Towards a European-wide harmonised transport-specific LCA Approach

TranSensus LCA

Coordinated and Support Action (CSA)
Grant Agreement Number 101056715
Start date of the project: January 1st, 2023, Duration: 30 months

Deliverable D 5.2

TranSensus LCA Consolidated Guidelines

Status: Final

Lead contractor for this deliverable: ***UBx***

Due date of deliverable: **31.03.2025**

Actual submission date: **09.04.2025**

Coordinator:

Thilo Bein & Felipe Cerdas
Fraunhofer LBF & IST
Bartningstr. 47 – 64289 Darmstadt - Germany
Phone +49 6151 705 463 | +49 151 74416873
E-mail thilo.bein@lbf.fraunhofer.de | felipe.cerdas@ist.fraunhofer.de

Project co-funded by the European Commission within Horizon Europe (2021-2027)		
Dissemination Level		
PU	Public, fully open	x
SEN	Sensitive, limited under the conditions of the Grant Agreement	
R-UE/EU-R	Classified: EU RESTRICTED under the Commission Decision No2015/444	
C-UE/EU-C	Classified: EU CONFIDENTIAL under the Commission Decision No2015/444	
S-UE/EU-S	Classified: EU SECRET under the Commission Decision No2015/444	

APPROVAL STATUS			
	Beneficiary	**Name**	**Signature**
WP Leader approval	UBx	Guido Sonnemann	Date: 31.03.2025 Signature: G. Sonnemann
Approval on behalf of the SC	Fraunhofer LBF	Thilo Bein	Date: 8.04.2025 Signature: Th. Bein

CONTRIBUTING PARTNERS		
	Beneficiary	**Name**
Overall Document Manager	UBx	Guido Sonnemann/ Takunda Yeukai Chitaka
Document Managers for specific parts		
E-LCA Goal and Scope	TU BS	Jana Husmann
E-LCA Life cycle Inventory	UBx	Takunda Yeukai Chitaka
E-LCA Life Cycle Impact Assessment	UBx	Takunda Yeukai Chitaka
E-LCA Interpretation	BRGM	Jair Santillan Saldivar
S-LCA Goal and Scope	RWTH	Davis Jose/ Marzia Traverso
S-LCA Life Cycle Inventory	RWTH	Davis Jose/ Marzia Traverso
S-LCA Life Cycle Impact Assessment	RWTH	Davis Jose/ Marzia Traverso
S-LCA Interpretation	RWTH	Davis Jose/ Marzia Traverso
Reporting	BRGM	Jair Santillan Saldivar
Perspectives	UBx	Takunda Yeukai Chitaka
Partner 2	BMW	Diana Bartaune/ Katharina Gompf/ Patrick Musch
Partner 3	BRGM	Jair Santillan Saldivar/ Antoine Beylot/ Diae Hennioui
Partner 4	CEA	Anh-Linh Bui VAn
Partner 5	EDF	Richard Quatrain / Anne Grau
Partner 6	UGENT	Erasmo Cadena
Partner 7	ULEI	Lauran van Oers / Bernhard Steubing / Hazem Eltohamy/ Robert Istrate / Jeroen Guinée

Partner 9	REN/AMPERE	Gladys Moréac-Njeim
Partner 10	RIC	Nikolas Hill / Marco Raugei / Kadam Lokesh / Simon Tate
Partner 11	RWTH	Davis Jose / Marzia Traverso / Rose Manka
Partner 12	SCANIA	David Algesten / Erik Nellström-Montemartillo
Partner 14	IVL	Julia Lindholm / Christian Junestedt
Partner 15	TU BS	Jana Husmann / Steffen Blömeke / Christoph Herrmann
Partner 16	UBx	Takunda Yeukai Chitaka / Guido Sonnemann /Anish Koyamparambath
Partner 17	VW	Mara Neef / Lasse Schmidt
Partner 18	UMICORE	Benedicte Robertz / Emilie Deram

