documentation on the development and application of the GeoPolRisk method is available in Santillán-Saldivar *et al.* (2022) and Koyamparambath *et al.* (2024).

III.1.4 Dissipation

A previous review on the impact category of abiotic resource depletion presented in deliverable D1.1 "Review of current practices on life cycle approaches along the electromobility value chain" lead to the conclusion that an interesting alternative to this impact category is the dissipation of abiotic resources. One of the advantages of a dissipation model is that it might better address circularity issues, since it has the potential to help identify hotspots in which resources are lost for (future) recovery.

Two methods for the assessment of dissipation were short-listed for further testing: Average Dissipation Rate (ADR) and Environmental Dissipation Potential (EDP). These methods were applied to a case study (one electric vehicle) in parallel to abiotic depletion potential (ADP). Highlights of the method testing are described in the Table III-8, based partially on (1) the SUPRIM framework (Schulze *et al.* 2020 [12]) for impact assessment methods for resource use and (2) insights from the method testing conducted as part of TranSensus-LCA.

Table III-8: Highlights of different Dissipation method testing

Method	Abiotic Depletion Potential (ADP)	Environmental Dissipation Potential (EDP)	Average Dissipation Rate (ADR)
Reference	van Oers *et al.* 2019b [13]	van Oers *et al.* 2020 [14]	Charpentier Poncelet *et al.* 2019, 2021, 2022 [15]
Role of resources	Abiotic resources are valued by humans for their functions used (by humans) in the technosphere, taking into account primary production only.	Abiotic resources are valued by humans for their functions used (by humans) in the technosphere, taking into account both primary and secondary production.	
Problem definition	Decrease of accessibility to primary resources (from environment)	Decrease of accessibility to primary (from environment) and secondary resources (from technosphere)	Increase of dissipation (risks associated to the use of fast dissipating resources)
Time perspective	Long term (exhaust of primary stocks)	Very long term (focus on emissions of elements to the environment)	Short to long term (focus on current rates of resource dissipation)
Elementary flow to be assessed	Extraction (resources from ground)	Emission (emissions to the environment)	Extraction (resources from ground)
Availability of characterization factors	Available	Available on request (publication in preparation)	Available
Integration of method in LCA databases	Fully integrated and operational	Files available for import to LCA databases.	Operational in Ecoinvent, files available for import to other LCA databases.

The dissipation methods take the concept of dissipation of resources as a problem definition. These are developed as complementary methods for the currently used impact category Abiotic Depletion (AD). The rationale behind this shift in problem definition, from depletion to dissipation, is the notion that elements after extraction from the environment are actually not depleted for future use, since they end up in stocks in the technosphere, which are accessible again to a certain extent.

The application of the dissipation methods to the proposed case study reveals mechanisms of resource use that are not highlighted by the ADP method. These effects are mainly explained by the efficiency in the recovery of elements from primary and secondary sources, highlighting a different concern than the physical availability of elements in the earth's crust.

As part of the TranSensus-LCA methodology, both studied impact assessment methods are proposed as **options** for application; answering to two potential scenarios of technical and economic development. EDP considers an optimistic perspective in which only emissions to the environment contribute to dissipation, under the assumption that in the far future all materials will be recoverable from secondary sources. ADR considers a pessimistic scenario in which materials emitted to the environment, disposed as waste or hibernating in the technosphere are dissipative, assuming that current recovery remains the same in the near future. Table III-9 contains a list of specifications to help interpreting the results obtained with each impact assessment method.

Table III-9: Specifications for the use and interpretation of dissipation impact assessment methods.

Method	Environmental Dissipation Potential (EDP)	Average Dissipation Rate (ADR)
Time horizon	Very long term	Short term
Techno-economic assumptions	Optimistic -Only emissions to the environment are dissipative -In the far future, all materials in the technosphere are recoverable	Pessimistic -Emissions to the environment, materials in waste and hibernation are dissipative -In the near future, recoverability remains at current rates
Inputs for calculation of impact score	Sensitive to the inventory of emissions	Sensitive to the inventory of resources from ground
Characterization model	Based on (optimistic) global dissipation rates and reserves	Based on (pessimistic) global dissipation rates
Base for interpretation	Results reflect the importance of emissions of mineral resources to the environment in perspective with their physical availability in the lithosphere	Results reflect the current technological and economic conditions regarding mineral resources losses in the economy. When applied to LCI results, ADR Characterization Factors enable to highlight "a risk to use a resource that may

		dissipate faster than other resources, given the current state of its use, production processes, recycling practices, etc. at the global level." (Beylot *et al.*, 2024) [16]
Reliability	Probably leading to underestimation of impacts	Probably leading to overestimation of impacts
Interpretation of hotspots	Highlighted elements have high contributions in the inventory of substance emissions and/or are scarce in the lithosphere.	Highlighted elements have high contributions in the inventory of resource extractions from ground, have high dissipation rates and/or their obtention from primary/secondary sources is highly inefficient.

III.1.5 Circularity

Circular Economy (CE) is defined by the ISO standard which is under development as "an economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development" (ISO/DIS 59004). CE is often associated to "reduction", "reusability", "recovery" and "recycling" principles (Julian Kirchherr, 2017 [17]), called circularity aspects. To access Circular Economy strategies, a large variety of circularity indicators has been developed, they can be classified at micro- meso- or macro-level (from product level to company level) (Rigamonti, 2021 [18]), and measure one or more circularity aspects. The MCI (Material Circularity Indicator) for example, from Ellen MacArthur Foundation, indicates how much the product materials circulate and provides information on the utility of the product. The Recycled Content (RC) indicator simply described the fraction of secondary resource (scrap) in the total resource input (primary and secondary). The EoL Recycling Rate (EoL-RR) gives the fraction of the total waste flow of a resource that enters the recycling process and that is recycled (the recycled flow of a resource that is the output of the recycling process).

However, CE and environmental/social sustainability are not directly and necessary linked:

- First, circularity is not an environmental problem as such, as it is not based on assessment of elementary flows, but is linked to economic flows in the Technosphere (waste flows, secondary goods …)
- Second, CE strategies do not necessarily provide environmental benefits and could lead to shifting and rebound effects (Claudio Sassanelli, 2019 [19]). Several articles even demonstrated that the most circular solutions are not necessary the best environmental options (Rigamonti, 2021 [18]).

The table below gives the advantages and drawbacks of adding circularity indicator to the non-restrictive/optional list of impact categories of TranSensus-LCA.

Table III-10: Advantages and drawbacks of including circularity indictor in TranSensus-LCA methodology

	Circularity indicators
Advantages	reflects circularity aspects and efficiency of a product system high policy relevance (linked to Eco-design for sustainable Products Regulation) useful indicator on the driver-level of DPSIR
Drawbacks	large variety of indicators, which reflect only partial aspect of circularity ISO norms not finalized yet circularity is not an environmental or social impact (it is not based on assessment of elementary flows) it is a way to enhance sustainable use of resources and should be properly modelled in the LCI (% recycled content, mass, recyclability …)

When circularity aspects are measured, circularity indicators can be powerful tools to improve circular decision making. In line with the Eco-design for Sustainable Products Regulation (Commission), these indicators have high policy relevance. Circularity issues, like lifetime, repair, secondary material input, recycling of waste, should be solved in the LCI. The LCIA framework is based on assessment of elementary flows, whereas Circularity aspects relate to flows (waste, secondary goods …) which belong to the Technosphere and are not elementary. Thus, circularity aspects should be properly modelled in the LCI, distribution of burdens/benefits regarding recycling/recycled content should be addressed with EoL allocations (CFF, cut off …) and present impact categories, like abiotic resource depletion or resource dissipation, already differentiate between system with high or low circularity. In addition, an optional sensitivity or scenario analysis may be considered in Transensus-LCA (see interpretation chapter) to study the influence of circularity on the modelled system and its calculated LCIA to test its environmental relevance.

III.1.6 Biodiversity

Human activities have an impact on our planet biodiversity through the 5 pressures identified in the Millennium Ecosystem Assessment (2005): land use (habitat change), pollution, climate change, invasive species, overexploitation of species. Each of these 5 pressures are detrimental to our planet biodiversity because of the decrease in the number of local species and the decrease in the number of individuals per species they are responsible for.

Several biodiversity indicators exist to consider the impact of a given human activity on our planet biodiversity. Among them, two are the most advanced and take into consideration the whole life cycle of the impacting processes: the GBS (Global Biodiversity Score) and the PBF (Product Biodiversity Footprint).

The GBS indicator sets a particular focus on investments and aims to be used by financial institutions. It relies on money expenditures that are converted to biodiversity losses through models and databases, considering the 5 pressures the money expenditures are responsible for. Such models and databases are still in the process of being completed. It is possible to complete the indicator with more specific data (local practices…).

The PBF indicator also considers the 5 environmental pressures on biodiversity, with different tools: an LCA will give information on the land use (habitat change), pollutions (photochemical oxidation, eutrophication and acidification) and climate change impacts on biodiversity linked to the process under study through the LC-Impact method/tool. The results from the LCA will be completed by qualitative data reflecting local practices on biodiversity preservation that are related to: species habitat change (land occupation, land transformation and water stress), invasive species and species overexploitation.

The table below gives the advantages and disadvantages of adding biodiversity indicator to the non-restrictive/optional list of impact categories of TranSensus-LCA.

Table III-11: Advantages and disadvantages of adding biodiversity indicator to the non-restrictive / recommended list of impact categories of TranSensus-LCA

	Biodiversity method 1: GBS	Biodiversity method 2: PBF
Advantages	• Easy to compute (only financial data are needed)	• LCA approach completed with local data so that to reflect the impacts on biodiversity of the 5 pressures
Disadvantages	• Sectorial approach • Not easy to differentiate between companies of a given sector • Databases relating financial investments to the 5 pressures need to be completed	• LC-Impact model still in development • Qualitative approach for local actions • Shows improvements better than absolute values

Until more robust indicators are available, biodiversity indicators should not be used.

III.2 Normalization

Normalization and weighting are crucial steps in LCA that have been the subject of much debate and discussion. Normalization involves expressing the impact potentials concerning a reference situation to place a study on an understandable standard scale. It allows for comparing results with a reference situation and informs the interpretation phase of LCA by assessing the plausibility of the results' order of magnitude. Normalization transforms an indicator result by dividing it by a selected reference value. Weighting, on the other hand, measures the relative importance of different impact categories and creates a single score for the environmental impact of a product or service. This facilitates the comparison of different products or scenarios and supports decision-making. While normalization and weighting are important in LCA for facilitating the interpretation and communication of impact results and for comparing different products or scenarios, their subjective nature and potential to influence study conclusions make them controversial aspects of LCA. Multiple guidelines, standards and scientific literature address normalization and weighting, but in very different ways.

Normalization is an optional step under ISO 14044:2006, however there is no prescribed calculation procedure to be followed while considering this criterion. ISO 14044 mentions that normalization (& weighting) are optional, while VDA recommended to not consider normalization (& weighting) as it is subjective; PEF mandates normalization in LCA, and other guidelines do not mention normalization in their framework (Refer D1.1 TranSensus-LCA).

Normalization is advised for TranSensus-LCA **as an optional feature** for various reasons. One reason is that no guideline, other than the PEF, recommends it as mandatory. Furthermore, there are several discrepancies between the application of normalization factors in various software packages. Following normalization, some impact categories (ICs) are emphasized or downplayed. As a result, the normalization elements and their assessment are not deemed mature enough to make it obligatory.

There are different kinds of normalization: Internal, External and Absolute normalization (De Laurentiis, 2023 [20]). Although internal normalization allows to overcome issues of compensability and ensures consistency within the study, it is also very context-dependent and as such cannot be used with generic weighting. This type of normalization was left aside in the workgroup as it prevents comparability between studies. Then for the remaining two typologies of normalization, 5 normalization sets were found and compared, i.e.: (i) Global production-based; (ii) European production-based; (iii) European consumption-based, process-based LCA; (iv) European consumption-based, input/output; (v) Global planetary boundaries.

The European consumption-based input/output set of normalization factors is adapted for Economic input/output LCA and not for process-based LCAs which is why it was also set aside in the workgroup. The others European sets of normalization factors are not fit for systems with international supply chains, in the case of TranSensus the zero-emission vehicles come from international supply chains so only Global sets of normalization factors are relevant.

The advantages of using Global Planetary Boundary based normalization factors are the following. First and foremost, this provides an absolute basis for normalization (instead of relative), which makes the normalized results dependent on absolute thresholds (“boundaries”), instead of on total previous impact, which is always a moving target. This also avoids potentially controversial interpretation if or when an impact contributes to a category already affected by significant overall impact globally. Other advantages are: Adapted for international supply chains, no inverse proportionality, bias more transparent, cannot be affected by data coverage issues. But it has also several disadvantages such as: not applicable to all LCIA impact categories, potential issues with upscaling local environmental pressures to global level (some impact categories are context-specific and more relevant on a local scale).

The benefits and limitations of other normalization factors are mentioned in the table below.

Table III-12: Benefits and limitations of different normalization factors [20]

	Benefits	Limitations
Global production-based		Extrapolations and the assumptions made for that. Coverage of data. Inverse proportionality.
European production-based	Covers the whole economy.	Biased because of the internationality of supply chains. Coverage of data. Inverse proportionality.
European consumption-based, process based LCA	Same data source for system under study and normalization reference (=> consistency)	Coverage of activities (efficiency level and technologies in countries from which EU imports goods). Only household consumption. Inverse proportionality. Limited to EU studies.
European consumption-based, input/output		Biased and unfit for normalization regarding ecotoxicity. Lower granularity. Limited coverage of elementary flows. Inverse proportionality. High level of aggregation of industrial sectors in IO analysis and of inventories.

IV. Software Comparison

IV.1 Introduction

IV.1.1 Aim & Research Question

The aim of this section is to analyse the reasons why different choices in Life Cycle Assessment (LCA) software and databases can yield divergent results, despite the use of standardized conditions, such as identical Life Cycle Inventory (LCI) background data, Life Cycle Impact Assessment (LCIA) methods, system boundaries, and multi-functionality treatments. The study seeks to evaluate the extent of harmonization among currently available LCA data and assess the integration and consistency of the Environmental Footprint (EF) database and ecoinvent across different software platforms.

The overall research question to be answered through this research task is - What are the underlying reasons for the variation in results generated by different LCA software platforms, and how does the process of mapping LCI databases to LCIA methods influence the harmonization of LCA data and the implementation of the Environmental Footprint database?

IV.1.2 Modification of Initial Research Aim

Due to time constraints and limited access to the LCA software platform of LCA for Experts installed with the EF 3.1 LCIA method and EF LCI database, the scope here is adjusted to ensure a feasible and meaningful analysis. Instead of comparing results across different software, the focus was narrowed to a single LCA software platform, SimaPro, while examining the impact of different Life Cycle Inventory (LCI) databases - ecoinvent and EF 3.0 - on LCA results.

While comparing software was part of the initial plan, the underlying objective is to understand variability in LCA results. A single-software, multi-database comparison still aligns with this objective, as database-related variability is a major factor influencing LCA outcomes (Pauer, Wohner, and Tacker 2020)

IV.2 Methodology – EV Battery Case Study

The following methodology steps were constructed keeping in mind the mentioned research questions.

IV.2.1 Case Study Selection

The electric vehicle (EV) battery was selected as the case study for this comparative analysis due to its growing significance in sustainable transportation and the complexity of its life cycle inventory data. Electric vehicles are increasingly vital for reducing carbon emissions and combating climate change. As technology advances and infrastructure improves, EV adoption is set to revolutionize transportation and energy use (EEA 2024).

The selection process and methodology development proceeded through several structured phases:

IV.2.1.1 LCA Software and Database Selection

This case study was carried out using life cycle assessment software (LCA) SimaPro, version PhD Release 9.5.0.1. The Life Cycle Assessments (LCAs) were conducted using a consistent methodological framework to compare the results generated by two different Life Cycle Inventory (LCI) databases, ecoinvent 3 and Environmental Footprint (EF) 3.0. Both analyses employed the same Environmental Footprint 3.1 Life Cycle Impact Assessment (LCIA) method within the same software environment. By varying only, the LCI database while keeping all other analyses parameters constant, this approach effectively isolated database-specific variations in the LCA results, ensuring a focused evaluation of their influence on the outcomes.

This study also aims to understand LCI and LCIA methodologies and explore their interconnectivity. While LCI provides the necessary data, LCIA contextualizes this information within environmental frameworks. A well-executed LCI is critical for an effective LCIA and similarly the other way around as inaccuracies or gaps in data can lead to flawed impact assessments (Goedkoop *et al.* 2016). Hence studying the individual relationship between EF and ecoinvent databases with the EF 3.1 LCIA method helped understand how the new harmonised database is used to generate LCA results.

IV.2.1.2 Battery Chemistry Selection

This case study analysed the cradle-to-gate total climate change impact associated with production of lithium nickel manganese cobalt oxide (NMC) batteries for electric vehicle applications. The life cycle assessments are conducted till battery production and end-of-life is not analysed as part of this study.

The Nickel Manganese Cobalt (NMC 111) chemistry was chosen as the reference battery technology due to its widespread commercial adoption and data availability across databases (Blomgren 2016). The initial assessment began with the examination of the lithium-ion battery process documentations present in the ecoinvent database, which included a pre-defined process for the identified Li-ion battery production - *Battery, Li-ion, NMC111, rechargeable, prismatic {RoW}| battery production, Li-ion, NMC111, rechargeable, prismatic* (Wernet *et al.* 2016). This served as a preliminary reference point for the comparative analysis.

IV.2.2 Life Cycle Inventory Approach

The established framework of the Product Environmental Footprint Category Rules (PEFCR) for High Specific Energy Rechargeable Batteries for Mobile Applications under the RE-CHARGE project (European Commission 2020) model served as the foundation for a systematic decomposition of battery components and their associated material flows. Selecting the relevant PEFCR specific to battery production allowed for adherence to established guidelines that highlighted critical environmental indicators and methodologies tailored for this product category. This model was thus applied to the LCA framework due to its comprehensive documentation and detailed implementation guidelines and application (European Commission 2018). The model's comprehensive documentation of material flows, energy requirements, and process relationships (European Commission 2020) enabled a structured approach to process inventory development while maintaining consistency with established LCA principles.

In this approach, challenges arose in establishing a consistent basis for comparison between the databases, LCI and LCIA, specifically double characterised flows and mapping EF 3.1 LCIA method characterisation factors with the databases. To address these discrepancies, the methodology was refined to better align the processes being compared across both databases.

To better understand ecoinvent data the metadata for the pre-defined process in ecoinvent was also studied briefly. It mainly drew upon the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model (Dai *et al.* 2019), which provides detailed material composition data for a 23.5 kWh NMC 111 battery (Dai *et al.* 2018). Similarities could be seen between this approach and PEFCR hence solidifying PEFCR as the chosen framework.

IV.2.2.1 Life Cycle Inventory Data using PEFCR Guidelines

The Product Environmental Footprint Category Rules (PEFCR) guidelines were consulted to identify the processes to be included from the EF database, as well as the corresponding input amounts. Since the PEFCR framework is based on the Environmental Footprint (EF) database itself (European Commission 2018) there were specific processes defined from the database in the framework. Whereas for ecoinvent database, approximate substitute processes were identified to recreate the PEFCR framework inventory. This necessitated a methodical approach to inventory development and process creation, utilizing the incumbent processes available within the ecoinvent database.

To ensure comparability, processes with equivalent system boundaries and the same allocation method (cutoff system) were identified within the ecoinvent database. The PEFCR processes were then systematically replicated within the ecoinvent database, maintaining alignment with the specified parameters to ensure consistency in the analysis.

Thus, the PEFCR model served as a reference point for this reconstruction, providing a sound basis for translating the EF process architecture into the ecoinvent database structure.