REVISION Table		
Document Version	**Date**	**Modified sections - details**
0.1	28/02/2025	First draft version
0.22	24/03/2025	Revised after comments
0.3	31/03/2025	Revised after steering committee comments
Final	08/04/2025	Review and formatting by Project Secretariat
2.0	22/05/2025	Revised after input from Task 3.3
2.1	22/06/2025	Revised after review by IVL

EXECUTIVE SUMMARY

The transport sector is a major contributor to global greenhouse gas emissions. As a result, our road transport system is rapidly transforming with zero-emission propulsion systems achieving steadily increasing market shares. However, for all stakeholders in the mobility sector to define realistic sustainability goals and to select the most sustainable solutions, the environmental, economic, and social impacts of technologies and mobility concepts must be assessed in a holistic way. This highlights the need for a harmonised assessment approach for zero-emission transport systems to ensure consistency and comparability.

TranSensus Life Cycle Assessment (LCA) is a coordination and support action project funded by the European Union. The project aims to establish a commonly accepted and applied single LCA approach for LCA of so called “zero-emission” road transport systems in Europe. This was done through a consensus building approach, which engaged the consortium, associated partners, defined scientific and industry advisory boards as well as the wider stakeholder community including the European Commission, standardisation bodies and member states.

These guidelines are the result of TranSensus LCA’s efforts to develop a harmonised methodology. The guidelines establish 137 methodological requirements, of which 56 are mandatory, covering environmental and social LCAs for products, prospective scenarios, and fleet analyses.

The guidelines begin with a description of the relationships with other standards, guidelines and legislation for contextualisation. This is followed by details on the different steps in conducting an LCA specifically, i) goal and scope definition, ii) life cycle inventory, iii) life cycle impact assessment and iv) interpretation. The document also provides guidance on reporting to ensure adherence to the TranSensus methodology. The guidelines conclude with a section on future perspectives, highlighting areas for future research that may be applied to future iterations of the methodology.

It is important to emphasize that these guidelines are a “living document and will be updated as needed.

Table of Contents

Table of Contents 5
List of Tables 9
List of Figures 11
Important abbreviations 12
Glossary 14

I. Introduction 19
I.1 Relationships to existing standards, methodologies and legislation 20
I.1.1 Standards and guidelines 20
I.1.2 Legislation and regulations 21
I.2 Scope of guidance book 22
I.3 Structure of guidance book 22
I.4 Terminology 22

PART A: Environmental Life Cycle Assessment (E-LCA) 23
II. Goal and Scope 23
II.1 Goal 23
II.2 Scope 25
II.3 Functional unit 26
II.3.1 Lifetime distance 26
II.3.2 Lifetime years 29
II.4 System boundaries 31
III. Life Cycle Inventory 34
III.1 Production stage modelling 34
III.1.1 Data requirements for level 3 34
III.1.2 Electric energy supply in manufacturing stage 35
III.2 Use stage modelling 42

III.2.1 Estimating the energy requirements of vehicles ... 42
III.2.2 The Well to Tank (WTT) modelling ... 47
III.2.3 Non-exhaust emissions ... 54
III.2.4 Maintenance ... 56
III.3 End-of-life stage modelling ... 60
III.3.1 Data Choices ... 60
III.3.2 Electric energy supply in the End-of-Life stage ... 60
III.4 Multifunctionality problems ... 61
III.4.1 Identifying multifunctional unit processes: ... 62
III.4.2 Solving multifunctionality in co-production cases ... 63
III.4.3 Solving multifunctionality resulting from waste treatment ... 70
III.5 Data quality rating (DQR) ... 74

IV. Life Cycle Impact Assessment ... 75
IV.1 Mandatory set of Impact Categories ... 75
IV.2 Optional set of Impact Categories ... 77
IV.3 Normalisation ... 78

V. Interpretation ... 79
V.1 Scenario analysis and sensitivity analysis ... 79
V.1.1 Definitions and methodology ... 79
V.1.2 Mandatory analysis of parameters ... 80
V.1.3 Recommended analysis of parameters ... 83
V.1.4 Optional analysis of parameters ... 85
V.2 Integration into the product development process with Prospective LCA ... 88

PART B: Social Life Cycle Assessment (S-LCA) ... 90

VI. S-LCA Goal and scope ... 91
VI.1 Application of S-LCA ... 91
VI.2 Selection of Activity Variable ... 91

VI.3 Defining the Geographical Scope 92

VII. Social Life Cycle Inventory Analysis 92

VII.1 Collecting inventory data for Impact subcategories and related Indicators 93

VII.2 Data Collection to create the Reference Scales 93

VII.3 Multifunctionality 94

VII.4 Data for activity variable stakeholders and impact subcategory 94

VII.5 Data Quality Assessment 95

VIII. Social Life Cycle Impact Assessment 96

VIII.1 Calculation of S-LCIA results 96

VIII.1.1 Mandatory set of Impact Subcategories 96

VIII.1.2 Optional set of Impact Subcategories 97

IX. Social Life Cycle Interpretation 99

PART C: Reporting 101

X. TSLCA Adherence statement 101

X.1 Adherence Levels 101

X.2 Compliance Summary 102

X.3 Exceptions & Best Practices 102

XI. Result display and public reporting 103

XI.1 Results of the LCA study 103

XI.2 Choices made along the application of TranSensus LCA methodology 103

XI.2.1 Requirements for Reporting Choices 103

XI.3 Supporting information 106

XI.4 List of all reporting requirements 106

XII. Verification process 123

XII.1 Verification Levels 123

XII.2 Definitions of Verification Parties 123

XIII. Summary of all TranSensus LCA requirements 124

XIV. Result display and Public Reporting S-LCA........ 139

XV. Summary of TranSensus requirements for S-LCA 141

PART D: Perspectives 147

XVI. Perspectives 147

XVI.1 Functional unit........ 147

XVI.2 Tyre and break wear 147

XVI.3 Electricity Modelling........ 147

XVI.4 Multifunctionality........ 148

References........ 149

A1. OEM fleet LCA 154

Passenger cars and light commercial vehicles........ 154

Heavy-Duty Vehicles: 157

Two-wheelers........ 157

List of Tables

Table I1: List of guidelines and standards reviewed. 20

Table A II-1: LCA types in TranSensus LCA. 23

Table A II-2: Functional unit for different vehicle types. 26

Table A II-3: Lifetime in kilometres for different passenger cars and LCVs. 26

Table A II-4: Scaling values for different HDVs. 28

Table A II-5: Lifetime in kilometres for two-wheelers. 28

Table A II-6: Lifetime in years for all vehicle types. 29

Table A II-7: Default distribution of yearly driven distance for passenger cars, LCVs and HDVs. 29

Table A II-8: Processes to include or exclude from the system boundary. 31

Table A III-1: Proposed prioritization for the real-world adjustment factor to apply to WLTP-based energy consumption. 44

Table A III-2: Summary of the default WLTP-RW conversion factors proposed to be used for prioritisation approach 3, in the absence of other datasets. 44

Table A III-3: Proposed prioritisation for the underlying assumptions of fuel cell life and average operational efficiency. 46

Table A III-4: Proposed default H2 supply chain emission rates for hydrogen produced from (i) steam reforming of natural gas, (ii) electrolysis of water. 55

Table A III-5: 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. 57

Table A III-6: Typologies of mono- and multi-functional processes (based on Guiinée et. Al. 2021). 62

Table A III-7: Cases where some physical relationships for allocation shall be followed. 68

Table A III-8: Prospective LCA Multifunctionality additional considerations. 69

Table A IV-1: Mandatory environmental impact category list from TranSensus LCA. 75
Table A IV-2: Optional impact category list from TranSensus LCA. 77
Table A V-1: Definition of scenarios and sensitivity analysis in TranSensus LCA. 79
Table A V-2: Summary of mandatory parameters with definitions, analysis types, and recommended approaches. 81
Table A V-3: Summary of recommended parameters, analysis types, and approaches. 84
Table A V-4: Summary of optional parameters. 86