IV.2.3 Methodology for Comparison of LCA Result Between Databases

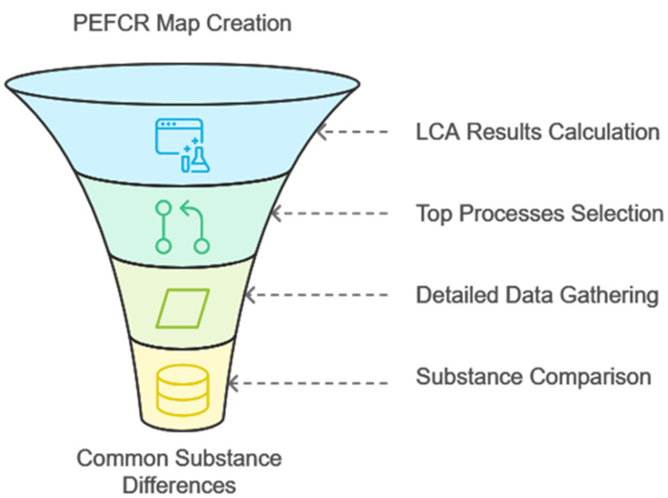
IV.2.3.1 Comparison of Documentation of same component processes

As part of the methodology, the documentation of Life Cycle Assessment (LCA) processes from the EF and ecoinvent databases will be systematically compared. This comparison involves analysing the descriptions, system boundaries, input-output flows, and allocation methods provided for similar processes in both databases. By identifying any differences in how these processes are modelled and documented, this approach will help uncover potential sources of divergence in LCA results. Understanding these variations provides an initial insight into how database-specific factors, such as differences in assumptions, data granularity, and methodological implementations, influence the outcomes of LCA studies. This step lays the groundwork for interpreting database-related discrepancies and assessing their impact on the overall harmonization of LCA results.

After gaining an initial understanding of the reasons behind the differences in climate change impact results, a more detailed analysis was conducted, focusing on the specific substance flow mapping of these processes as described in the following sections.

IV.2.3.2 Substance Flow Mapping Between Databases

An orderly framework was developed to evaluate the database harmonization challenges through the following structured approach:



:

Figure IV-1: Top-down approach for investigation of database related divergence of data

This methodology was devised to ensure consistency with EF methodology requirements, standardized system boundaries, comparable process definitions and higher data quality and completeness.

IV.2.3.2.1 PEFCR Mapping

As mentioned in section 2.4.1 Life Cycle Inventory Data using PEFCR Guidelines, within the PEFCR reference document for High Specific Energy Rechargeable Batteries for Mobile Applications there was a list of all processes taking place in this life cycle stage with default values used for the representative products (European Commission 2020). Using this documentation the process for Li-ion battery production was created in both the database ecoinvent and EF by mapping each input process to the incumbent processes in respective database.

A comprehensive PEFCR mapping framework was established through a multi-tier battery component structure. The primary tier encompassed the fundamental battery components, including cathode, anode, electrolyte, and auxiliary materials. Each component was subsequently mapped to its constituent materials and associated manufacturing processes. The mapping exercise documented:

- PEFCR dataset nomenclature and unique identifiers
- Corresponding ecoinvent process identifiers
- Material flow quantities and units
- Process-specific parameters
- Geographical and temporal scope declarations

Table IV-1: Sample showing PEFCR Processes mapping between EF and ecoinvent databases

No.	Battery Component	Material/ Process	PEFCR Dataset name	Ecoinvent	EF
1	**Others**	Power_electrode	Electricity grid mix	Electricity, medium voltage {Europe without Switzerland}| market group for electricity, medium voltage | Cut-off, S	Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
2	**Others**	Power_cell forming	Electricity grid mix	Electricity, medium voltage {Europe without Switzerland}| market group for electricity, medium voltage | Cut-off, S	Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result18

No.	Battery Component	Material/ Process	PEFCR Dataset name	Ecoinvent	EF
3	**Others**	Power_battery assembly	Electricity grid mix	Electricity, medium voltage {Europe without Switzerland}| market group for electricity, medium voltage | Cut-off, S	Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result19
4	**Others**	Water	Tap water	Water, deionised, from tap water, at user {Europe without Switzerland}| market for water, deionised, from tap water, at user | Cut-off, S	Tap water {EU+EFTA+UK} | average technology mix | consumption mix, at consumer | Technology mix for supply of drinking water to users | LCI result
5	**Others**	Auxiliary materials	Hydrochloric acid mix (100%)	Hydrochloric acid, without water, in 30% solution state {RER}| market for hydrochloric acid, without water, in 30% solution state | Cut-off, S	Hydrochloric acid production {EU+EFTA+UK} | technology mix | production mix, at plant | 100% active substance | LCI result
6	**Others**	Auxiliary materials	n-Methylpyrolidone (NMP)	N-methyl-2-pyrrolidone {GLO}| market for N-methyl-2-pyrrolidone | Cut-off, S	Methylpyrolidone production {EU+EFTA+UK} | technology mix | production mix, at plant | 100% active substance | LCI result
7	**Others**	Waste water treatment	Municipal waste water treatment (sludge incineration)	Water, completely softened {RER}| market for water, completely softened | Cut-off, S	Water, completely softened {EU+EFTA+UK} | average technology mix | production mix, at plant | Technology mix for supply of softened water to users | LCI result
8	**Anode**	Copper foil	Copper Foil (11 µm) for 1 m2	Copper, anode {GLO}| market for copper, anode | Cut-off, S	Copper sheet {EU+EFTA+UK} | melting and mechanical treatment (fabrication) | single route, at plant | 8.92 g/cm3 | Partly terminated system

No.	Battery Component	Material/ Process	PEFCR Dataset name	Ecoinvent	EF
9	**Anode**	Graphite powder	Graphite powder (estimate)	Synthetic graphite, battery grade {CN}| synthetic graphite production, battery grade | Cut-off, S; Graphite, battery grade {RoW}| graphite production, battery grade | Cut-off, S	Carbon black, general purposes production {EU+EFTA+UK} | technology mix | production mix, at plant | 100% active substance | LCI result

This systematic mapping enabled the identification of direct correlations, partial matches, and gaps between the database architectures.

IV.2.3.2.2 Selection of Processes for Analysis

Table IV-2: Table showing top five processes selected for detailed comparison

PEFCR Dataset name	Ecoinvent	Ecoinvent Climate Change	EF	EF Climate Change	Difference in Climate Change
Switch PCB (EPTA)	Printed wiring board, surface mounted, unspecified, Pb free {GLO}| printed wiring board production, surface mounted, unspecified, Pb free | Cut-off, S14	17.5035	Printed wiring board (PWB) (2-layer) {GLO} | via the subtractive method (as opposed to additive method) | production mix, at plant | 2-layer, 1.32 kg | LCI result15	5.7558	11.7477
Aluminium ingot mix PE	Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| aluminium production, primary, ingot | Cut-off, S	4.776	Aluminium ingot mix (high purity) {EU+EFTA+UK} | primary production, aluminium casting | single route, at plant | 2.7 g/cm3, >99% Al | LCI result	1.6635	3.1128
Cobalt sulfate	Cobalt sulfate {RoW}| cobalt sulfate production | Cut-off, S	6.744	Cobalt {GLO} | hydro- and pyrometallurgical processes | production mix, at plant | >99% Co | LCI result	8.54	1.7964
Electricity	Electricity, medium voltage {Europe	3.717	Electricity grid mix 1kV-60kV {EU+EFTA+UK} |	4.654	0.937

PEFCR Dataset name	Ecoinvent	Ecoinvent Climate Change	EF	EF Climate Change	Difference in Climate Change
	without Switzerland}| market group for electricity, medium voltage | Cut-off, S		technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result		
Nickel Sulfate from electrolyt-nickel	Nickel sulfate {GLO}| nickel sulfate production | Cut-off, S	1.799	Nickel sulphate production {EU+EFTA+UK} | technology mix | production mix, at plant | 100% active substance | LCI result	1.106	0.6931

The quantitative analysis for selecting the processes of interest commenced with the computation of absolute differences in Life Cycle Assessment results obtained by analysing the PEFCR dictated inventories in both databases, focusing on the climate change impact indicator. Based on these differential values, the five processes exhibiting the highest magnitude of variation were identified for detailed investigation. This selection criterion ensured focus on the most significant contributors to database-related divergence in LCA results.

IV.2.3.2.3 Impact Contribution Data Gathering

For these identified processes, a detailed impact contribution analysis was conducted at the substance flow level across both databases. The methodology involved:

- Extraction and documentation of detailed impact contribution data at the characterised substance flow impact contribution level
- Identification of the ten highest-contributing substances to climate change impacts for each selected PEFCR process within both databases
- Comparative analysis of substance lists between databases to identify commonalities and gaps
- Quantification of numerical differences in characterized results for common substances and identifying flows which do not match in nomenclature and/or reporting method.

Table IV-3: Sample from showing impact contribution comparison for selected inventory process for Switch PCB component

Substance	Compartment	Unit	Impact Contribution ECO	Impact Contribution EF	Difference
Carbon dioxide, fossil	Air	kg CO2 eq	1.53E+01	5.28E+00	-9.98E+00
Methane, fossil	Air	kg CO2 eq	1.62E+00	4.07E-01	-1.21E+00
Dinitrogen monoxide	Air	kg CO2 eq	1.88E-01	3.96E-02	-1.48E-01
Carbon dioxide, land transformation	Air	kg CO2 eq	3.52E-02	1.03E-02	-2.49E-02
Methane, biogenic	Air	kg CO2 eq	3.45E-02	1.90E-02	-1.55E-02
Methane, trifluoro-, HFC-23	Air	kg CO2 eq	1.01E-02	2.62E-05	-1.00E-02
Methane, tetrafluoro-, CFC-14	Air	kg CO2 eq	3.20E-03	4.03E-05	-3.16E-03
Ethane, hexafluoro-, HFC-116	Air	kg CO2 eq	2.63E-01	0.00E+00	-
Sulfur hexafluoride	Air	kg CO2 eq	7.77E-02	1.56E-08	-7.77E-02
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	kg CO2 eq	2.31E-03	9.58E-16	-2.31E-03
Ethane	Air	kg CO2 eq	1.12E-04	4.14E-05	-7.02E-05
HFC-116 [duplicate, EF3]	Air	kg CO2 eq	na	7.84E-06	-
Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa	Air	kg CO2 eq	na	4.45E-06	-

From such results there were many comparisons drawn between the two databases such as reported zero values in only one database, substances reported in one database but not the other and qualitative trend of the reported values.

IV.2.4 Methodology for Flow Mapping between LCI and LCIA

The following methodology was developed to analyse and compare the substance characterization frameworks across the ecoinvent and Environmental Footprint (EF) databases, comprising several sequential analytical steps:

IV.2.4.1 Substance Flow Analysis

Initially, a compilation of characterized flows and their respective impact contributions was established for each substance. This detailed inventory enabled granular analysis of substance-specific environmental impacts across both databases. The data structure incorporated, individual substance identifiers, characterized flow quantities, impact contribution metrics and database-specific nomenclature.

To ensure the reliability of the comparisons the compartment was restricted to ‘air’, sub-compartment ‘air, unspecified’ and the flows for only Climate Change impact indicator were considered.

IV.2.4.2 Comparative Database Assessment

A comparison framework was implemented to enhance the clarity and reliability of the analysis. To facilitate direct analysis, a parallel structure was developed, allowing for an evaluation of both lists. This was done by placing both the lists next to each other and each substance was concatenated with the relevant compartment to make sure each entry was unique.

Table IV-4: Sample from Excel worksheet showing the combined list of flows from both databases (duplicates highlighted in red)

Database	S.No	Substance	Compartment	Concatenated Term
EF	1	(1S)-(-)-alpha-Pinene	Air	(1S)-(-)-alpha-Pinene Air
ECO	12	1,4-Butanediol	Air	1,4-Butanediol Air
EF	19	1,4-Butanediol	Air	1,4-Butanediol Air
EF	21	1,4-Dioxane	Air	1,4-Dioxane Air
ECO	1	1-Bromopropane	Air	1-Bromopropane Air
ECO	3	1-Butanol	Air	1-Butanol Air
EF	3	1-Butanol	Air	1-Butanol Air
EF	5	1-Butene	Air	1-Butene Air
EF	7	1-Butene, 2-methyl-	Air	1-Butene, 2-methyl- Air
EF	8	1-Octene	Air	1-Octene Air
ECO	5	1-Pentanol	Air	1-Pentanol Air
EF	9	1-Pentanol	Air	1-Pentanol Air

This was complemented by the implementation of a gap analysis aimed at identifying several critical aspects: database-specific substance coverage, the depth and granularity of reporting, variations in nomenclature, and differences in substance classification.

IV.2.4.3 EF 3.1 LCIA Method Characterization Factors Mapping Analysis

IV.2.4.3.1 Mapping of Non-zero Impact Contribution Results

The methodology focused on the mapping of characterization factors, beginning with the extraction and documentation of these factors from the Environmental Footprint (EF) 3.1 Life Cycle Impact Assessment (LCIA) method documentation. To ensure a targeted and manageable analysis, the characterization factors were filtered to include only those relevant to the Climate Change impact indicator and limited to the flow class "Emissions to air, unspecified." This selection was justified as emissions to air are directly associated with Climate Change impacts and represent one of the most critical and widely studied environmental indicators in life cycle assessments. Additionally, restricting the scope to a specific flow class allowed for a more thorough examination and ensured clarity in mapping.

The extraction process involved cross-referencing the filtered characterization factors with the substance lists reported in both databases under consideration. This step was undertaken to ensure comprehensive coverage and to verify the accuracy of the mapping process. Substances with mapped non-zero results were assumed to be correctly mapped and suitable for comparison. This assumption was necessary because of the challenges in discerning whether a calculated result of zero was due to a legitimate cutoff, data gaps, or errors in the mapping process. By focusing on non-zero results, the analysis prioritized data points that could confidently be attributed to successful mapping.

This cross-referencing served to identify several key aspects: direct correlations between substances and factors, partial or ambiguous mappings, unmapped substances and factors, and potential inconsistencies in the mapping process. By analysing these elements, the study aimed to enhance the clarity and robustness of the characterization framework.

Table IV-5: Sample from characterisation factor mapping matrix

FLOW_LCIA	Presence in ECO	Presence in EF
1,2-dichloroethane	Present	Present
carbon dioxide (biogenic)	Present	Present
carbon dioxide (fossil)	Present	Present
Carbon dioxide (land use change)	Present	Present
CFC-10	Present	Present
CFC-11	Present	Present

IV.2.4.3.2 Mapping Including Zero Impact Contribution Results

The reported substances list from both databases was also compared in its entirety, including the substances which were reported to have impact contribution results of zero for all five processes. This was done to have a holistic overview of the difference in reporting from both database runs and assuming the values of zero could mean they have been mapped correctly but had values too small to be reported due to internal cutoff or calculations. The mapping files from the GLAD project were used to ensure comparison to all substance synonyms were included.

IV.3 Results – EV Battery Case Study

IV.3.1 Overall PEFCR LCA Results

The table below captures the LCA results when the same PEFCR dictated process was run in the ecoinvent and Environmental Footprint (EF) databases using the EF 3.1 LCIA method for both in SimaPro. The difference in the last column was calculated by subtracting the result obtained using ecoinvent database from that of the EF database.

Table IV-6: Overall LCA Results using ecoinvent and EF databases

Damage category	Unit	PEFCR EF Results	PEFCR ecoinvent Results	Difference
Acidification	mol H+ eq	5.36E-01	5.37E-01	1.38E-03
Climate change	kg CO2 eq	2.74E+01	3.81E+01	1.07E+01
Ecotoxicity, freshwater	CTUe	4.75E+02	9.52E+02	4.77E+02
Eutrophication, freshwater	kg P eq	1.91E-03	6.06E-03	4.14E-03
Eutrophication, marine	kg N eq	2.67E-02	4.99E-02	2.31E-02
Eutrophication, terrestrial	mol N eq	2.79E-01	5.56E-01	2.77E-01
Human toxicity, cancer	CTUh	3.11E-08	4.87E-08	1.76E-08
Human toxicity, non-cancer	CTUh	5.17E-07	2.23E-06	1.71E-06
Ionising radiation	kBq U-235 eq	3.77E+00	2.82E+00	-9.49E-01
Land use	Pt	8.04E+01	1.78E+02	9.71E+01
Ozone depletion	kg CFC11 eq	1.40E-06	2.11E-06	7.10E-07
Particulate matter	disease inc.	2.90E-06	2.71E-06	-1.94E-07
Photochemical ozone formation	kg NMVOC eq	1.00E-01	1.82E-01	8.20E-02
Resource use, fossils	MJ	4.47E+02	5.45E+02	9.73E+01
Resource use, minerals, and metals	kg Sb eq	8.98E-04	1.12E-02	1.03E-02
Water use	m3 depriv.	1.54E+01	6.07E+01	4.53E+01

It could be seen that the results from the ecoinvent database were higher than those from using the EF database in most impact categories. To limit the focus of the case study analysis, climate change was chosen as the impact indicator of interest to be analysed.

The investigation of impact assessment value disparities adopted a reverse-engineering approach, beginning with the above LCIA results and systematically working upstream to identify the input sources. While impact categories typically contained vast numbers of contributing substances, ranging into thousands, our analysis revealed that a select few substances dominated the overall impact contributions (IC). Through analysing the quantitative contributions of the substances, we successfully isolated the key substances that accounted for more than 95% of the total impact within each category. This identification process allowed us to pinpoint crucial parameters including substance quantities and their contributions to the total climate change indicator value.

First, a closer look was taken at the individual top five PEFCR categorised processes which contributed the highest in terms of climate change by adopting the above-mentioned methodology. Then an overall analysis was done on these identified differences and general trends or commonalities that could be observed in the data.

IV.3.2 Comparing PEFCR Processes in ecoinvent and EF Database

IV.3.2.1 Switch PCB (EPTA)

Switch PCBs play a critical role in EVs, managing electrical connections and ensuring efficient energy distribution within the vehicle's electronic systems. A comparison of climate change impacts between EF and ecoinvent datasets highlights differences in process metadata, energy modelling, and system boundaries for assessing the environmental footprint of switch PCB production.

The following processes from each database were chosen as part of the EV life cycle inventory:

- Ecoinvent Process- Printed wiring board, surface mounted, unspecified, Pb free {GLO}| printed wiring board production, surface mounted, unspecified, Pb free | Cut-off, S
- EF Process - Printed wiring board (PWB) (2-layer) {GLO} | via the subtractive method (as opposed to additive method) | production mix, at plant | 2-layer, 1.32 kg | LCI result

IV.3.2.1.1 Comparing Documentation within Databases

There are significant differences in the reported climate change impacts of the two PCB production processes, 17.50 kg CO_2-eq for the ecoinvent process and 5.755 kg CO_2-eq for the EF process. While both processes aim to capture cradle-to-gate impacts for printed wiring board (PWB) production, their methodological variations result in divergent outcomes.

System Boundaries and Scope

The system boundaries differ substantially between the two processes, which directly affects their calculated impacts. The ecoinvent process describes a generic Pb-free surface-mounted PWB with cradle-to-gate coverage, including infrastructure, production, and waste management. However, it lacks detailed modelling of energy and water inputs, relying instead on generalized assumptions. In contrast, the EF process defines the cradle-to-gate production of a 2-layer PWB and includes explicit details on energy use, water consumption, and auxiliary materials. It incorporates modern manufacturing steps, such as subtractive copper plating, finishing techniques, and overhead energy use for cleaning and wastewater treatment.

This broader and more specific scope of the EF process allows for a more comprehensive and accurate representation of environmental impacts. The ecoinvent process's reliance on older data and less detailed assumptions inflates its climate change indicator, while the EF process benefits from refined system boundary definitions and detailed process modelling.

Technological Representativeness

The technological assumptions in the two processes also diverge significantly. The ecoinvent process reflects average PWB mounting technologies relevant between 2005 and 2022, relying on solder paste production lines without incorporating advancements in manufacturing methods. In contrast, the EF process represents technologies from 2015 to 2024, explicitly modelling modern subtractive methods for copper plating and advanced finishing techniques, such as electrolytic gold-on-nickel and chemical tin treatments. These technological advancements significantly reduce emissions by improving process efficiency and resource use.