Table B VIII-1: Mandatory social impact subcategory list from TranSensus LCA. 96
Table B VIII-2: Optional impact subcategory list from TranSensus LCA. 98

Table C X-1: Adherence Levels and Compliance Criteria in TranSensus LCA. 101
Table C X-2: Description of two levels of adherence to TSLCA that can be claimed. ... 102
Table C XI-1: Detailed content for some reporting requirements for TranSensus LCA choices. 104
Table C XI-2: List of all reporting requirements. 106
Table C XIII-1: List of TranSensus LCA requirements. 124
Table C XV-1: List of TranSensus LCA requirements for S-LCA. 141

List of Figures

Figure A II-1: Process for deviating lifetime assumptions. 27

Figure A III-1: Iterative approach to fulfil the TranSensus LCA Level 3 minimum data requirements. 35

Figure A III-2: Mandatory hierarchy for the selection of appropriate datasets for use-stage dynamic mix electricity modelling. 48

Figure A III-3 : Illustrative example on subdivision. 63

Figure A III-4: 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. 64

Figure A III-5: Illustration of substitution (avoided burdens approach). 65

Figure A III-6: A reference vehicle EoL model (a guide for waste streams whose market values are untraceable). 72

Figure A III-7: A way to consider the benefits of traction battery repurposing (for stationary applications) in the vehicle prospective life cycle assessment (pLCA for a vehicle). 74

Figure A V-1 : Categorization in mandatory, recommended, and optional analysis of parameters. 80

Figure A1-1: Minimum criterion for performed OEM fleet LCAs: one vehicle LCA per powertrain-segment combination of the most sold model with respective equipment. 155

Figure A1-2: Process to adjust vehicle LCAs based on the curb weight. 156

Figure A1-3: Summary of process for the OEM fleet LCA for passenger cars and LCVs. 156

Important abbreviations

ADP:	Abiotic Depletion Potential (Resources)
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
CSRD:	Corporate Sustainability Reporting Directive
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
LDV:	Light-Duty Vehicle
LFP:	lithium iron phosphate
NMC:	Nickel Manganese Cobalt (battery)
OEM:	Original Equipment Manufacturer
PEF:	Product Environmental Footprint
PHEV:	Plug-in Hybrid Electric Vehicle
pkm:	Passenger kilometre
PSILCA:	Product Social Life Cycle Impact Assessment
REEV:	Range-Extended Electric Vehicle
SHDB:	Social Hotspots Database
S-LCA:	Social Life Cycle Assessment
SoC:	State of Charge
SoH:	State of Health
STEPS:	Stated Policies Scenario
tkm:	metric tonne kilometre
TSLCA:	TranSensus LCA
TTW:	Tank to Wheel
vkm:	Vehicle kilometre
WLTP:	Worldwide Harmonised Light Vehicles Test Procedure
WP:	Work Package
WTT:	Well to Tank
ZEV:	Zero Emission Vehicle

Glossary

Allocation: an approach to solving multi-functionality problems. It refers to 'partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Attributional LCA: a type of LCA focusing on one specific functional unit of the system/product under study, while assuming that the system/product itself does not alter the larger system into which it is embedded/deployed. (e.g., an LCA of one EV, without considering the effects that a large-scale roll-out of EVs may be expected to have on: (i) the demand for LIB metals[1], and hence on the changing impacts of their supply chains, and (ii) the increased total demand for electricity due to the vehicle's use phase, which may necessitate deployment of new generators and changes in grid mix composition).

Average Data: production-weighted average of specific data.

Background processes: refers to those processes in the product life cycle for which no direct access to information is possible. For example, most of the upstream life-cycle processes and generally all processes further downstream will be considered part of the background processes.

Climate change: EF impact category considering all inputs and outputs that result in greenhouse gas (GHG) emissions. The consequences include increased average global temperatures and sudden regional climatic changes.

Company-specific data: refers to directly measured or collected data from one or more facilities (site-specific data) that are representative for the activities of the company (company is used as synonym of organisation). It is synonymous to 'primary data'. To determine the level of representativeness a sampling procedure may be applied.