The ecoinvent process's reliance on older, less efficient technologies inflates its environmental impact values, while the EF process, which reflects state-of-the-art manufacturing practices, results in significantly lower climate change impacts.

Functional Unit and Product Definition

The choice of functional unit in each process further contributes to the discrepancies in their results. The ecoinvent process uses 1 kg of an unspecified PWB as its functional unit, which does not define the size, layer count, or specific material composition of the board. In contrast, the EF process defines its functional unit as 1 m^2 of a 2-layer PWB, providing precise details about the board's dimensions, layers, and materials.

The functional units considered in both inherently measure different aspects of PCB production, making direct comparisons challenging.

To align the functional units, the conversion from kg (ecoinvent) to m² (EF) requires data on the material density and weight per unit area of the PCB. From the EF dataset, the production of a 2-layer PWB (1.32 kg/m²) provides the necessary conversion factor:

Ecoinvent result per m² = Ecoinvent result per kg × 1.32 kg/m²

For the ecoinvent dataset:

17.503541 kg CO_2-eq/kg × 1.32 kg/m² = 23.105 kg CO_2-eq/m²

This converted result shows that the climate change indicator for the ecoinvent process is significantly higher than that for the EF process (5.7557722 kg CO_2-eq/m²).

The disparity after conversion stems from differences in system boundaries and process assumptions. The EF process specifies a 2-layer PWB, detailing substrate material, finishing types, and manufacturing processes, while the ecoinvent process models an unspecified PWB. Without explicit information on the number of layers, materials, and finishing in the ecoinvent dataset, it represents a more generalized and conservative estimate. This generalization likely contributes to the higher climate change impact even after unit alignment.

Energy and Data Modelling

Differences in energy modelling also play a crucial role in the varying climate change impacts. The ecoinvent process uses a generalized global electricity mix, which does not account for regional variations in grid composition, renewable energy integration, or transmission losses. This lack of regional specificity likely overestimates emissions. By contrast, the EF process also incorporates global electricity data, reflecting energy grid mixes, renewable energy contributions, and supply chain variations. This detailed and localized modelling results in a more accurate estimation of energy-related emissions.

Data Quality and Updates

The quality and timeliness of data are additional factors influencing the results. The ecoinvent process relies on legacy data from Version 2 of the database, which has been minimally updated during its transition to Version 3. Although it adheres to ecoinvent quality guidelines, it does not incorporate recent methodological improvements or industry-specific updates. In contrast, the EF process uses primary data from the electronics industry, collected under stricter guidelines as part of the European Commission's Environmental Footprint initiative. This ensures that the EF process reflects current manufacturing practices and benefits from higher-quality data inputs.

The outdated nature of the ecoinvent process's data results in overestimated impacts, while the EF process's reliance on more recent, high-quality data ensures greater accuracy and lower reported emissions.

Higher Results in the ecoinvent Process

The higher climate change impact reported in the ecoinvent process can be attributed to several factors. Its reliance on older technologies, broader functional unit definitions, generalized energy modelling, and legacy data inflates the calculated emissions. The lack of specificity and updates in its assumptions further contributes to the overestimation of environmental impacts.

Lower Results in the EF Process

The EF process, on the other hand, reports a lower climate change impact due to its incorporation of modern and efficient manufacturing technologies, precise functional unit definitions, region-specific energy modelling, and high-quality data. These factors allow for a more accurate and realistic representation of the environmental impacts associated with PWB production.

IV.3.2.1.2 Comparing Substance Impact Contributions

In an electric vehicle battery, populated printed wiring boards (PWB) are used in the safety management unit. Around 0.057 kg of PCB is used per kg of the selected battery chemistry (European Commission 2020). For the specified amount, the contribution of various substances towards the climate change indicator calculated using the two databases is in the following Table IV-7:

Table IV-7: Impact Contribution comparison – Switch PCB

Substance	Compartment	Unit	IC in ecoinvent	IC in EF	Difference (EF-ECO)
Carbon dioxide, fossil	Air	kg CO2 eq	1.53E+01	5.28E+00	-9.98E+00
Methane, fossil	Air	kg CO2 eq	1.62E+00	4.07E-01	-1.21E+00
Dinitrogen monoxide	Air	kg CO2 eq	1.88E-01	3.96E-02	-1.48E-01
Carbon dioxide, land transformation	Air	kg CO2 eq	3.52E-02	1.03E-02	-2.49E-02
Methane, biogenic	Air	kg CO2 eq	3.45E-02	1.90E-02	-1.55E-02

The table displays the five substances with the highest difference in the calculated values. The total number of distinct substances analysed combining the top substances from both databases was thirteen. The following table 8 states how many of those combinations showed unique characteristics.

Table IV-8: Compilation of discrepancies when reporting non-zero values - Switch PCB

Characterisation factor data	Ecoinvent database	EF database
Instances when database had a value of zero while other had non-zero	0	1
Instances when substance is not reported in data-base but present in the other	2	0

IV.3.2.2 Electricity Grid Mix

Electricity processes are critical in EV production, powering both battery manufacturing and vehicle assembly, with significant implications for carbon footprints.

The following processes from each database were chosen as part of the EV life cycle inventory:

- Ecoinvent Process - Electricity, medium voltage {Europe without Switzerland}| market group for electricity, medium voltage | Cut-off, S
- EF Process - Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | con-sumption mix, to consumer | 1kV - 60kV | LCI result

IV.3.2.2.1 Comparing Documentation within Databases

Functional Unit and Product Definition

The ecoinvent process represents a market group for electricity at medium voltage in Europe without Switzerland. This grouping aggregates multiple national and regional electricity markets within the specified geography. The functional unit corresponds to 1 kWh of electricity at medium voltage supplied at the market gate, where the losses are integrated in the markets feeding this market group.

The EF process, by contrast, models electricity supply at medium voltage (1kV–60kV) for the EU, EFTA countries, and the UK. The functional unit also corresponds to 1 kWh of electricity at medium voltage, but it includes transmission and distribution losses, infrastructure impacts, and imports from neighbouring regions. By integrating these additional aspects, the EF dataset provides a more complete representation of electricity supply to end users.

The broader inclusion of downstream processes in the EF process results in a higher reported climate change impact compared to the ecoinvent dataset, which excludes such elements.

Energy and Data Modelling

Energy modelling is a critical differentiator between the datasets. The ecoinvent dataset uses a market group approach, which aggregates data from multiple markets within its geographical boundary. The markets that are part of the market group represents the energy mixes of each countries, and the different imports.

In contrast, the EF process integrates detailed regional electricity data, including energy carrier contributions (e.g., coal, gas, renewable sources), power plant efficiencies, and emissions from upstream processes such as mining and fuel transport. The EF dataset also incorporates transmission and distribution losses and includes detailed modelling of energy imports and exports between countries.

The absence of these elements in the ecoinvent dataset leads to a lower reported climate change impact. The EF dataset's comprehensive energy modelling, reflecting the complexity and diversity of the European electricity grid, results in higher emissions.

Data Quality and Updates

The ecoinvent process considered for analysis in the current version of the dataset has a reference period from 2015 to 2022 and relies on generalized assumptions for electricity markets in Europe without Switzerland. While it includes data from various sources, it does not explicitly model the evolution of energy mixes or the increasing penetration of renewables in recent years. Additionally, it excludes losses and emissions related to transmission and distribution infrastructure, limiting its completeness.

The EF dataset, with a reference year of 2012 and validity until 2024, incorporates detailed, region-specific data for electricity generation and consumption. It uses primary data for emissions from power plants and secondary data for upstream processes, ensuring a higher level of granularity and accuracy. The EF dataset also accounts for evolving energy carrier mixes and regional variations in electricity generation efficiency.

Lower Results in the ecoinvent Process

The lower climate change impact reported in the ecoinvent process stems from its simplified market group approach. By aggregating data across multiple markets without modelling specific energy carriers or regional variations, the ecoinvent dataset underestimates the emissions associated with electricity production.

Higher Results in the EF Process

The EF process reports higher climate change impacts due to its comprehensive and detailed energy modelling. By including regional electricity mixes, power plant efficiencies, transmission and distribution losses, and energy imports and exports, the EF dataset provides a more complete picture of the emissions associated with electricity production. The integration of upstream processes, such as mining, transport, and refining of fuels, further increases the reported impacts.

The EF dataset's explicit modelling of energy carrier contributions, including fossil fuels and renewables, highlights the higher emissions intensity of regions relying on coal and gas. The inclusion of detailed emissions data for non-combustible renewables, such as hydro and wind, ensures that all energy sources are accounted for, leading to a more accurate assessment.

IV.3.2.2.2 Comparing Substance Impact Contributions

Table IV-9: Impact Contribution comparison - electricity grid mix

Substance	Compartment	Unit	Value in ecoinvent	Value in EF	Difference (EF-ECO)
Carbon dioxide, fossil	Air	kg CO2 eq	3.05E-05	4.37E+00	4.37E+00
Methane, fossil	Air	kg CO2 eq	2.75E-06	2.35E-01	2.35E-01
Dinitrogen monoxide	Air	kg CO2 eq	1.61E-05	3.40E-02	3.39E-02
Carbon dioxide, land transformation	Air	kg CO2 eq	6.34E-08	4.59E-03	4.59E-03
Methane, biogenic	Air	kg CO2 eq	4.57E-08	1.29E-02	1.29E-02

The Table IV-9 displays the five substances with the highest difference in the calculated values. The total number of distinct substances analysed combining the top substances from both databases was thirteen. The following Table IV-10 states how many of those combinations showed unique characteristics.

Table IV-10: Compilation of discrepancies when reporting non-zero values – Electricity Grid Mix

Characterisation factor data	Ecoinvent database	EF database
Instances when database had a value of zero while other had non-zero	1	0
Instances when substance is not reported in database but present in the other	1	0

IV.3.2.3 Aluminium Ingot Mix

Aluminium ingots are a critical component in electric vehicle (EV) production, used extensively in battery casings, structural components, and lightweight body parts to enhance vehicle efficiency and reduce emissions. The environmental impact of aluminium production, particularly its high energy intensity, plays a significant role in the overall life cycle assessment (LCA) of EVs.

The following processes from each database were chosen as part of the EV life cycle inventory:

- Ecoinvent Process - Aluminium production, primary, ingot {IAI Area, EU27 & EFTA} | Cut-off, S
- EF Process - Aluminium ingot mix (high purity) {EU+EFTA+UK} | primary production, aluminium casting | single route, at plant | 2.7 g/cm3, >99% Al | LCI result

IV.3.2.3.1 Comparing Documentation within Databases

Functional Unit and Product Definition

The ecoinvent process represents the production of 1 kg of primary aluminium ingot, emphasizing the casting process, alloying, and handling of molten aluminium. It explicitly excludes processes like scrap remelting and assumes a theoretical 100% aluminium composition for ingots. The focus on alloying and the exclusion of scrap remelting simplify the dataset but also limit its applicability to real-world scenarios where scrap is a significant factor.

In contrast, the EF process models the production of 1 kg of high-purity aluminium ingot (>99% Al), including all upstream processes from bauxite mining to the casting of ingots. The EF dataset focuses on cradle-to-gate emissions, capturing the full supply chain impacts associated with aluminium production, including electricity consumption, mining, transportation, and refining. The EF process also emphasizes the integration of alloying elements and country-specific practices.

The narrower focus of the ecoinvent dataset on alloyed ingots and its exclusion of scrap recycling leads to a higher reported impact compared to the broader cradle-to-gate scope of the EF process, which captures efficiencies and real-world practices such as the integration of renewable energy sources in electricity generation.

Energy and Data Modelling

The ecoinvent process provides a detailed focus on energy use during the casting and alloying stages, including natural gas heating for furnaces and handling processes such as metal treatment and packaging. However, it does not explicitly include the impacts of electricity used in smelting or regional variations in energy supply. Instead, it utilizes the electricity mix for the region with the upstream mixes for each country.

In comparison, the EF process comprehensively models the entire energy supply chain for aluminium production, including the Hall-Héroult electrolytic process, which is highly energy-intensive. The dataset incorporates regional differences in electricity generation, including contributions from renewable energy sources and variations in energy efficiency standards across Europe, EFTA, and the UK. Additionally, the EF dataset includes details on upstream energy carriers, such as coal, natural gas, and hydropower, providing a more accurate representation of the energy inputs.

Data Quality and Updates

The ecoinvent dataset uses primary data collected for the IAI Area, EU27, and EFTA regions, with a reference period of 2015–2022. While it provides a detailed description of casting and alloying processes, it excludes data on upstream processes such as bauxite mining, alumina refining, and electricity production. This omission reduces the scope of the dataset and affects its accuracy for life cycle assessments.

The EF dataset, on the other hand, is based on primary industry data and includes all upstream processes, from bauxite extraction to aluminium ingot production. The reference year is 2016, with data validity extending until 2024. It also incorporates country-specific energy modelling and industry-specific practices, ensuring a high level of geographic and technological representativeness.

Lower Results in the EF Process

The lower climate change impact reported in the EF dataset can be attributed to its broader system boundaries and detailed energy modelling. By incorporating renewable energy contributions, regionally optimized electricity generation, and upstream supply chain impacts, the EF dataset captures efficiencies and modern practices in aluminium production. The inclusion of upstream processes, such as bauxite mining and alumina refining, adds to the comprehensiveness of the dataset, ensuring that it reflects real-world efficiencies and environmental benefits.

Additionally, the EF process models a high-purity aluminium ingot (>99% Al), which represents a more standardized product with lower alloying requirements. The integration of primary data from internationally recognized production processes further enhances the accuracy and reliability of the EF dataset.

Higher Results in the ecoinvent Process

The higher climate change impact reported in the ecoinvent dataset results from its narrower scope and exclusions. The dataset focuses on specific activities within the aluminium production process, such as alloying, casting, and packaging, while excluding upstream processes like mining and refining. This limited scope fails to account for regional efficiencies and renewable energy contributions, leading to an overestimation of emissions. Moreover, the ecoinvent process models a theoretical 100% aluminium ingot, excluding the use of recycled aluminium and the associated environmental benefits. By omitting scrap remelting and its potential to reduce emissions, the dataset inflates the climate change impact.

IV.3.2.3.2 Comparing Substance Impact Contributions

Table IV-11: Impact Contribution comparison - Aluminium Ingot Mix

Substance	Compartment	Unit	Value in ecoinvent	Value in EF	Difference (EF-ECO)
Carbon dioxide, fossil	Air	kg CO2 eq	4.29E+00	1.51E+00	-2.78E+00
Methane, fossil	Air	kg CO2 eq	3.13E-01	7.83E-02	-2.35E-01
Dinitrogen monoxide	Air	kg CO2 eq	2.29E-02	6.00E-03	-1.69E-02
Methane, tetrafluoro-, CFC-14	Air	kg CO2 eq	8.65E-04	3.54E-05	-8.30E-04
Carbon dioxide, land transformation	Air	kg CO2 eq	8.65E-04	5.26E-04	-3.39E-04

The Table IV-11 highlights the five substances with the highest difference in the calculated values. The total number of distinct substances analysed combining the top substances from both databases was twelve. The following Table IV-12 states how many of those combinations showed unique characteristics.

Table IV-12: Compilation of discrepancies when reporting non-zero values – Aluminium Ingot Mix

Characterisation factor data	Ecoinvent database	EF database
Instances when database had a value of zero while other had non-zero	1	3
Instances when substance is not reported in database but present in the other	1	0

IV.3.2.4 Cobalt Sulfate

Cobalt sulfate is a key precursor material used in the production of cathodes for lithium-ion batteries in electric vehicles (EVs), playing a crucial role in energy storage and performance. Its production involves significant environmental impacts.

The following processes from each database were chosen as part of the EV life cycle inventory:

- Ecoinvent Process - Cobalt sulfate {RoW}| cobalt sulfate production | Cut-off, S
- EF Process - Cobalt {GLO} | hydro- and pyrometallurgical processes | production mix, at plant | >99% Co | LCI result

Here notably, the EF database does not provide a specific cobalt sulfate process, instead modelling cobalt production more broadly through hydrometallurgical and pyrometallurgical routes. These differences in process focus, system boundaries, and data assumptions contribute to the variations in reported impacts.

IV.3.2.4.1 Comparing Documentation within Databases

Functional Unit and Product Definition

The ecoinvent process represents the production of 1 kg of cobalt sulfate ($CoSO_4$), a refined product primarily used in Li-ion battery production. The functional unit includes the treatment of cobalt hydroxide with sulfuric acid and disodium disulfite, followed by impurity removal, evaporation, and crystallization. The dataset represents a conservative estimate as it includes shared energy and material use from other cobalt-related products produced in the same facility. As such, it aggregates emissions associated with multiple processes, potentially diluting the specific impacts of cobalt sulfate production.

In contrast, the EF process represents 1 kg of refined cobalt (>99% Co) produced through a weighted mix of hydrometallurgical and pyrometallurgical processes. The functional unit reflects cobalt production as a co-product of nickel and copper mining and processing. This broader scope captures emissions not only from cobalt extraction but also from its association with other metals.

Energy and Data Modelling

Energy modelling plays a critical role in the reported climate change impacts. The ecoinvent process relies on data from a Chinese cobalt production plant, using estimates of energy and material demand based on regional data. This dataset includes the use of electricity for crystallization and drying processes but lacks specific regional energy mix details or the contribution of renewable energy sources. Additionally, it models energy inputs as part of a combined facility, making it challenging to distinguish the emissions associated solely with cobalt sulfate production.

The EF process, on the other hand, integrates regional electricity mixes and considers the energy-intensive nature of cobalt production through hydrometallurgical and pyrometallurgical methods. It accounts for country-specific energy carrier inputs, including renewable and non-renewable sources, and incorporates losses and efficiencies in electricity production. By including energy inputs for the entire cobalt value chain, including mining, processing, and refining, the EF dataset provides a comprehensive representation of energy use and its associated emissions.

The ecoinvent process's reliance on generalized data and the aggregation of facility-wide energy inputs result in lower reported emissions. The EF process, with its detailed modelling of region-specific energy mixes and process-specific energy use, attributes higher emissions to cobalt production.

Data Quality and Updates

The ecoinvent process relies on data from a 2018 life cycle analysis of cobalt production at a single facility. While this ensures relevance for battery-grade cobalt sulfate, it limits the dataset's scope and generalizability. The exclusion of regional differences in production methods and energy sources further restricts its applicability. The dataset is a conservative estimate, as it attributes all material and energy demands at the facility to cobalt sulfate production.

The EF process, by contrast, is based on a critically reviewed life cycle analysis using primary data from members of the Cobalt Development Institute. It reflects global practices in cobalt mining and processing, capturing the two dominant production routes and their associated co-products. The EF dataset includes upstream and downstream processes, such as ore mining, transport, and refining, and considers emissions from diverse geographical regions. However, the dataset relies on data from 2016 and uses regional or global averages where country-specific information is unavailable, which may introduce uncertainties.

Lower Results in the ecoinvent Process

The lower climate change impact reported in the ecoinvent process is primarily influenced by its narrower system boundaries, which focus on cobalt sulfate production – a step downstream from the cobalt production process represented in the EF dataset. While it is true that the energy modelling is based on data from a single Chinese facility, the ecoinvent dataset has been extrapolated to represent other regions of the world (RoW). Consequently, it accounts for regional variations in electricity mixes by incorporating Rest of World electricity market data. However, despite this, the reliance on estimates from a single facility still introduces some limitations in terms of accurately capturing global variations in energy mix and efficiency across different regions.

Higher Results in the EF Process

For EV inventories, cobalt sulfate is the material utilized in battery manufacturing, making it essential to model its production separately. Using the EF cobalt production process inflates the reported climate change impact as it includes the full upstream supply chain impacts that are not directly attributable to the sulfate conversion step.

The EF dataset's focus on cobalt production rather than the specific cobalt sulfate production process introduces discrepancies when evaluating its relevance for EV inventory assessments. While this provides a comprehensive view of the environmental burdens associated with raw cobalt production, it does not directly address the impacts specific to converting cobalt into cobalt sulfate, which is a distinct downstream chemical process.

IV.3.2.4.2 Comparing Substance Impact Contributions

Table IV-13: Impact Contribution comparison - Cobalt Sulfate

Substance	Compartment	Unit	Value in ecoinvent	Value in EF	Difference (EF-ECO)
Carbon dioxide, fossil	Air	kg CO2 eq	5.77E+00	7.95E+00	2.18E+00
Methane, fossil	Air	kg CO2 eq	6.18E-01	4.82E-01	-1.36E-01
Sulfur hexafluoride	Air	kg CO2 eq	1.73E-01	7.92E-03	-1.65E-01
Dinitrogen monoxide	Air	kg CO2 eq	1.13E-01	7.65E-02	-3.66E-02
Carbon dioxide, land transformation	Air	kg CO2 eq	3.31E-02	1.71E-03	-3.14E-02

The Table IV-13 highlights the five substances with the highest difference in the calculated values. The total number of distinct substances analysed combining the top substances from both databases was twelve. The following Table IV-14 states how many of those combinations showed unique characteristics.

Table IV-14: Compilation of discrepancies when reporting non-zero values - Cobalt Sulfate

Characterisation factor data	Ecoinvent database	EF database
Instances when database had a value of zero while other had non-zero	1	1
Instances when substance is not reported in data-base but present in the other	0	0

IV.3.2.5 Nickel Sulfate

The following processes from each database were chosen as part of the EV life cycle inventory:

- Ecoinvent Process - Nickel sulfate {GLO}| nickel sulfate production | Cut-off, S
- EF Process - Nickel sulphate production {EU+EFTA+UK} | technology mix | production mix, at plant | 100% active substance | LCI result

The climate change indicators for nickel sulfate production differ between the ecoinvent process (1.79 kg CO_2-eq) and the EF process (1.10 kg CO_2-eq). These differences result from variations in system boundaries, functional unit definitions, energy and data modelling, and data quality. Additionally, the reliance on stochiometric estimations in the ecoinvent dataset contributes to these discrepancies. Below is an analysis of the processes under key aspects, along with an explanation of the differences.

IV.3.2.5.1 Comparing Documentation within Databases

Functional Unit and Product Definition

The ecoinvent process models the production of 1 kg of nickel sulfate as either hexahydrate or heptahydrate. The functional unit includes the chemical conversion of nickel and nickel oxide with sulfuric acid to produce nickel sulfate. Most of the nickel sulfate in the dataset is assumed to be a by-product of electrolytic copper refining, but direct production through nickel dissolution is also included. The dataset is based on stochiometric calculations and assumes a generic global production scenario.

The EF process also represents the production of 1 kg of nickel sulfate but focuses on regional production in Europe, EFTA countries, and the UK. It includes similar chemical reactions but integrates specific data for inputs, such as sulfuric acid, tap water, electricity, and thermal energy. It models the full production chain while maintaining consistency with European production practices.

The ecoinvent dataset's reliance on global assumptions and stochiometric modelling leads to a more generalized representation of nickel sulfate production, whereas the EF dataset provides a more region-specific and detailed account of the process. This difference in specificity is one reason for the discrepancy in climate change impacts.

Energy and Data Modelling

The ecoinvent process estimates energy consumption based on data from a large chemical plant and stochiometric calculations. It lacks detailed modelling of regional electricity grid mixes and uses global averages for energy inputs. This generalization leads to an overestimation of energy-related emissions, as it does not consider the potential for lower-carbon energy sources in specific regions.

The EF process, by contrast, incorporates regional electricity grid mixes, including renewable and non-renewable energy contributions. It also explicitly models thermal energy requirements and integrates detailed data for transport and other background inputs. These considerations allow for more accurate accounting of energy-related emissions, reflecting the specific energy mix and technological efficiency of nickel sulfate production in Europe.

The Ecoinvent dataset's reliance on generic global energy data inflates its climate change indicator, whereas the EF dataset's use of region-specific data lowers its reported emissions.

Data Quality and Updates

The ecoinvent dataset relies on data from 2011 to 2015 and applies stochiometric calculations to estimate material and energy inputs. While it provides a reasonable approximation of nickel sulfate production, the lack of primary industry data and reliance on global averages reduce its accuracy. Furthermore, the dataset does not account for recent advancements in nickel sulfate production technologies or changes in energy sourcing.

The EF dataset integrates more recent data, with a reference year of 2017 and updates valid until 2024. It uses primary data from European production facilities and detailed modelling of material and energy flows, including infrastructure and waste management. These updates ensure that the EF dataset reflects current practices and regional specifics, resulting in a more robust representation of nickel sulfate production.

The older data and generalized assumptions in the ecoinvent dataset contribute to higher climate change impacts, while the EF dataset benefits from updated and region-specific inputs, leading to a lower overall indicator.

Lower Results in the EF Process

The lower climate change indicator reported in the EF process reflects its integration of detailed energy modelling, updated regional data, and precise material flow calculations. By incorporating renewable energy contributions and higher-efficiency production practices specific to Europe, the EF dataset reduces the carbon footprint associated with nickel sulfate production. The inclusion of waste management and infrastructure impacts further enhances the dataset's completeness, ensuring that emissions are accurately attributed to the production process.

Higher Results in the ecoinvent Process

The higher climate change indicator in the ecoinvent process is primarily due to its reliance on global averages for energy inputs and stochiometric calculations for material flows. These generalized assumptions lead to an overestimation of energy-related emissions and do not capture regional variations in energy sourcing or technological efficiency. Additionally, the lack of recent updates and reliance on older data further inflate the reported climate change impacts.

IV.3.2.5.2 Comparing Substance Impact Contributions

Table IV-15: Impact Contribution comparison - Nickel Sulfate

Substance	Compartment	Unit	Value in ecoinvent	Value in EF	Difference (EF-ECO)
Carbon dioxide, fossil	Air	kg CO2 eq	1.54E+00	1.02E+00	-5.19E-01
Methane, fossil	Air	kg CO2 eq	1.92E-01	5.77E-02	-1.34E-01
Dinitrogen monoxide	Air	kg CO2 eq	3.30E-02	9.99E-04	-3.20E-02
Sulfur hexafluoride	Air	kg CO2 eq	2.41E-02	1.49E-04	-2.40E-02
Methane, biogenic	Air	kg CO2 eq	5.22E-03	3.34E-03	-1.87E-03

The Table IV-15 displays the five substances with the highest difference in the calculated values. The total number of distinct substances analysed combining the top substances from both databases was thirteen. The following Table IV-16 states how many of those combinations showed unique characteristics.

Table IV-16: Compilation of discrepancies when reporting non-zero values - Nickel Sulfate

Characterisation factor data	Ecoinvent database	EF database
Instances when database had a value of zero while other had non-zero	0	0
Instances when substance is not reported in database but present in the other	1	0

IV.3.3 Trend in Results

IV.3.3.1 Common Differences in Processes

By compiling the results obtained from the comparison within individual processes, some common substances were seen which contributed to the disparity in results. The Table IV-17 below highlights the name of the substances which were irregular in such results.

Table IV-17: Substances in common which contributed to disparity in results

	Switch PCB	Electricity grid mix	Aluminium ingot mix	Cobalt sulfate	Nickel Sulfate
Impact Contribution reported but zero in EF	Ethane, hexafluoro-, HFC-116	-	Sulfur hexafluoride Ethane, hexafluoro-, HFC-116 Methane, tetrachloro-, CFC-10	Ethane, hexafluoro-, HFC-116	-
Impact Contribution reported but zero in ecoinvent	-	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	-
Impact Contribution not reported in EF	-	-	-	-	-
Impact Contribution not reported in ecoinvent	HFC-116 Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa	Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa	HFC-116	-	HFC-116

Here, the substance Ethane, hexafluoro-, HFC-116 can be seen reported as value zero in multiple processes and on the other hand we have HFC-116 substance which is not reported in ecoinvent results at all for three out of the five processes. This could imply that there is a duplicate in EF database for HFC-116 substance and the characterisation factors are not being mapped correctly during calculations.

Another substance Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114 is seen consistently being reported as zero in ecoinvent while having non-zero value in EF database. Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa is not present in the ecoinvent results as well.

IV.3.3.2 Trends in Substance Contribution Calculations

Looking at the results from all five processes together led to certain observations about the fundamental difference in the calculations from both databases and how the same LCIA method behaves differently in both.

IV.3.3.2.1 Difference in Distribution of Impact Contributions

An angle which was studied to understand the influence of databases on the LCIA results is the distribution of substance amounts in the process. These two graphs have been created by mapping the reported substance contribution values along a logarithmic scale on the Y axis in decreasing order of magnitude for all five processes analysed.

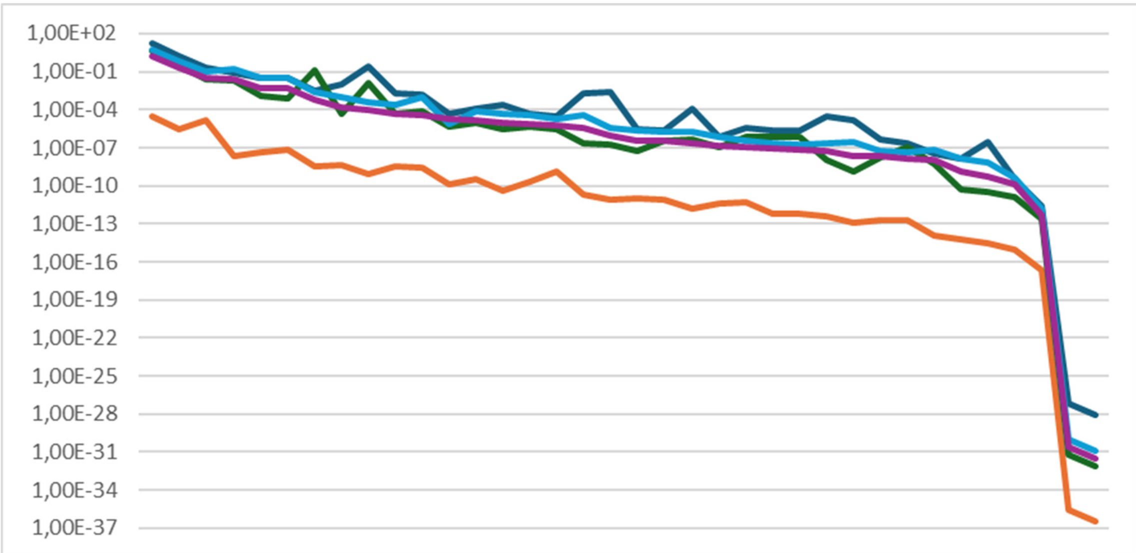


Figure IV-2: Distribution of reported flows in ecoinvent database

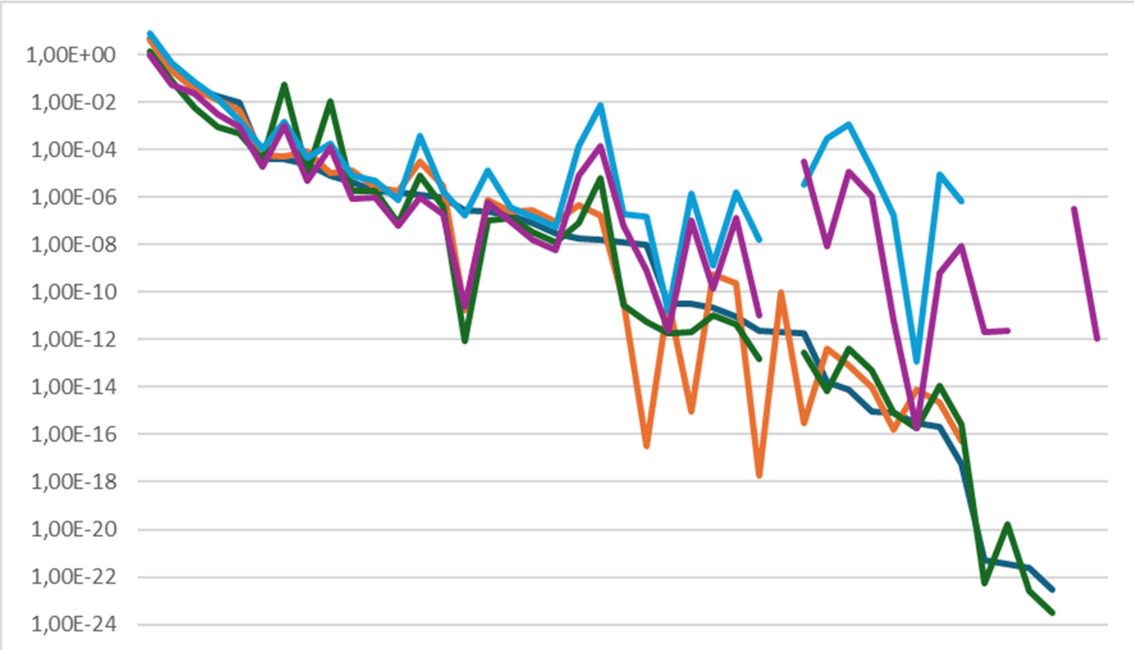


Figure IVV-3: Distribution of reported flows in Environmental Footprint database

While ecoinvent database has values approaching E-37 and EF has its lowest only at E-24, there seems to be a more even distribution of the substance contribution results in EF. Ecoinvent results have a much larger gap between the highest contributing substance and the lowest consistently across the processes. This could also imply that the cutoff for recording the values in EF is lower and hence encompasses more reported values within the characterised results.

IV.3.3.2.2 Number of Calculated Substances

From the following Table IV-18 it can be observed that on average EF database includes calculations for more substances in its results than in ecoinvent.

Table IV-18: Overall number of non-zero substances analyses

	Switch PCB (EPTA)	Electricity grid mix	Aluminium ingot mix PE	Cobalt sulfate	Nickel sulfate
Total non-zero values EF	41	38	40	37	40
Total non-zero values ecoinvent	36	36	36	36	36

This could be attributed to the possibility that the LCIA method EF 3.1 is being better mapped to the EF database than the ecoinvent database and thus producing more results as zero in ecoinvent.

IV.3.4 Comparing LCI to LCIA

IV.3.4.1 Database Characterized Flows Comparison

IV.3.4.1.1 Number of Total Reported Flows

In the base list of substances reported within the results from EF and ecoinvent databases, there is a wide difference in the number of substances captured. On one hand ecoinvent database reports 2326 entries, EF reports a wide 18649 substance results. A major contributor to this difference in the number of reported results is that EF database includes regional level break-down for a lot of the results which ecoinvent does not provide as seen for Nitrogen oxides as an example in the Table IV-19 below:

Table IV-19: Sample difference in databases due to regional focus

Database	Substance Name
Ecoinvent	Nitrogen oxides
EF	Nitrogen oxides, AL Nitrogen oxides, AT Nitrogen oxides, BA Nitrogen oxides, BE Nitrogen oxides, BG Nitrogen oxides, BY Nitrogen oxides, CH Nitrogen oxides, CZ Nitrogen oxides, DE Nitrogen oxides, DK Nitrogen oxides, EE Nitrogen oxides, ES

IV.3.4.1.2 Mapping Non-Zero Reported Flows

The analysis originated with the compilation of a comprehensive list of total reported substance flows from both databases. This list was then filtered to exclude entries with a reported value of zero, as those substances reported with a non-zero value were assumed to be mapped correctly with certainty, unlike those with a reported value of zero. Subsequently, the nomenclature of each flow was matched to identify counterparts in the other database. Notably, the Environmental Footprint (EF) database contained a broader list of substance flows reported as non-zero in EF but as zero in ecoinvent, while on the other hand the ecoinvent database had only two non-zero flows — Ethane, 1,1,1-trifluoro- (HFC-143a) and Methane, dichloro- (HCC-30) — that were reported as zero in the EF database. Additionally, synonyms for each flow were included in the dataset, which would further facilitate the mapping of these substances to their respective characterization factors within the Life Cycle Impact Assessment (LCIA) methodology.

Table IV-20: Mapping Non-Zero Reported Flows

Substance_Flow_ECO	Substance_Flow_EF
-	Bromoform
Butane	Butane
Carbon dioxide, fossil	Carbon dioxide, fossil
Carbon dioxide, to soil or biomass stock	Carbon dioxide, in air, land transformation
Carbon dioxide, land transformation	Carbon dioxide, land transformation
Chloroform	Chloroform
-	Dichloromethane [duplicate, EF3]
Dinitrogen monoxide	Dinitrogen monoxide
Ethane	Ethane
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113
-	Ethane, 1,1,2-trifluoro-, HFC-143
Ethane, 1,1-difluoro-, HFC-152a	Ethane, 1,1-difluoro-, HFC-152a
-	Ethane, 1,2-dibromo-
Ethane, 1,2-dichloro-	Ethane, 1,2-dichloro-
-	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124
Ethane, chloro-	Ethane, chloro-
Ethane, hexafluoro-, HFC-116	Ethane, hexafluoro-, HFC-116
Ethane, pentafluoro-, HFC-125	Ethane, pentafluoro-, HFC-125
Ethane, 1,1,1-trichloro-, HCFC-140	HCFC-140 [duplicate, EF3]
-	HFC-116 [duplicate, EF3]
Methane, biogenic	Methane, biogenic
Methane, bromo-, Halon 1001	Methane, bromo-, Halon 1001
Methane, bromochlorodifluoro-, Halon 1211	Methane, bromochlorodifluoro-, Halon 1211
Methane, bromotrifluoro-, Halon 1301	Methane, bromotrifluoro-, Halon 1301
Methane, chlorodifluoro-, HCFC-22	Methane, chlorodifluoro-, HCFC-22
-	Methane, chlorotrifluoro-, CFC-13
Methane, dichlorodifluoro-, CFC-12	Methane, dichlorodifluoro-, CFC-12
Methane, dichlorofluoro-, HCFC-21	Methane, dichlorofluoro-, HCFC-21
-	Methane, difluoro-, HFC-32
Methane, fossil	Methane, fossil
Methane, land transformation	Methane, land transformation

Substance_Flow_ECO	Substance_Flow_EF
Methane, monochloro-, R-40	Methane, monochloro-, R-40
Methane, tetrachloro-, CFC-10	Methane, tetrachloro-, CFC-10
Methane, tetrafluoro-, CFC-14	Methane, tetrafluoro-, CFC-14
Methane, trichlorofluoro-, CFC-11	Methane, trichlorofluoro-, CFC-11
Methane, trifluoro-, HFC-23	Methane, trifluoro-, HFC-23
Nitrogen fluoride	Nitrogen fluoride
Propane	Propane
-	Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa
Sulfur hexafluoride	Sulfur hexafluoride
Tetrachloroethylene	Tetrachloroethylene
Trichloroethylene	Trichloroethylene

IV.3.4.2 Mapping EF 3.1 Characterization Factors to Reported Non-Zero Flows

The compiled list of reported non-zero flows from before were then mapped to the list of characterization factors from the EF 3.1 LCIA method documentation (European Commission 2021). The entries highlighted in orange below in Table IV-21 were not present in the master list of characterization factors from EF 3.1.

Table IV-21: Compiled list of reported non-zero flows

Non-zero Substance_Flow_All	
Bromoform	Methane, biogenic
Butane	Methane, bromo-, Halon 1001
Carbon dioxide, fossil	Methane, bromochlorodifluoro-, Halon 1211
Carbon dioxide, in air, land transformation	Methane, bromotrifluoro-, Halon 1301
Carbon dioxide, land transformation	Methane, chlorodifluoro-, HCFC-22
Chloroform	Methane, chlorotrifluoro-, CFC-13
Dichloromethane [duplicate, EF3]	Methane, dichlorodifluoro-, CFC-12
Dinitrogen monoxide	Methane, dichlorofluoro-, HCFC-21
Ethane	Methane, difluoro-, HFC-32
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Methane, fossil
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Methane, land transformation
Ethane, 1,1,2-trifluoro-, HFC-143	Methane, monochloro-, R-40
Ethane, 1,1-difluoro-, HFC-152a	Methane, tetrachloro-, CFC-10
Ethane, 1,2-dibromo-	Methane, tetrafluoro-, CFC-14
Ethane, 1,2-dichloro-	Methane, trichlorofluoro-, CFC-11
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Methane, trifluoro-, HFC-23

Non-zero Substance_Flow_All	
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Nitrogen fluoride
Ethane, chloro-	Propane
Ethane, hexafluoro-, HFC-116	Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa
Ethane, pentafluoro-, HFC-125	Sulfur hexafluoride
HCFC-140 [duplicate, EF3]	Tetrachloroethylene
HFC-116 [duplicate, EF3]	Trichloroethylene
Ethane, 1,1,1-trifluoro-, HFC-143a (only ecoinvent)	Methane, dichloro-, HCC-30 (only ecoinvent)

Within the long list of characterization factors from EF 3. 1 consisting of 211 flows, only 27 were found to be reported in the results for LCA analysis in both databases. It is unclear if this is due to erroneous mapping of the characterization factors, low cutoff thresholds or more flows were mapped correctly but were reported to contribute zero to the impact indicator.

IV.3.4.3 Cross-referencing Flows reported as Zero in ecoinvent and EF

Mapping reported zero values in life cycle assessments (LCA) is also essential for ensuring a holistic and accurate analysis of environmental impacts. Zero values may stem from data gaps, cutoffs, or uncharacterized flows rather than the actual absence of impact and mapping them helps identify and address such inconsistencies. This process ensures consistency across LCA databases and software platforms, allowing for a reliable comparison of methodologies and results. Additionally, it captures the full scope of environmental impacts, highlighting flows that may be negligible in one context but relevant under different conditions. Mapping zero values also verifies the accuracy of substance linking between life cycle inventory (LCI) databases and life cycle impact assessment (LCIA) methods, distinguishing correctly mapped flows with no impact from those erroneously omitted. Ultimately, this step enhances the robustness of LCA results, addressing potential biases and providing a more comprehensive foundation for decision-making and policy development.

Comparing the characterization factors of the EF 3.1 LCIA method with the reported values in LCI databases is what has already been extensively addressed under the GLAD (Global LCA Data Access) project. The GLAD initiative focuses on improving the interoperability and harmonization of LCA datasets globally, including the alignment of characterization factors across various LCIA methods and databases. This ensures consistency and transparency in how environmental impacts are calculated and reported. Since GLAD has established a robust framework for comparing characterization factors and aligning them across different datasets, further such analysis would not contribute new insights to the field. Instead, the research can focus on more nuanced issues, such as exploring the difference in mapping of processes between LCI databases, addressing data gaps, or assessing how inconsistencies influence specific case studies, which are areas where additional contributions are still needed.

The following results are derived from comparing the reported impact contributions for both the LCI databases, ecoinvent and EF. Only the compartment 'Air' is considered for the analysis. This comparison provides valuable insights into the consistency and discrepancies between the two widely used databases, highlighting variations in how environmental flows are mapped and characterized. Understanding these differences is crucial for improving the harmonization of LCI data

IV.3.4.3.1 Impact Contribution flows missing in EF

There are a total of 86 missing impact contribution flows in EF when compared to ecoinvent as shown in Table IV-22 below. This is on comparing the full list of reported substances (zero, non-zero).

Table IV-22: Missing impact contribution flows in EF

1-Bromopropane	Lithium (I)
2,4-D ester	Manganese
Abamectin	Mercury
Acetamiprid	Mesotrione
Alkylbenzene (C10-C15)	Metalaxyl-M
Alpha-cypermethrin	Methane
Aluminium (III)	Methane, dichloro-, HCC-30
Amine oxide	Methoxyfenozide
Antimony	Metsulfuron-methyl
Argon-40	Molybdenum
Arsenic	Nickel
Barium	Nicosulfuron
Beryllium	NMVOC, non-methane volatile organic compounds, unspecified origin
Bifenthrin	Octaethylene glycol monododecyl ether
Cadmium	Organic carbon
Carbendazim	Paraffins
Chlorantraniliprole	Potassium
Chromium	Prothioconazol
Chromium IV	Pyraclostrobin (prop)
Chromium VI	Pyriproxyfen

Cobalt (II)	Quizalofop-P-ethyl
Copper	Selenium (IV)
Copper oxychloride	Silicon tetrachloride
Cyfluthrin	Silver
Cyproconazole	Simazine
Dichlorodimethylsilane	Strontium
Difenoconazole	Tebuthiuron
Dimethyldichlorosilane	Teflubenzuron
Diquat dibromide	Thallium
Diuron	Thiabendazole
Dodecanoic acid	Thiamethoxam
Epoxiconazole	Thiophanate-methyl
Ethane, 1,1,1-trichloro-, HCFC-140	Tin, ion
Ethene	Titanium, ion
Ethene, chloro-	Triflumuron
Ethene, tetrachloro-	Trisodium phosphate
Ethene, trichloro-	Vanadium (V)
Fenoxaprop	VOC, volatile organic compounds
Fluazinam	Zeta-cypermethrin
Fludioxonil	Zinc
Gibberellic acid	Indoxacarb
Haloxyfop-ethoxyethyl	Iron
Hydrogen chloride	Lead

A closer examination reveals that these substances can be broadly grouped into distinct categories based on their chemical properties and sources. Metals and metal ions, such as Aluminium, Antimony, Chromium, and Lead, are prominent in the list and are commonly associated with industrial activities, including manufacturing, mining, and energy production. These metals often contribute to environmental toxicity and bioaccumulation, making their characterization critical for accurate life cycle assessments. Similarly, volatile organic compounds (VOCs), such as Methane, Ethene derivatives, and NMVOCs, are prevalent and are well-documented contributors to greenhouse gas emissions and photochemical smog formation.

In addition to industrial byproducts, a significant portion of the listed substances includes agricultural chemicals, such as pesticides and herbicides like Abamectin, Cyproconazole, and Indoxacarb. These substances are primarily used in farming and pest control and are known for their ecotoxicity and potential to impact both terrestrial and aquatic ecosystems. The list also contains acids, oxides, and other complex organic compounds, such as Hydrogen chloride and Thiophanate-methyl, which are often byproducts of industrial processes and combustion.

These commonalities highlight the diverse range of substances contributing to airborne emissions, spanning industrial, agricultural, and energy-related sources. Their inclusion in life cycle assessment databases is vital for accurately assessing their environmental impacts and for ensuring the comprehensiveness of LCA models used in decision-making. However, discrepancies in their characterization and representation across databases, as discussed in this study, underscore the need for improved harmonization and standardization efforts in LCA methodologies.

IV.3.4.3.2 Impact Contribution flows missing in ecoinvent

There are a total of 119 missing impact contribution flows in ecoinvent when compared to ecoinvent as shown in Table IV-23 below. This is on comparing the full list of reported substances (zero, non-zero).

Table IV-23: Missing impact contribution flows in ecoinvent

(1S)-(-)-alpha-Pinene	Nitrogen, total
1-Butene	Nonane
1-Butene, 2-methyl-	o-Cresol
1-Octene	p-Cresol
1-Pentene [duplicate, EF3]	Paraquat dichloride
1,4-Dioxane	Particulates, < 10 um
2-Butene (trans)	Pentane, 2,4-dimethyl-
2-Chloroacetophenone	Pentane, 3-methyl-
2-Pentene (cis)	Phosphate
2-Pentene (trans)	Phthalate, n-dioctyl-
Acetochlor	Plutonium
Acetophenone	Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa
Acidity, unspecified	Propylene glycol methyl ether
Aldicarb	Propylene glycol methyl ether acetate
Ammonium nitrate	Pyridine
Ammonium, ion	Sulfur
AOX, Adsorbable Organic Halogen	Sulfuric acid, dimethyl ester
Argon	Tar
Argon-40/kBq	Terbufos
Arsenic (V)	Tetradecane
Arsenic trioxide	Thifensulfuron-methyl

Benomyl	Tin (IV) oxide [duplicate, EF3]
Benzene, 1,2,3-trimethyl-	TOC, Total Organic Carbon
Benzene, 1,3,5-trimethyl-	Toluene, 2,4-dinitro-
Benzene, chloro-	Total reduced sulphur compounds
Benzyl chloride	Trichlorfon
Biphenyl	Tridecane
Bromoform	Undecane
Butane, 2,2-dimethyl-	Used air
Butyl acetate	Vinyl acetate
C12-14 fatty alcohol	Water
Caprolactam	Water (evapotranspiration)
Carbofuran	Zinc dichloride
Chloride	Zinc oxide
Chlorides, unspecified	Zinc sulphate
Chlormequat chloride	Lead dioxide
Chromium, ion	m-Cresol
Clean gas	Mecoprop-p
Cyclopentane	Methacrylic acid
Cyclopentane, methyl-	Methane, chlorotrifluoro-, CFC-13
Cyhalothrin, gamma- [duplicate, EF3]	Methane, difluoro-, HFC-32
Cyprodinil	Methyl methacrylate
Decane	N-octane
Deltamethrin	Nitrogen dioxide
Dichloromethane [duplicate, EF3]	Hydrogen bromide
Diflufenican	Hydrogen cyanide
Dimethoate	Hydrogen iodide
Dimethyl formamide	Ioxynil
Dodecafluoropentane [duplicate, EF3]	Isobutane
Dodecane	Isopentane
Ethane thiol	Isophorone
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	Isoproturon
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	Lanthanum
Ethane, 1,1,2-trifluoro-, HFC-143	Lanthanum-141
Ethane, 1,1,2,2-tetrachloro-	Fenvalerate
Ethane, 1,2-dibromo-	Fluoride
Ethylene glycol	HCFC-140 [duplicate, EF3]
Fatty acid methyl ester	Hexamethylene diamine

Fenoxaprop ethyl ester	HFC-116 [duplicate, EF3]
Hydrazine	

The presence of substances such as ammonia, nitrogen oxides, and multiple isomers (e.g., cis/trans 2-pentene) in certain databases, alongside established sources like ecoinvent, reflects differences in data structure and emphasis. Some databases integrate broader geographic and sectoral representations, often incorporating country-specific data to better capture regional variations in emissions and their associated impacts. This granularity is particularly beneficial for global LCAs requiring nuanced modelling of regionally specific environmental factors.

The inclusion of multiple isomers and specific chemical configurations in some datasets highlights an effort to enhance data specificity and comprehensiveness. Such details allow researchers to model distinct chemical pathways with greater precision. Additionally, databases aligned with evolving environmental priorities tend to capture substances increasingly recognized as critical for addressing challenges like air quality and the impacts of non-CO_2 climate forcers. For instance, substances like VOCs, sulfur compounds, and aerosols reflect growing attention to regional air quality, photochemical smog, and secondary environmental effects.

Further integration of system-level entries, such as "used air" or "water (evapotranspiration)," demonstrates a shift toward encompassing both natural and anthropogenic processes in LCA models. This expanded scope enables multi-indicator assessments that go beyond climate change impacts to include areas such as acidification and photochemical smog.

Databases such as ecoinvent remain foundational to LCA research and are often integrated into broader frameworks or other databases to provide robust baseline data. In this context, newer approaches aim to complement ecoinvent's comprehensive coverage by filling specific data gaps or aligning with emerging research and policy needs. For example, substances like VOCs and sulfur compounds, which contribute to secondary emissions and regional environmental impacts, are documented in various datasets to meet evolving requirements, offering additional perspectives to LCA practitioners while maintaining consistency across tools and methodologies.

IV.4 Conclusion & Outlook

IV.4.1 Data Availability in EF and ecoinvent Databases and the Path Forward

The comparison of EF and ecoinvent databases reveals important differences in data availability, system boundaries, and granularity that significantly influence the results of life cycle assessments (LCAs). These distinctions arise from differences in the design and focus of each database. Ecoinvent provides a foundational dataset that has been widely used for over two decades, offering extensive coverage across various sectors. Its standardized processes ensure reliability and consistency.

The EF database, which incorporates ecoinvent as part of its data sources, builds on this foundation with additional granularity in certain areas, such as country-specific energy modelling and process-level details for chemical configurations, isomers, and secondary emissions. EF's alignment with recent environmental policies, such as the inclusion of volatile organic compounds (VOCs), aerosols, and sulfur compounds, reflects its focus on addressing contemporary environmental concerns like air quality and non-CO_2 climate forcers. However, the EF dataset still lacks harmonization with some ecoinvent processes, as evidenced by discrepancies in functional units and system boundaries for key materials such as cobalt sulfate and aluminium ingots.

These differences highlight a critical challenge for LCA practitioners: the need to reconcile the unique strengths of different databases to facilitate meaningful comparisons. For example, while EF datasets may capture regionalized electricity or energy carrier supply chains with a high degree of specificity, ecoinvent's broader coverage across multiple sectors provides a more comprehensive baseline for global LCAs. Differences in the modelling of substances like ammonia, nitrogen oxides, and sulfur dioxide further emphasize the need for consistent representation of elementary flows across databases.

IV.4.2 Facilitation of Comparisons Through Broader Coverage

One clear path forward is increasing the breadth of coverage in each database to improve compatibility. This involves expanding the scope of both EF and Ecoinvent to fill existing data gaps while aligning their methodologies for consistency. For instance, implementation of regionalized impact assessment in ecoinvent and further extending EF's sectoral representation could enhance the complementarity between the two. EF datasets often provide higher granularity in specific areas but might not encompass the wide-ranging industrial sectors ecoinvent covers. By expanding the scope of EF to include a broader range of sectors, it would enable better alignment and complementarity between the two databases, facilitating more holistic and comparable life cycle assessments. This approach supports the goal of increasing coverage across databases to bridge existing gaps and improve their collective utility in global LCAs.

IV.4.3 Path to a Harmonized Database

Achieving harmonization across databases requires a collaborative effort involving both technical advancements and institutional cooperation. A unified framework for database development is essential to align methodologies, system boundaries, and functional units.

IV.4.3.1 Standardizing Elementary Flows and Functional Units

Establishing common definitions for elementary flows and functional units across databases will improve comparability. For example, representing cobalt sulfate as a separate downstream process in both EF and ecoinvent ensures consistency in evaluating its impacts within EV battery production.

IV.4.3.2 Regionalization of Emissions

Having more regionalized inventories to represent key emissions like nitrogen oxides and sulphur compounds, that have geographically specific impacts in a more regionalised way at inventory level. More regionalized inventories allow for an improved regionalized impact assessment. This requires collaboration between database providers and stakeholders to ensure accuracy and applicability.

IV.4.3.3 Data Integration and Interoperability

Developing protocols for data sharing and integration would enable databases to complement one another. For instance, EF's regional energy modelling could be integrated into ecoinvent, while ecoinvent's broader sectoral coverage could enrich EF datasets. This integration could be facilitated through shared platforms or data-exchange agreements.

IV.4.3.4 Expanding Temporal and Geographic Representativeness

Both databases should prioritize updates to maintain relevance, reflecting the latest technological advancements and regional changes. For example, incorporating renewable energy trends and evolving industrial practices into their datasets would ensure continued accuracy and applicability.

IV.4.4 Conclusion

The differences between EF and ecoinvent databases underscore the need for greater alignment in their structure and content. While each database brings unique strengths to LCA, their integration and harmonization are essential for enabling consistent and meaningful comparisons. Increasing the coverage of sectoral, regional, and system-level data across both databases represents a key step toward this goal. By standardizing elementary flows, improving interoperability, and fostering collaborative efforts driven by international policy frameworks, the development of a harmonized database is not only achievable but also critical for advancing the accuracy and reliability of life cycle assessments in addressing global environmental challenges.

V. Life Cycle Interpretation requirements: background, justification & consensus building

V.1 Results display

V.1.1 Scenario analysis, uncertainty analysis and sensitivity analysis

V.1.1.1 Definitions

Table V-1 provides the long version of the definition of scenario analysis, uncertainty analysis and sensitivity analysis as agreed in TranSensus-LCA. This definition complements the short definition provided in Table I-1 in the deliverable D 2.3.

Table V-1: Extended definitions of scenario analysis, uncertainty analysis, and sensitivity analysis in TranSensus-LCA.

Analysis	Long definition
Scenario analysis	A scenario in LCA as described in the ILCD and PEF guidelines is a choice of model. Those choices encompass the inventory data, parameters, flow properties, functional unit, but also method assumptions such as allocation. Thus, a scenario analysis evaluates how varying the choices made can have an influence on the results. In scenario analysis there is more than one parameter that can vary in each scenario (but not necessarily all the parameters at the same time). This variation is determined by a storyline that must be relevant to the situation. The likelihood of these storylines should appear in the scenario analysis. Scenario analysis is a part of sensitivity analysis and is distinct from local or global sensitivity analysis. With this definition, scenario analysis can be seen as a means to compensate for lack of knowledge of a present system, uncertainties about the methodology/functional unit and variability of the products.
Uncertainty analysis	Uncertainty analysis, in general, is carried out to investigate the accuracy and reliability of the LCA model of a product or a process, which has been developed with various underlying variables and assumptions as the basis of LCA. Particularly applied to comparative LCA, uncertainty analysis must be applied to estimate and report any statistical differences in the results reported for the different variables. Where not possible, a thorough evidence-based justification of the preference of one system over the other should be provided.
Sensitivity analysis	Most guidelines refer to sensitivity as a 2-step-process. First step (“check”, “analysis”) is changing parameters like inventory data, used methods, impact categories or assumptions to be able to evaluate the influence these changes have on the final results of the LCA. According to the ISO 14040 this can be done in absolute numbers or a variation in %. The aim of the second step (“evaluation”) is to assess the results concerning their relevance for final conclusions and suggestions. This step is an iterative process along all steps of the LCA and should also incorporate expert knowledge and prior experiences. The most commonly used approach is the local sensitivity analysis (LSA) which evaluates the variation caused by one input around its reference point as opposed to global sensitivity analysis (GSA) which evaluates the variation of outputs caused by all input parameters.

V.1.2 Mandatory analysis of parameters

This section provides additional background information for the mandatory analysis of parameters.

Table V-2: Overview on mandatory parameters

Mandatory parameter	Comments
Usage: vehicle lifetime activity	In the internal vote in Task 2.5, there was an equal number of votes in favour for a scenario analysis and a sensitivity analysis. Due to the lower complexity, it was decided that a sensitivity analysis will be carried out.
Usage: variation of energy mix consumption	In the last voting the geographical variation instead of the variation at all was agreed on. To make the question appliable to more contexts, the geographical was left out.
Future electricity/H2 mix for the use stage	In the 2nd voting, this proposed approach did not reach a qualified majority. Due to its importance for the LCA, this question was asked again, and more information is provided. After the 3rd voting it reached a qualified majority.

V.1.3 Agree/Disagree comments

Table V-3: Overview on comments provided

Parameter	Comments	Answer
Usage: consumption	Should be recommended. Shouldn't be mandatory.	Qualified majority vote for mandatory.
	with sufficient documentation and justification.	Background information and guidelines were reviewed.
	depends on the scope of the study and available data (representative vehicle... high or low equipped...)	Was added in main body
	Ambient temp can also be part of this guideline	Was added in main body
	Requires harmonisation with question 17 (Use stage electricity consumption modelling)	Reference to *general guidance for the Use stage electricity consumption "dynamic" modelling approach* added
Quantity value	This question is not super clear. I had to reread it multiple times to see that it was different to Q63.	Although the comment refers to the question submitted for voting, the definition of "quantity value" has been revisited for clarity as follows: "*The quantity value refers to the amount of any LCI flow associated with a specific activity (e.g., the input amount of a component/material/energy or the output amount of a substance emitted to air from cell production)*".
	There needs to be more guidance here. The recommendation is not clear. What is considered a hotspot, is there a % of the total impact that we should look at? How much	Reference to hotspots based on T2.3 has been included in the description of the analysis.

Parameter	Comments	Answer
	should you vary your data to study the sensitivity?	
	General comments on mandatory parameters analysis: A lot of analysis to be performed by OEMs!	Voted mandatory and recommended parameters.
	with sufficient documentation and justification	Background information and guidelines were reviewed.
	Requires further development for agreement	Background information and guidelines were reviewed.
	Already very high accuracy in LCI due to vehicle specific BOM and foreground data makes sensitivity irrelevant. Sensitivity for background datasets is too time consuming	Included a special provision.
	It is more relevant to improve process for selecting relevant background datasets rather than performing sensitivity for each single LCA.	Noted
	OEMs know the quantities based on the BOM. Maintenance is already included.	Noted
Usage: vehicle lifetime activity	should not be mandatory Should be recommended	Qualified majority vote for mandatory.
	with sufficient documentation and justification	Included in the proposed approach: "*the data used and the underlying assumptions must be properly documented and reported*"
	Requires further development for agreement	An example of low-high value has been included.
Usage: variation of energy mix consumption	It is expected for OEMs to have a mapped market for their vehicles (i.e. the region(s) in which the vehicle will be used). However, this analysis can be useful when adapting results to different geographies.	Acknowledged in the parameter definition.
	The scope of the study specifies the region. Scenarios can be recommended but not mandatory	Qualified majority vote for mandatory.
	This depends on the decision made for the dynamic-mix modelling during use stage. What is the goal of this analysis? You will just be comparing countries? Seems irrelevant to a product LCA.	The definition of the parameter has been updated to enhance clarity
	with sufficient documentation and justification	Background information and guidelines were reviewed.
	Should not be limited to a country or region. More relevant to use for example a renewable mix.	New parameter to be analysed: variation of energy mix consumption

Parameter	Comments	Answer
	Add guidance on when a single power generating source can be used.	Not taken into account.
	Would it make sense to combine this with the scenario analysis of future electricity supply?	Separate analysis for these two timespans.
Future electricity/H2 mix for the use stage	more effort without significant added value, if a sensitivity for electricity mixes (e.g. renewables, which is already proposed in Q17 1.d) is already performed. This should be recommended only. okay for recommended analysis Useful, however doesn't require to be mandatory (mandatory sensitivity analysis is sufficient) Method ok but not mandatory. Some mandatory analyses seem very complicated and it seems like it will be difficult for OEMs to comply with everything.	Qualified majority vote for mandatory.
	We see a bigger value in that the dynamic approach is done at all, than doing sensitivity/scenario on the dynamic approach.	Noted.
	We do not understand how this question differs from Q52.	Background information and guidelines were reviewed.
	with sufficient documentation on the future electricity/H2 mix scenario used for the use stage.	Reference to Q17 T2.3
	okay for recommended analysis; note: free dataset of IEA does not contain detailed information for each energy source on country level (only most important on regional level). Data need to be purchased for full details.	Qualified majority vote for mandatory. How to access the IEA data should also be part of the guidelines for modelling the future mix (Q17 of Task 2.3)
Choice of secondary data	Sensitivity for background datasets is too time consuming. It is more relevant to improve process for selecting relevant background datasets rather than performing sensitivity for each single LCA.	Should be for each dataset, but for those identified as large contributors (hotspots). Clarified in the text.
	"Is this mandatory or recommended? The background uses the term ""have to"".	Only recommended. Wording was adjusted.
	Also, isn't it better to ask for a conservative approach for all secondary databases? If multiple inventories could correspond to the needed input/output, the higher impact one shall be chosen.	Does this refer to the recommendation for the sensitivity analysis, or also to the default guidelines for inventory modelling in TranSensus-LCA? If it's the former, we believe it should be recommended by default from

Parameter	Comments	Answer
		the outset. In any case, this is certainly a very interesting approach.
	Please write down the full wording for OAT as people may not know the abbreviation.	Full wording was added.
	with sufficient documentation and justification	Background information and guidelines were reviewed.
Location of the value chain: electricity mix	"Scenario analysis for location of supply chain is not relevant since we always try to represent the actual supply chain set up and geography. Improvements will always be done but is not linked to a single LCA. A vehicle LCA of a vehicle produced at another production unit in another region (ex China) is a completely other LCA and not a scenario/sensitivity. We have a few reasons to disagree: 1- Why is only the electricity mix targeted by this sensitivity? 2- This implies having access to primary consumption data which is not often the case. If you do know your supply chain enough to be able to change the electricity mix, why have a sensitivity on it? 3- Isn't it better to ask for a conservative approach for secondary databases? i.e. If the location is unknown, the inventory with the highest impact should be chosen. 4- This is also probably tackled in the mandatory sensitivity on hotspots (Q61) and we fear that adding so many recommended and optional analyses will deter practitioners from following the TSLCA. It may be wiser to reduce the amount of steps so as to not scare people away. Not necessary for OEMs though because they know their suppliers. This could be added as a note. It is expected for OEMs to have a mapped supply chain. However, this analysis can be useful when selecting suppliers / markets under sensible scenarios.	This analysis should be performed only for inputs that were modelled with average datasets. A special provision has been included to exclude from this analysis inputs that are modelled with supplier-specific data. The focus on only electricity mix is for simplicity and practicality reasons.
	There are many scenarios already to be done mandatory. Not wise in our opinion to have too many mandatory and recommended scenarios.	It is a recommended analysis.
	with sufficient documentation and justification	Background information and guidelines were reviewed.

Parameter	Comments	Answer
	Why only have the electricity grid mix reflect the geographical variance? It would be better to give guidance on how to choose alternative datasets that represent production in another region as well, changing the electricity mix used can be a backup. If you have Europe as the baseline, you can often just pick the "same" dataset but for another region such as Asia or Global. Then there will be more relevant parameters that has changed rather than only electricity grid mix. It is also possible even with black box datasets and feasible in both ecoinvent and GaBi (with very few expectations).	This type of analysis should be covered by the "choice of secondary data"
Supply chain improvements: recycled vs primary materials	Don't see any added value. This is part of a company's analysis of potential decarbonisation actions and not linked to a single LCA.	It is a recommended analysis. The definition of the parameter has been revised to emphasize that the goal is to test the sensitivity of the LCA results to varying rates of recycled content, rather than to provide insights into process improvements.
	I agree with the concept to test secondary material shared but not with the wording. Process improvements of recycling or production? Or both? Is really always a process improvement necessary to allow more secondary material?	Parameter name changed to "supply chain modifications: recycled vs primary materials" The definition of the parameter has been revised to emphasize that the goal is to test the sensitivity of the LCA results to varying rates of recycled content, rather than to provide insights into process improvements.
	It is expected for OEMs to have a mapped supply chain. However, this analysis can be useful for ecodesign under sensible scenarios.	Helpful comment for practitioners
	Is it really about how the use of primary or secondary materials can improve the process? I'm not sure this is part of TSLCA rules. If it's about improving the impact, please mention this clearly in the question.	Parameter name changed to "supply chain modifications: recycled vs primary materials". The definition of the parameter has been revised to emphasize that the goal is to test the sensitivity of the LCA results to varying rates of recycled content, rather than to provide insights into process improvements.
	link between process improvements and use of secondary material not clear with this wording since the process is not changed when using more secondary material	Noted.
	0% is not always a reasonable lower value - e.g. for batteries there will be mandatory secondary material shares soon for some	Acknowledged.

Parameter	Comments	Answer
	materials. Lower value should be based on regulatory targets; Can we integrate somehow in the concept that it is important to evaluate that the material is additionally recycled (not taken from another sector) and that realistic supply is considered?	
	with sufficient documentation and justification	-
	It is also important that they follow the MF guidelines when considering recycled material.	This analysis should not affect the way multifunctionality is handled.
	zero doesn't make sense for all materials (quotas for secondary materials coming up)	Noted.
Usage: maintenance & wearing	Maintenance has a strong connection with driven distance. As long as the driven distance is constant, altering maintenance and wear parts is not relevant (at least not for HDV).	Also depends on factors such as load, driving style, road conditions
	Maintenance already mandatorily included	-
	Too much effort for too little outcome.	It is a recommended analysis.
	Guidance is too basic. A scenario analysis should be recommended mainly for items that have a significant effect on the overall result. Plus, a clear link should also be made to being consistent with the proposed methodology on calculating maintenance impacts (based on activity and/or calendar replacement frequencies). According to this proposed methodology for maintenance impacts, by default the maintenance requirements should be impacted/updated for the sensitivity on lifetime km; This should be highlighted in this guidance and/ or in the sensitivity recommended.	-
	with sufficient documentation and justification	-
Usage: payload/nb of passengers	we (LDV) do not have access to changes in consumption values with more passengers; there is one type approval value and that's it. as the vehicle is always approved for a maximum of load-weight (passengers or trailer/payload) I don't see any other dependencies…	The baseline requirement is just to consider the influence through the functional unit (dividing the impacts by the number of passengers/payload). A more advanced analysis considering e.g. the influence on energy consumption could be performed provided data availability.
	with sufficient documentation and justification	-

Parameter	Comments	Answer
	"agree for HDV only. For LDV: we do not have access to changes in consumption values with more passengers; there is one type approval value and that's it. as the vehicle is always approved for a maximum of load-weight (passengers or trailer/payload) I don't see any other dependencies..."	Text has been adjusted to indicate that the minimum requirement is to consider this through the functional unit.
	Guidelines for base scenario and sensitivity for bus have to be developed	Analysis approach has been improved.
	Not our expertise.	-
	What about passenger cars? Why only LDV and HDV?…	Added reference to passenger cars
Usage: temperature	no proven data systematically available that could be used to change parameters	?
	Overlap with sensitivity on consumption. Temp changes effect fuel consumption. Is already kind of included in consumption analysis.	-
	It is expected for OEMs to have a mapped market for their vehicles (i.e. the region(s) in which the vehicle will be used). However, this analysis can be useful when adapting results to different geographies under sensible scenarios	-
	with sufficient documentation and justification	-
Future mix: EoL electricity/H2 mix	No added value Impact is minimal. Too much effort for too little outcome too many uncertainties in EoL electricity mix and not enough impacts	It is a recommended analysis.
	note: free dataset of IEA does not contain detailed information for each energy source on country level (only most important on regional level). Data need to be purchased for full details.	It is a recommended analysis. How to access the IEA data should also be part of the guidelines for modelling the future mix (Q17 of Task 2.3)
	There are no guidelines in the question. The proposed approach is a hierarchy on dynamic modelling for EoL which should be in the Inventory section.	Dealt with in chapter about electricity modelling
Second use	not compliant with cut-off approach Do not understand exactly how this would change the way you calculate EoL if you	Exception for using the substitution approach for the purpose of this analysis has been included.

Parameter	Comments	Answer
	send the battery to second use after the vehicles life. Battery refurbishment would belong to the next product system if we follow the cut-off approach? Please clarify how it would affect the modelling. How to define or list considerations for a 'credit' for second-life applications."	
	Second use of the vehicle or components (such as the traction battery)? Clarify	Clarified.
	Disagree with splitting between vehicle and battery. Any second use of the vehicle should be already considered in the amount of km over vehicle lifetime	Only second use of the battery.
	The guidance is too simplistic and overlooks several key considerations: The impact of the second life application and the reference system versus using a second-life battery.	Text has been changed.
	The shorter remaining lifespan of cells in their second life compared to new cells.	-
	Regional variations in second-life use.	-

V.2 Integration into the product development process

Why frontloading?

A retrospective LCA aims to evaluate environmental impacts slightly before or after the start of production. A nearly finalised bill of materials of all parts is available to the OEM at this stage. Figure IV-3 from the D 2.3 methodology report shows how the product LCA results can feed into the end of the product development timeline at the final validation steps of the process. At this stage all the decisions on design, suppliers and materials have been made. Figure V-1 shows the relationship between cost and ability to change decisions within the product development process. Early in the product development process, there is freedom in design and choice of suppliers or materials. Later in the process, designs are "frozen", and changes become increasingly difficult. Product LCA is therefore unlikely to have a large positive impact on the environmental performance of the vehicle due to cost and timing implications of making late changes to address hotspots. Additionally, late changes will also be resisted as these can generate quality problems as it may not be possible to validate all the systems sufficiently.

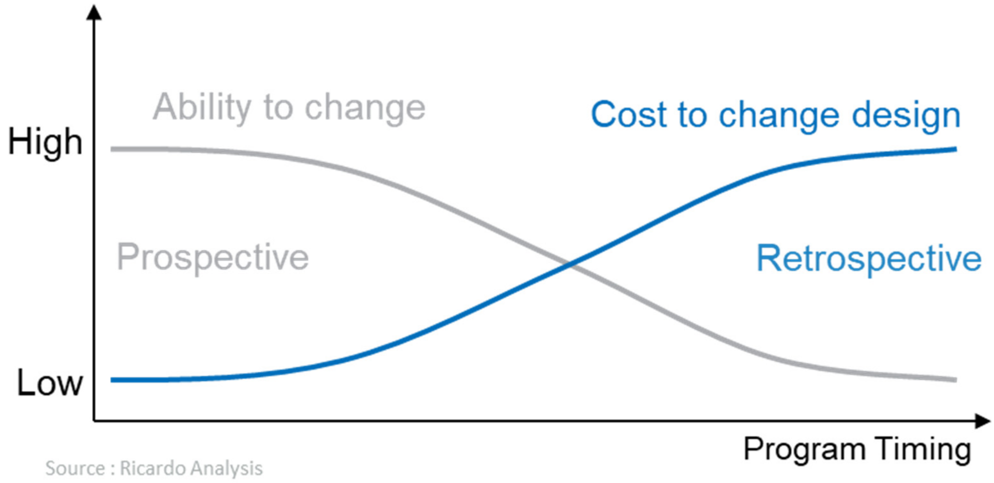


Figure V-1 : Project Timeline Cost and Changeability

A prospective LCA is conducted during the earlier development stages and aims to estimate environmental impacts before the start of production. The bill of materials is not completely defined. Using prospective LCA to feed into the left-hand side of the product development process (Figure IV-1) to review calculated LCA impacts versus requirements and identify hotspots will frontload the consideration of the environmental performance. In contrast to the application of a retrospective LCA only, it is far more likely a balanced set of attributes can be achieved, life cycle emissions can meet requirements, costs are reduced, and quality is improved.

Prospective LCA within TranSensus

The review and development of a harmonized process for Prospective LCA is included within the TranSensus-LCA project scope. This harmonized process will be developed and reported in other TranSensus-LCA deliverables (for example WP1 Review of Current Practices and WP2 Conceptualising LCA approach) and will not be duplicated in detail in this frontloading study. Characteristics recommended by TranSensus-LCA for a product LCA such as impact categories, impact assessments and indicators should carry over and apply to the Prospective LCA. Goal and scope can be simplified within TranSensus-LCA for prospective LCA, which will make it a more streamline process suitable for early application and iteration as the product design matures.

Survey on Application of Prospective LCA

A survey of partners within TranSensus-LCA was performed to assess the state-of-the-art use of prospective LCA for frontloading the product development process. A questionnaire was sent to and completed by eight OEM partners with questions focussing on the application of prospective LCA. It was decided to focus on vehicle OEMs as the TranSensus-LCA process considers the full vehicle lifecycle, whereas it is not possible to allocate emissions for the use stage for a single component or system. Alternatively, cradle to gate analysis is typically performed by the tier 1s to provide input data for the OEM full life cycle assessments. A tier 1 was included in the frontloading study team to provide supplier input of this methodology.

All the respondents used prospective LCA to support and direct the product development process. All of the OEMs performed this analysis on new vehicle designs. In addition, 25% of the OEM's performed Prospective LCA calculations on priority parts, materials, and components and 25% performed LCA on model year upgrades.

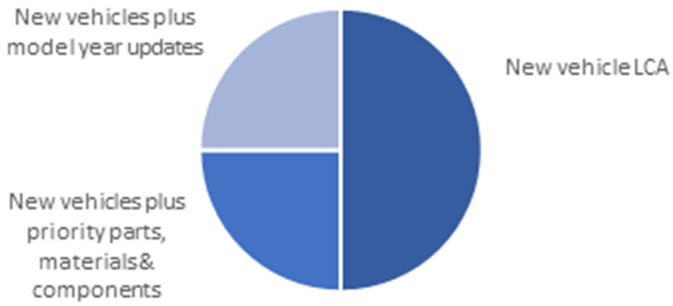


Figure V-2 : Selected vehicles for prospective LCA

88% of the OEM's performed the Prospective LCA over the full life cycle and 12% considered the cradle to gate stages only.

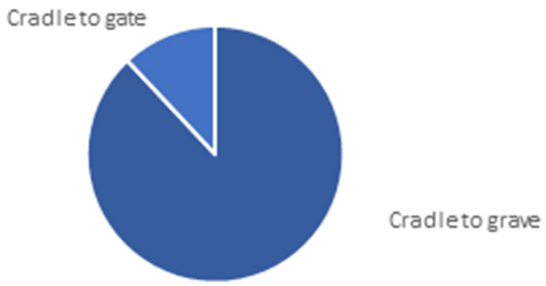


Figure V-3 : Prospective LCA boundaries

75% of the OEM's use in-house spreadsheet tools plus commercial LCA software. All of the respondents use a mixture of primary data and commercial databases when the primary data is not available.

Figure V-4 : Prospective LCA Tools

5% of OEM's use supplier input data which is self-certified. 12.5% perform checks and reviews on all data supplied and 12.5% review suppliers with Environmental Product Declarations.

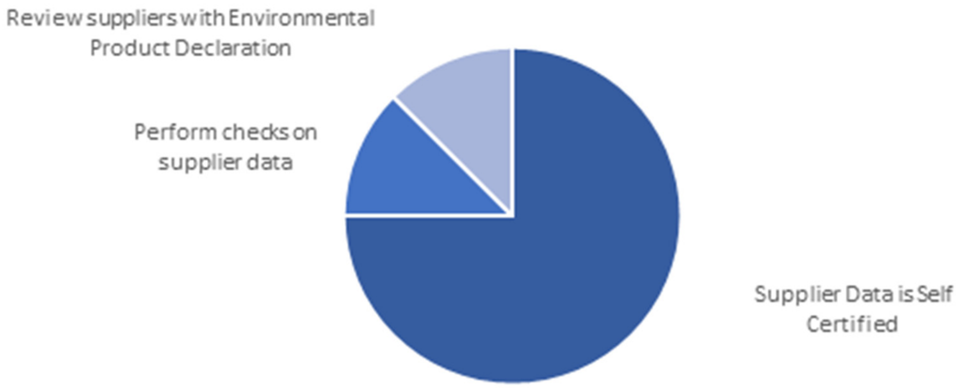


Figure V-5 : Supplier data certified for prospective CA

When applying prospective LCA, 50% of the OEM's perform the calculations once only. 25% iterate their analysis without specifying how many times. 12.5% iterate three times, and 12.5% iterate five times.

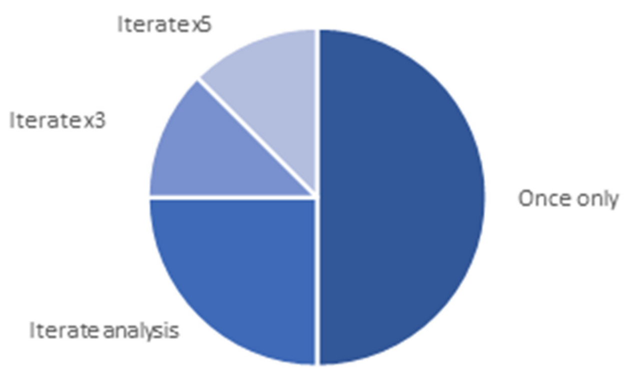


Figure V-6 : Iterations made for prospective LCA

Within the calculations, 50% include trajectories within the calculation and 50% use current data (e.g., current energy mix) for calculating future emissions. All of the OEMs calculate GWP eCO2 in the results, with 25% also using other indicators.

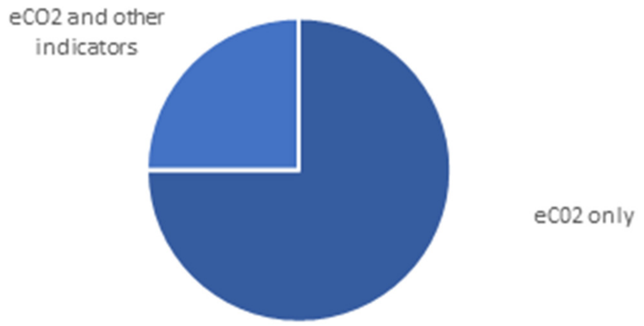


Figure V-7 : LCA indicators

To support the ranking of GWP eCO2 with other attributes 63% of the OEMs use internal emissions pricing (e.g., €150/tonne eC02). All of the OEMs use the data for supporting objective corporate targets (e.g., fleet targets) and vehicle model comparisons. 88% of the OEMs use the Prospective LCA results to form part of a project gateway (go/no-go) decision.

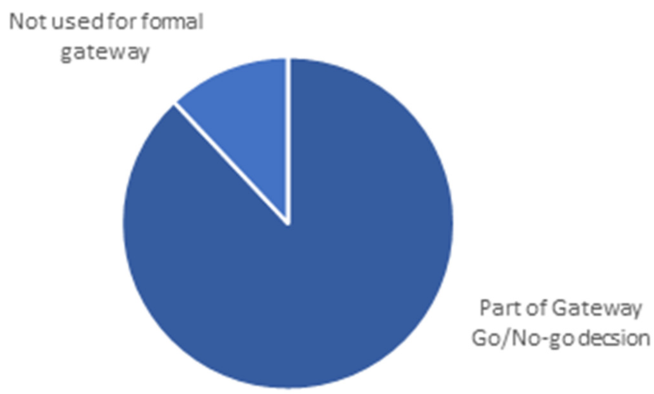


Figure V-8 : LCA results from part of gateway review

All of the OEM's use prospective LCA for internal purposes only.

Additional summaries and comments were provided by the OEM's as follows:

- It is recommended to ask all environmental questions early in the process.
- It is recommended to harmonise methods for efficient and accurate supplier data collection.
- Full life cycle analysis is essential.
- Scenario analysis, for example around electricity supply assumptions, is important.

Discussion of Survey Results

All OEMs in the survey use prospective LCA to frontload the product development process. The tools and methodology used in the analysis is reported as being quite similar amongst all the respondents. In-house spreadsheet tools are used by all of the OEMs. This is potentially to reduce investment in licence cost and software skills development and also to tailor the inputs and outputs to the OEM requirements to simplify and reduce complexity. Most of the OEMs supplemented the in-house tools with commercial software and external life cycle inventory databases.

Differences in approach were identified were in the vehicles/components chosen for prospective LCA by the OEMs and the number of iterations of the LCA models performed as the design matures during the product development process. State of the art would be the most comprehensive i.e., modelling all vehicles and model year upgrades for the full life cycle, cascading the environmental requirements and cradle to gate analysis to key systems and components. The LCA analysis should be performed as early as possible, using early concepts and iterating the model regularly as the design matures.

The tier 1 included on the sub-task team also completed the questionnaire. The approach taken was very similar to the most comprehensive methods by the OEMs, with eCO2 plus additional indicators used, iteration of results and similar toolsets. The main difference, as expected, was the limit of component cradle-to-gate analysis only, rather than a full vehicle calculation with a use stage for automotive LCA.

Recommendations

Based on the analysis of best practice, Figure V-9 shows a representation of how TranSensus-LCA can be implemented effectively within the V-model product development process. In this representation, multiple staggered Vs are shown to represent the different development phases and design freeze gateways typical in automotive development. These are nominally shown as A-Sample, B-Sample and C-Sample although the naming convention and number of phases will vary dependant on the OEM. Good practice would be to iterate Prospective LCA for each of the development phases to support design decisions with environmental status against the requirements and hotspot analysis to identify areas for improvement. Supplier LCAs are performed at a sub-system or component level to support this analysis. TranSensus-LCA recommends that all impact categories used in product LCA are also applicable for prospective LCA. This requires extension of the analysis to comprise GWP CO_2eq and in addition photochemical ozone formation, acidification, freshwater eutrophication, cumulative energy demand, abiotic resource depletion and particulate matter (see Impact Category of WP2 reporting). LCA results are then used to support gateway reviews to enable “go or no-go" decisions based on status versus requirements.

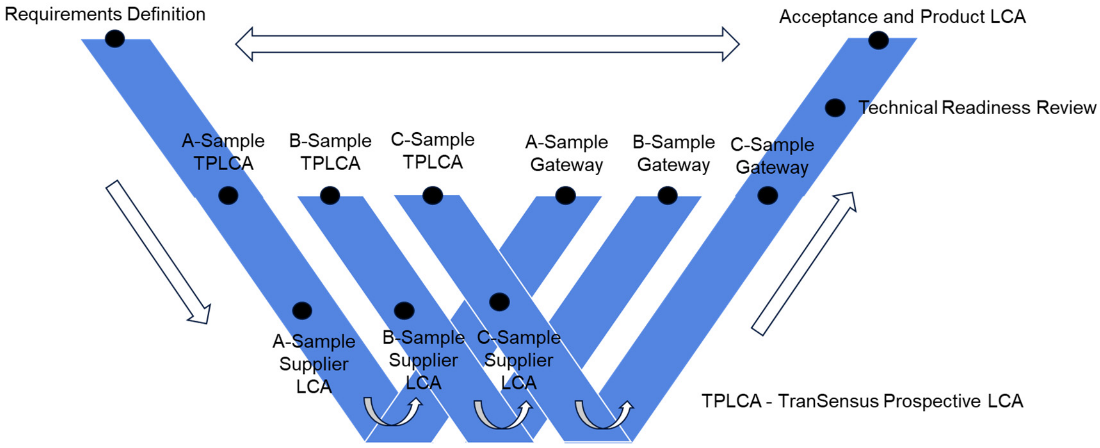


Figure V-9 : TranSensus LCA Calculations within Product Development Process

Conclusions

TranSensus(LCA proposes performing prospective LCA to frontload support to the engineering development process of new vehicles and automotive components (adaptation from the V-Model). The LCA effort should be performed as early as practicably possible within the development process to support decision making on technology, design and manufacturing choices from an environmental perspective. The LCA process should follow the recommended TranSensus framework for prospective LCA. Models with a subset of key indicators can be used to provide early direction to the design and manufacturing teams within the OEM or Tier 1. These models can be updated and iterated as the design matures and more accurate input data is provided by suppliers and design teams. Best practice is to iterate the LCA calculation at every major gateway. The results are used to assess suitability of the designs against the requirements at a product level.

V.3 Result display, public reporting, adherence levels and verification

This section provides more information on how requirements for reporting and verification have been elaborated, in accordance with state-of-the-art, current practices and consensus building within the project.

V.3.1 Reporting and verification practices in existing guidelines

This section provides an overview of common practices in reporting from existing LCA guideline documents. We focused on selected guidelines related to the ZEVs field, including the ILCD Handbook, EU Batteries Regulation, PEFCR for Batteries, Catena-X PCF, GBA Battery Passport GHG Rulebook, EPD, GHG Protocol, lithium PCF from the International Lithium Association, and the cobalt PCF from the Cobalt Institute. We review practices for the reporting of the following elements: third party verification, goal and scope, inventory data collection and modelling, and results and interpretation.

Third-party verification

Almost all the reviewed documents include requirements for third-party verification. Within the EU Batteries Regulation, a notified body shall assess whether the electric vehicle battery carbon footprint meets the established methodological and data requirements. Similarly, the PEFCR for batteries establishes that a verifier shall verify that the environmental footprint study has been conducted in compliance with the PEFCR. Third-party verification of the declaration and data is also required for EPDs. The PCF for lithium and cobalt requires a statement of verification from an independent third-party confirming that calculations were done in accordance with the provided guidance. The GBA Battery Passport GHG rulebook establishes that the GHG calculations needs to be reviewed and verified by an auditor.

Goal and scope

Elements for the reporting of goal and scope found across the reviewed LCA guideline documents include:

- Product information, such as product name or manufacturing location (e.g., EU Batteries Regulation, EPD, GHG Protocol)
- Functional unit (e.g., ILCD Handbook, EPD)
- Reference flow (e.g., ILCD Handbook, GHG Protocol)
- Information of cut-offs (e.g., cobalt PCF, EPD, GHG Protocol)
- System boundaries applied (e.g., ILCD Handbook, lithium PCF, cobalt PCF, EPD, GHG Protocol)
- Method for calculating land-use change impacts (e.g., GHG Protocol)

Inventory data collection and modelling

Elements for the reporting of inventory data collection and modelling found across the reviewed LCA guideline documents include:

- Flow diagrams (e.g., ILCD Handbook, EPD, GHG Protocol)
- Reference year for data collection (e.g., EU Batteries Regulation, lithium PCF, cobalt PCF, EPD, GHG Protocol)
- Description of datasets used (e.g., ILCD Handbook, EU Batteries Regulation, GHG Protocol)
- Information on primary data collected (e.g., GBA Battery Passport, lithium PCF)
- Information on secondary data used (e.g., EU Batteries Regulation, lithium PCF, EPD, GHG Protocol)
- Share of primary and secondary data used (e.g., Catena-X PCF, lithium PCF, cobalt PCF)
- Share of primary and recycled materials (e.g., EU Batteries Regulation, GBA Battery Passport, lithium PCF, EPD)
- Electricity modelling (e.g., EU Batteries Regulation, lithium PCF, cobalt PCF)
- Parameters used for fuel combustion (e.g., cobalt PCF)
- Information about packaging (EPD)
- Allocation assumptions and modelling (e.g., EU Batteries Regulation, lithium PCF, cobalt PCF, EPD, GHG Protocol)
- Data quality assessment (e.g., EU Batteries Regulation, EPD, GHG Protocol)
- Calculated LCI results (e.g., ILCD Handbook, PEFCR Batteries)

Results and interpretation

Elements for the reporting of results found across the reviewed LCA guideline documents include:

- Impact assessment results (all documents).
- Normalized results (e.g., PECFR Batteries)
- Weighted results (e.g., PECFR Batteries)
- Contribution analysis, often disaggregated by life cycle stage (e.g., EU Batteries Regulation, lithium PCF, cobalt PCF, EPDs, GHG Protocol).
- Impact results with and without credits (e.g., lithium PCF, cobalt PCF)

- Separate reporting of biogenic and fossil CO_2 emissions (GHG Protocol)
- Separate reporting of land use (e.g., GHG Protocol)
- Completeness and consistency checks (e.g., ILCD Handbook)
- Data quality rating score for the calculated impact (e.g., EU Batteries Regulation)
- Qualitative assessment on uncertainty (e.g., GHG Protocol)
- Sensitivity analysis results (e.g., ILCD Handbook, lithium PCF, cobalt PCF)
- Conclusion and recommendations (e.g., ILCD Handbook)

V.3.2 Consensus building for reporting and verification

Regarding LCA public reporting and verification, we defined mandatory requirements to claim that a study was "carried out following the TSLCA methodology" or "carried out partially following the TSLCA methodology". This additional subtask and the resulting voting question was deemed necessary because some OEMs voiced their concern of not being able or not wanting to disclose all results of the vehicle LCA studies conducted following the TSLCA methodology. The agreed upon mandatory reporting requirements therefore encompass mandatory information necessary for a recipient of the LCA study to evaluate or judge the results and to enable drawing meaningful insights when comparing across different LCAs of ZEVs.

Recommendations on the mandatory content of public reporting have been built on:

- A consultation sheet collecting information individuals would like to read from a study claiming adherence to TSLCA, circulated among project's beneficiaries -> called the "wish list"
- A 2nd consultation sheet collecting acceptable level of transparency for respondent organization for every requirement in the "wish list" between mandatory, recommended, optional, no preference or no communication – circulated among project's beneficiaries
- A collection of T2.2, T2.3, T2.4 and T2.5 requests regarding the level of transparency in reporting they expect for the methodological requests they have built.
- T2.5 reporting meetings to confront and enable the convergence of these three points of view.
- Bilateral discussions with T2.2, T2.3, T2.4 and T2.5 task leaders to adjust remaining disagreements.
- T2.2 and T2.4 requests were collectively assessed and refined by T2.5 reporting contributors

- T2.3 and T2.5 requests were not collectively refined but we collectively agreed in our last meeting to submit them as they were in a decisive voting anyway.

At least 5 industrials among beneficiaries actively participated to consultations and/or T2.5/reporting meetings with valuable and valued contributions to enable following questions.

The reporting subtask is a subtask under Task 2.5: **"Interpretation, Decision making and frontloading concept**". It sought to answer the question: (Which mandatory requirements must be fulfilled to claim that a study was "carried out following the TSLCA methodology" or "carried out partially following the TSLCA methodology")?

A total of 9 questions were analysed by the beneficiaries under the following categories:

- *6 questions under product LCA*
- *1 question under product LCA (specifically only level 3 (UNECE) ones)*
- *2 questions under Prospective LCA, OEM fleet LCA, Macro fleet LCA*

Out of the 9 questions:

- 3 questions were fully agreed to by the beneficiaries (100 %).
- 3 questions were mostly agreed to by the beneficiaries with a few disagreeing (94 % against 6 %).
- 2 questions were mostly agreed to by the beneficiaries with a few disagreeing (89 % against 11 %).
- 1 question was mostly agreed to by the beneficiaries with a few disagreeing (83 % against 17 %).

In all, a majority of 2/3 was reached, thus results accepted.

Below is a detailed description of the results.

Table V-4: Detailed description of results

S/N	Question Topic / Subtopic	CONSORTIUM	INDUSTRY ADVISORY	SCIENTIFIC ADVISORY
1	TSLCA adherence levels for product LCA	94%	✓ (includes 1 no answer)	(includes 2 no preference) (includes 1 no answer)
2	TSLCA partial adherence for product LCA	94%	✓ 89% (includes 1 no answer)	67% (includes 3 no preference) (includes 1 no answer)

S/N	Question Topic / Subtopic	CONSORTIUM	INDUSTRY ADVISORY	SCIENTIFIC ADVISORY
3	3rd party verification if level 3 Product LCA (TSLCA will provide a checklist in D5.2)	94%	88% (includes 1 no preference) (includes 1 no answer)	✓
4	Public reporting content for Product LCA: Minimum info (Goal and scope)	83%	83% (includes 3 no preference) (includes 1 no answer)	80% (includes 2 no preference)
5	Public reporting content for Product LCA: Minimum info (LCI)	89%	✓ (includes 4 no preference) (includes 1 no answer)	✓ (includes 1 no preference)
6	Public reporting content for Product LCA: Minimum info (LCIA)	✓	✓ (includes 3 no preference) (includes 2 no answer)	✓ (includes 1 no preference)
7	Public reporting content for Product LCA: Minimum info (Interpretation)	89%	✓ (includes 3 no preference) (includes 1 no answer)	✓ includes 1 no preference)
8	TSLCA adherence for other type of LCAs	✓	(includes 3 no preference) (includes 1 no answer)	✓ (includes 3 no preference)

These results were exploited during few last reporting task meetings to adjust, clarify some information. A short list of public reporting information was proposed by OEMs based on majority of OEM's acceptance of each proposed information, tested with T2.6.

Some 3rd voting comments and results shown that choices among Transensus-LCA methodology public reporting was still a bit left to interpretation. In addition to 3rd voting, a decision was agreed during a steering board in November to mandate public reporting of any choices during methodology implementation and their justification. This decision was justified to allow comparability objective of the methodology. Since this requirement was highly demanding, a consistency check has been conducted between reporting task leaders and T2.2, T2.3, T2.4 and T2.5 task leaders to assess needs and confront them with practical possibilities of reporting of end-users. This assessment enabled to decide to mandate choices to be publicly reported and documentation or justification to be only handed to verifier since it served more verification purposes than comparability allowance.

From this list, reporting requirement were formatted and distinguished among three categories: results, choice and supporting information presented in the main body.

Annex B: Background and justification of TSLCA requirements for Social LCA

VI. Social LCIA requirements: background, justification & consensus building

VI.1 Non-restrictive set/ Optional and Restrictive/mandatory set of Impact sub-categories and Stakeholder categories for S-LCIA

The goal of this subtask is to select and recommend a set of Non-restrictive set/ Optional and Restrictive/mandatory set of Impact sub-categories, and Stakeholder Categories for S- LCIA for TranSensus-LCA. The objective of conducting a thorough analysis of social and socio-economic impacts in S-LCA studies gives rise to the requirement for prioritizing social life cycle impact sub-categories and corresponding stakeholder categories.

VI.1.1 Description of the main findings and learnings from WP1 & WP2 analysis

Prioritizing impact sub-categories and stakeholder categories enables a more specialized evaluation of the social impacts connected to a process or product (Bouillass, Blanc, & Perez-Lopez, 2021). Since ZEVs are in the path of replacing conventional vehicles across the globe, it becomes necessary to conduct S-LCA to identify its social impacts. Prioritizing social life cycle impact sub-categories and stakeholder categories for ZEVs before performing a Social Life Cycle Assessment (S-LCA) is important for several reasons:

I. Comprehensive assessment: Prioritizing allows for a more comprehensive assessment of the ZEV's overall sustainability performance. Prioritizing the assessment can focus on the most relevant and significant social issues (Sharma & Manthiram, 2020).

II. Identifying hotspots: Prioritizing helps identify the areas of the ZEV's life cycle that have the most significant social impacts. This can help guide decision-making and resource allocation towards addressing and mitigating these impacts. By understanding the hotspots, stakeholders can work towards improving social performance or risk and ensuring that it aligns with sustainability goals (Sharma & Manthiram, 2020).

III. Transparency and accountability: Prioritizing social issues promotes transparency and accountability in the assessment process. By clearly identifying the social impact sub-categories that are being assessed, stakeholders can understand the scope and focus of the S-LCA. This transparency helps build trust and credibility in the assessment results and allows for meaningful comparisons and benchmarking across different ZEVs (Ahamed, Nazzal, Darras, & Deiab, 2023).

IV. Stakeholder engagement: Prioritizing social impact sub-categories involves engaging relevant stakeholders in the assessment process. Stakeholders, such as workers, local communities, and advocacy groups, can provide valuable insights and perspectives on the social impacts of the ZEV. Engaging stakeholders ensures that their voices are heard and considered in the assessment, leading to more robust and meaningful results (Ahamed, Nazzal, Darras, & Deiab, 2023).

VI.1.2 Methodology

The process for determining which set of impact subcategories were mandatory and optional was a four-step filtering method. The impact sub-categories in Filter 1 are determined by a materiality assessment based on the European Financial Reporting Advisory Group (EFRAG) in accordance with the frequency of their reporting in the relevant ZEV policies and frameworks and opinions derived from TranSensus participants (List 1). The UNEP Guideline (List 2) subcategories that correspond with the social impact sub-categories that OEMs evaluate using the Sustainability Assessment Questionnaire (SAQ) from Drive Sustainability are matched in the second filtering step. By comparing Lists 1 and 2, the common set of impact sub-categories (List 3) for the third filtration phase was determined. Each impact subcategory from List 3 is matched with indicators from the PSILCA and SHDB databases in the fourth filtering step. The impact subcategories for TranSensus that are required to be included in these databases are listed in List 7. On the other hand, the lists of impact categories designated as optional (List 8) impact sub-categories are those that are not filtered during filtration steps 3 and 4. Explore the following tables to understand the steps followed to find the Mandatory and optional impact sub-categories. Each step followed in the methodology is explained in the following section.

VI.1.2.1 Filtration 1: Materiality Assessment

Understanding the context and defining the Stakeholders.

A stakeholder approach that considers potential impacts on different stakeholder categories is essential for the S-LCA framework towards ZEV. This is comparable to how an important aspect of social sustainability handles the positive as well as negative impacts on stakeholders. Stakeholder categories are used to categorize social impacts in order to help operationalize and ensure that the framework is comprehensive. A S-LCA assessment's foundation is its stakeholder categories because they are the ones on which justification for inclusion or exclusion in the scope must be given (UNEP, 2020). The (UNEP, 2020) have published the updated version of the S-LCA guidelines and have defined the relevant stakeholder categories along with its impact sub-categories. The different stakeholder categories identified are Workers, Local Community, Value Chain Actors, Consumer, Society and Children.

Identification of the potential material social impacts.

The potential impacts on each of these stakeholder categories can be classified into a number of impact sub-categories depending on the issues of concern that are potentially affected. The identified impact sub-categories from UNEP Guideline cover a wide range of social and socio-economic aspects related to the product which is given in the table below. Hence, the outcome of this step is the definition of list of potential material matters.

Determination of List 1 of material matters based on an assessment of the materiality of the impacts.

The list of material social impacts is the result of this stage in the materiality assessment process. Taking the scope from cradle to grave, the materiality assessment technique prioritizes the impacts connected to ZEV by considering it as a whole. Then, explore how different impact sub-categories related to various ZEV stages, such as extraction, manufacturing, distribution, use, and end-of-life, have been addressed by the various policy documents, frameworks, and TranSensus participants associated with ZEVs. The total number of reports based on each impact subcategory is taken into consideration while ranking the sub-categories.

In the table below (List 1), impact sub-categories that were frequently addressed over the entire lifecycle based on the UNEP guideline are mentioned. On the other hand, several impact sub-categories that are not mentioned in the table below were either rarely or never mentioned in the sources that were gathered.

Table VI-1: List 1- Set of 15 impact sub-categories

Stakeholder Categories	Worker	Local community	Value chain actors (not including consumer)	Consumer	Society
Impact Subcategories	• Freedom of association and collective bargaining • Child labor • Fair salary • Working hours • Forced labour • Equal opportunities/discrimination • Health and safety • Social benefits / social security • Sexual harassment	• Delocalization and migration • Respect of Indigenous rights • Community engagement	• Wealth distribution	• Health and safety	• Corruption

VI.1.2.2 Filtration 2: Identifying the relevant Impact Sub-Categories from SAQ

Drive Sustainability is an alliance of automakers who commit to working together to strengthen the sustainability of the automotive supply chain. Drive Sustainability has developed a Sustainability Assessment Questionnaire (SAQ) (Drive Sustainability, 2023) for the automotive suppliers with aim of achieving some targets among which one of the main goals is to introduce key supplier performance indicators on the environmental, social and governance (ESG) topics that are prioritized by the OEM members of the Automotive Partnership (Drive Sustainability, 2023). In order to map the potential social risks or performance, SAQ has therefore established a collection of social issues that are pertinent to particular domains or stakeholder categories. Several common social issues were discovered after carefully comparing the social subjects described in SAQ with the impact sub-categories mentioned in UNEP guidelines. These issues are listed in the table below, which is organized according to stakeholder categories from UNEP guidelines.

Table VI-2: List 2- Set of 20 impact sub-categories

Stakeholder Categories	Worker	Local community	Value chain actors (not including consumer)	Consumer	Society
Impact Subcategories	• Freedom of association and collective bargaining • Child labour • Fair salary • Working hours • Forced labour • Equal opportunities/discrimination • Health and safety • Social benefits / social security • Sexual harassment	• Cultural heritage • Respect of Indigenous rights	• Fair competition • Supplier relationships • Respect of intellectual property rights	• Health and safety • Consumer privacy • Transparency	• Prevention and mitigation of armed conflicts • Corruption • Ethical treatment of animals

VI.1.2.3 Filtration 3: Shortlisted Impact Sub-categories

The impact sub-categories that have been reported more than or equal to five times using materiality assessment were then matched to the Drive Sustainability impact categories from List 2. Thus, the impact categories that have been shortlisted are given in the List 3 below. Other Set of 3 impact sub-categories from List 1 which is not common to List 2 and Set of 8 impact Sub-categories from List 2which is not common to List 1 are given in the List 4 and List 5 below respectively.

Table VI-3: List 3 - Common Set of 12 impact sub-categories from List 1 and List 2

Stakeholder Categories	Worker	Local community	Consumer	Society
Impact Subcategories	• Freedom of association and collective bargaining • Child labour • Fair salary • Working hours • Forced labour • Equal opportunities/ discrimination • Health and safety • Social benefits / social security • Sexual harassment	• Respect of Indigenous rights	• Health and safety	• Corruption

Table VI-4: List 4 - Other Set of 3 impact sub-categories which is not common to List 2

Stakeholder Categories	Local community	Value chain actors (not including consumer)
Impact sub-categories	• Delocalization and migration • Community engagement	• Wealth distribution

Table VI-5: List 5 - Set of 8 impact Sub-categories which is not common to List 1

Stakeholder Categories	Local community	Value chain actors (not including consumer)	Consumer	Society
Impact Subcategories	• Cultural heritage	• Fair competition • Supplier relationships • Respect of intellectual property rights	• Consumer privacy • Transparency	• Prevention and mitigation of armed conflicts • Ethical Treatment of Animal

VI.1.2.4 Filtration 4: Identifying and Matching the Indicators in Databases with shortlisted Impact Sub-Categories

In order to assess the impact on the sub-categories, indicators can be used as the main metric or tool which can provide valuable information and insights on decision making for the OEMs. Hence, to find the indicators, the SHDB (Social Hotspot Database) and PSILCA (Product Social Impact Life Cycle Assessment) databases are commonly used. More information on Database can be found on D1.1.

See table below for final impact sub-categories which are classified as mandatory (List 7) based on the availability of indicators from databases such as PSILCA and SHDB and optional (List 8) impact sub-categories which is a combination of List 4, List 5 and List 6 (see below).

Table VI-6: List 6 - Unmatched set of Impact Categories with Database indicators

Stakeholder Categories	Worker	Consumer
Impact Subcategories	Sexual harassment	Health and safety

Table VI-7: List 7 - Mandatory set of Impact sub-categories

Stakeholder Categories	Worker	Local community	Society
Impact Subcategories	• Freedom of association and collective bargaining • Child labour • Fair salary • Forced Labour • Working hours • Health and safety • Social benefits / social security	• Respect of Indigenous rights	• Corruption

Table VI-8: List 8 - Optional set of Impact sub-categories

Stakeholder Categories	Worker	Local community	Value chain actors (not including consumer)	Consumer	Society
Impact Subcategories	• Equal opportunities/discrimination • Sexual harassment	• Cultural Heritage • Delocalization and migration • Community engagement	• Fair competition • Supplier relationships • Respect of intellectual property rights • Wealth distribution	• Health and safety • Consumer privacy • Transparency	• Prevention and mitigation of armed conflicts • Ethical Treatment of Animal

VI.2 Calculation of S-LCIA results

The primary goal in this task was to evaluate an extensive list of social indicators and recommend a concise shortlist based on specific criteria. These proposed social indicators are directly linked to the final list of impact sub-categories identified. The focus was on the stakeholders and social impact sub-categories that were designated as mandatory during the initial analysis.

The process began with the identification of social indicators from the most widely used social LCA databases, PSILCA and SHDB. Table VI-9 illustrates the number of social indicators identified for each impact sub-category. Some impact sub-categories included more than 10 social indicators (e.g., health and safety), necessitating a preliminary materiality analysis to determine their "relevance" in the context of ZEVs. Partners involved in the social LCA subtask evaluated each social indicator, categorizing them as "relevant," "not relevant," or "maybe relevant."

Table VI-9: List 9 - Social indicators identified for each impact sub-category

Stakeholder	Impact Sub-categories	Number of social indicators (from PSILCA and SHDB)
Worker	Health and safety	20
Worker	Freedom of association and collective bargaining	7
Worker	Child labour	9
Worker	Fair salary	9
Worker	Working hours	4
Worker	Social benefits / social security	10
Worker	Forced labour	5
Local community	Respect of Indigenous rights	7
Society	Corruption	5

Following this initial analysis, a shortlist of 19 social indicators was identified as relevant in the context of ZEVs. To finalize this selection and recommend the social indicators for the TranSensus LCA project, the methodology proposed by Haslinger *et al.* (2024)[9] was utilized. This methodology involved a Multi-Criteria Decision Analysis (MCDA) that evaluated each indicator based on four criteria: i) achievability; ii) feasibility; iii) ease of interpretation, and; iv) relevance (Table VI-10). Each criterion was scored on a scale from 0 to 3, with specific

[9] Haslinger, A.S., Huysveld, S., Cadena, E. and Dewulf, J., 2024. Guidelines on the selection and inventory of social life cycle assessment indicators: a case study on flexible plastic packaging in the European circular economy. *The International Journal of Life Cycle Assessment*, pp.1-18.

reference points used to justify the reduction of the extensive list from a scientific perspective. For instance, in the achievability criterion, an indicator receives the highest score (i.e., 3) when it involves access to specific supplier data obtained by the company, such as those available in Corporate Social Responsibility (CSR) reports or internal health and safety management systems. Conversely, an indicator receives a score of 0 if there is no access to the necessary data or if the data collection phase is too time-consuming.

Table VI-10: Criteria considered to evaluate the 19 social indicators selected

Criteria	Scale	Reference Point (RF)
Relevance	3	High relevance of the assessed impact.
	2	Medium relevance of the assessed impact.
	1	Low relevance of the assessed impact.
	0	No relevance of the assessed impact.
Feasibility	3	Information to be found at company.
	2	Information to be found in database i.e. PSILCA, SHDB, ecovadis, datamaran, RepRisk, Sedex, Supplyshift (country level and specific company data) or in relevant open data sources i.e. from NGOs.
	1	Information to be found in reliable online sources (e.g., local and global news).
	0	No information available.
Easiness to interpret	3	High clarity and awareness of the assessed impact.
	2	Medium clarity and awareness of the assessed impact.
	1	Low clarity and awareness of the assessed impact.
	0	No clarity and awareness of the assessed impact.
Achievability	3	Access to supplier specific data from company, already available in CRS reports or via internal reporting (health and safety management systems).
	2	Access to company specific data (e.g., ecovadis, datamaran, RepRisk, Sedex, Supplyshift), medium term availability.
	1	Access to regional /country level data from databases (e.g., PSILCA, SHDB, Verisk Maplecroft, NGO sources), long term collection phase.
	0	No access and/or too time extensive collection phase.

Based on the results obtained from the evaluation, TranSensus LCA proposed recommending social indicators that scored more than 2.0. However, the social indicators that are only linked with one impact sub-category (e.g., Social benefits / social security) were considered as recommended even if the score was below 2.0; this approach was decided in order to cover all the impact sub-categories. In some cases, multiple social indicators were selected for one impact sub-category, while in others, only one indicator was available, such as "Respect of Indigenous rights" for the Local community stakeholder or "Corruption" for the Society stakeholder. Additionally, the selected social indicators were cross-referenced with those included in the UNEP guidelines, ensuring that the majority of selected indicators were directly connected with that recognized guideline.

This comprehensive approach ensures that the final selection of social indicators for the TranSensus LCA project is scientifically robust and contextually relevant, providing a solid foundation for evaluating and improving the social performance of ZEVs.

Table VI-11 shows the recommended social indicators. In this table, the description of the social indicators, as well as the units or metrics are included.

Table VI-11: List of social indicators recommended

Stakeholder	Impact Sub-categories	Source/Database	Social indicators	Units/Metrics	Description
Worker	Health and safety	PSILCA	Rate of fatal accidents at workplace	#/yr and 100 000 employees	Explanation of unit of measurement: Number of fatal accidents per 100 000 employees and year
Worker	Health and safety	PSILCA	Rate of non-fatal accidents at workplace	#/yr and 100 000 employees	Explanation of unit of measurement: Number of non-fatal accidents per 100 000 employees and year
Worker	Freedom of association and collective bargaining	PSILCA	Right of Association	4 point scale	Explanation of unit of measurement: ordinal 4 point scale (0-3)
Worker	Child labour	PSILCA	Children in employment, total	% of all children ages 7-14	Explanation of unit of measurement: Percentage of all children ages 7-14
Worker	Fair salary	PSILCA	Minimum wage, per month	USD	Explanation of unit of measurement: Minimum wages can be used to evaluate the sector average or actually paid wage in a company. Together with the living wage it is an important indicator to assess if salary is fair and allows the worker a dignified life.

Stakeholder	Impact Sub-categories	Source/Database	Social indicators	Units/Metrics	Description
Worker	Working hours	PSILCA	Weekly hours of work per employee	hr	Explanation of unit of measurement: Hours of work per employee and week
Worker	Social benefits / social security	PSILCA	Social security expenditures	% of GDP	Explanation of unit of measurement: Social security expenditures as a percentage of Gross Domestic Product (GDP)
Local community	Respect of Indigenous rights	PSILCA	Presence of indigenous population	Y/N	Explanation of unit of measurement: Presence of indigenous population 1 (Yes) and 0 (No)
Society	Corruption	Social Hotspots Database	Corruption Perception Index (CPI) (Transparency International)	Semi -quantitative indicator	A high CPI score suggests lower perceived corruption, whereas a low score indicates higher corruption risk

VII. Social Life Cycle Interpretation

VII.1 Description of each recommended S-LCA interpretation parameter

VII.1.1 Integration of the quantity value for certain components/materials/flows leading to hotspots as recommended S-LCA interpretation parameter

Varying quantities of components, materials, or flows from a particular region/country in a S-LCA can significantly impact the identification of hotspots. This is because changes in quantity can alter the relative importance of different stages in the life cycle, as well as the corresponding social impacts related to those processes and locations. For instance, increasing the volume of a particular material might intensify social impacts in its extraction phase, while decreasing it could shift the hotspot to another stage, such as manufacturing or transportation. Therefore, considering quantity is crucial for accurate hotspot identification and effective mitigation strategies. A social hotspot is a location and/or activity in the life cycle where a social issue (as impact) and/or social risk is likely to occur. It is usually linked to life cycle stages or processes. In other words, social hotspots are unit processes located in a region where a problem, a risk, or an opportunity may occur in relation to a social issue that is threatening social well-being or that may contribute to its further development.

VII.1.2 Integration of geographical variation of the value chain as recommended S-LCA interpretation parameter

Geographical variation significantly influences social impacts within a value chain. Factors like labor standards, human rights conditions, and other social regulations differ widely between regions. Interpretation helps identify how these geographical shifts impact social performance. By altering the location of specific value chain stages, analysts can assess the resulting changes in social hotspots and social impacts, informing decisions about sourcing, production, and supply chain management for improved social sustainability.

VII.1.3 Integration of the choice of the activity variable as recommended S-LCA interpretation parameter

The choice of activity variable (working hours vs. value added) significantly influences the allocation of social impacts in a life cycle. Using working hours may overemphasize labour-intensive processes, while value added might prioritize processes with higher economic output. Conducting a sensitivity analysis on these variables helps to understand the potential impact of this choice on the overall results and identify potential biases.

VII.1.4 Variation of assumptions on social data as recommended S-LCA interpretation parameter

Given the inherent uncertainties associated with primary and secondary social data, exploring how variations in data assumptions impact the final outcomes is essential. By varying the assumptions on social data, practitioners can identify critical data points influencing hotspot identification and understand the potential range of impacts. This enhances the reliability and credibility of the S-LCA findings, ultimately leading to more informed decision-making.

VII.1.5 Integration of the price related to process or materials as recommended S-LCA interpretation parameter

By varying prices of processes or materials, analysts can identify which cost factors significantly influence social performance indicators. This helps to pinpoint areas where economic incentives could be leveraged to improve social conditions, such as fair wages, safe working conditions, or community well-being.

VII.1.6 Integration of the geographical variation of the energy consumed during usage as recommended S-LCA interpretation parameter

Geographical variation in energy consumption during product usage significantly influences the overall social impact of a product as it also varies the labour conditions in the energy production and distribution sector. Conducting interpretation on this factor allows for a more accurate and comprehensive assessment of social hotspots and social impacts. By analysing how changes in energy sources, production methods, and regional social conditions impact the product's social performance, LCA practitioners can identify potential risks, evaluate mitigation strategies, and inform decision-making based on geographically specific contexts.

VII.1.7 Integration of the quantity of energy consumed during the use stage as recommended S-LCA interpretation parameter

Interpretation analysis of energy consumption during the use stage is crucial in S-LCA interpretation as it can significantly influence social impacts. Variations in energy consumption can directly affect labour conditions, human rights, and community well-being in energy production and distribution sectors.

VII.2 Selection process for S-LCA interpretation parameters

The process began with the review of the 2nd consortium voting results on (environmental) LCA interpretation parameters. In a first step, the list of LCA interpretation parameters that was voted on and reached consensus was evaluated by the partners involved in the social LCA subtask. In the meetings it was jointly decided which of the (environmental) LCA interpretation parameters might also be relevant for S-LCA, based on the following categorisation: 'relevant', 'maybe relevant' and 'not relevant'. In a second step, the resulting list of S-LCA interpretation parameters containing the categories 'relevant' and 'maybe relevant' was supplemented by missing S-LCA interpretation parameters that are exclusively relevant for S-LCA interpretation, as for example the choice of activity variable. This step was also conducted jointly in the social LCA subtask meetings. In a third step, the resulting comprehensive list of S-LCA interpretation parameters, including 14 different parameters, was circulated among the social LCA subtask members in order to select the most relevant S-LCA interpretation parameters that can be recommended for the 3rd consortium voting. This selection process was conducted by following a simplified approach similar to the methodology proposed by Haslinger *et al.* (2024)[9].

Each interpretation parameter was evaluated based on three criteria: i) relevance, ii) data availability and iii) ease of interpretation. Each criterion was scored on a scale from 0 to 3, with specific reference points used to justify the reduction of the extensive list from a scientific perspective. For example, an interpretation parameter can be of high relevance for the assessed impact, however, data is very limited and there might be no information available and/or would be too time extensive to collect the necessary data. In the following, the applied criteria including scale and reference points can be found:

Table VII-1: Applied criteria for S-LCA interpretation parameter selection

Criteria	Scale	Reference Point (RF)
Relevance	3	high relevance of the assessed impact
	2	medium relevance of the assessed impact
	1	low relevance of the assessed impact
	0	no relevance of the assessed impact
Data availability	3	access to supplier specific data from company (Drive Sustainability Questionnaire), already available in CSR reports or via internal reporting (health and safety management systems) and/or access to company specific data i.e. ecovadis, datamaran, RepRisk, Sedex, Supplyshift
	2	access to regional / country level data from databases i.e. PSILCA, SHDB, Verisk Maplecroft (fee based), NGO sources (open access), long term collection phase
	1	access to reliable online sources i.e. News (local and global)
	0	no information available and/or too time extensive collection phase

Criteria	Scale	Reference Point (RF)
Easiness to interpret	3	high clarity and awareness of the assessed impact i.e %
	2	medium clarity and awareness of the assessed impact
	1	low clarity and awareness of the assessed impact
	0	no clarity and awareness of the assessed impact

It was decided to only recommend the interpretation parameters for the 3rd consortium voting that reach a mean value combining all three criteria of above 2.0 (between 2.0 and 3.0). In that way, the threshold is consistent with the threshold for S-LCA indicator selection. This leads to the following final set, consisting of 7 remaining interpretation parameters that were confirmed by the 3rd consortium voting and are therefore recommended by the TranSensus-LCA project. A detailed description of each interpretation parameter can be found in the Annex.

Table VII-2: Recommended Interpretation Parameters

Recommended Interpretation Parameters	Relevance	Data availa-bility	Easiness to interpret	Total (mean)
Quantity value for certain components/materials/flows leading to hotspots	3.0	2.8	3.0	2.9
Geographical variation of the value chain	3.0	2.0	2.8	2.6
Choice of the activity variable (e.g. working hour vs. value added)	3.0	2.2	2.2	2.4
Variation of assumptions on social data	3.0	2.6	3.0	2.8
Price related to process or materials	2.7	3.0	2.4	2.7
Geographical variation of the energy consumed (electricity mix or H2 mix) during usage	3.0	2.6	3.0	2.8
Quantity of energy consumed during the use stage	2.4	2.6	2.6	2.5

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