Consequential LCA: a type of LCA focusing on the changes induced by the deployment of the system/product under study, on the larger system into which it is embedded/deployed (e.g., an LCA explicitly modelling the expected changes in supply-chain impacts for LIB metals due to a large-scale uptake of EVs).

Co-product: any of two or more products resulting from the same unit process or product system.

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

[1] Lithium-ion battery metals. Common LIB metals typically include Lithium (Li), Cobalt (Co), Nickel (Ni), Manganese (Mn), Graphite (used as anode material, though not a metal), Aluminium (Al) and Copper (Cu) (used in battery current collectors and housing).

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

Cut-off criteria: specification of the amount of material or energy flow or the level of significance associated with unit processes or product system to be excluded from a study. Adapted from ISO 14040 (2006).

Data quality: characteristics of data that relate to their ability to satisfy stated requirements. Data quality covers various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data.

Environmental impact: any change to the environment, whether adverse or beneficial, that wholly or partially results from an organisation's activities, products or services.

Fleet LCA: Life Cycle Assessment that considers an entire group of vehicles, rather than a single unit, for example, the entire EU vehicle fleet. It is used to capture aggregate impacts and system-level effects, such as fuel mix, vehicle replacements, or policy-driven shifts. It is mainly used for transport modelling, national emissions reporting, scenario analysis (e.g., impact of large scale implementation of electric vehicles).

Foreground elementary flows: direct elementary flows (emissions and resources) for which access to primary data (or company-specific information) is available.

Functional unit (LCA): defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions 'what?', 'how much?', 'how well?', and 'for how long?'.

Functional unit (S-LCA): quantified performance of a product system for use as a reference unit in a life cycle assessment study, and also valid for an S-LCA. ISO 14040 (2006) ISO 14075 (2024).

Goal and scope: the first phase of an LCA or S-LCA; establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim. For S-LCA, a unique aspect in practice is the specification of the stakeholder group(s) of interest, subcategories included and the type of assessment (type I Reference Scale Assessment or type II Life Cycle Impact Assessment).

Impact assessment: phase of the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. The impact assessment methods provide impact characterization factors for elementary flows, to aggregate the impact so as to obtain a limited number of midpoint indicators.

Impact assessment method: protocol for converting life cycle inventory data into quantitative contributions to an environmental impact of concern.

Impact category: class of resource use or environmental impact to which the life cycle inventory data are related.

Impact category indicator: quantifiable representation of an LCA impact category.

Impact category (S-LCA): a social impact category is a class that covers certain social issues of interest to stakeholders and decision makers. In practice, impact categories are logical groupings of S-LCA (subcategory) results.

Life cycle: consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life cycle approach: to take into consideration the spectrum of resource flows and environmental interventions associated with a product from a supply-chain perspective, including all stages from raw material acquisition through processing, distribution, use, and end-of-life processes, and all relevant related environmental impacts (instead of focusing on a single issue).

Life cycle assessment (LCA): compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life cycle costing / Environmental life cycle costing: Life cycle costing, or LCC, or more specifically environmental life cycle costing, is a compilation and assessment of all costs related to a product, over its entire life cycle, from production to use, maintenance, and disposal.

Life cycle impact assessment (LCIA): phase of life cycle assessment that aims to understand and evaluate the magnitude and significance of the potential environmental impacts for a system throughout the life cycle. The LCIA methods used provide impact characterization factors for elementary flows to aggregate the impact, to obtain a limited number of midpoint and/or damage indicators.

Multifunctionality: If a process or facility provides more than one function, i.e., it delivers several goods and/or services (‘co-products’), then it is ‘multifunctional‘. In these situations, all inputs and emissions linked to the process will be partitioned between the product of interest and the other co-products, according to clearly stated procedures.

Normalization: after the characterization step, normalization is the step in which the life cycle impact assessment results are divided by normalization factors that represent the overall inventory of a reference unit (e.g., a whole country or an average citizen). Normalised life cycle impact assessment results express the relative shares of the impacts of the analysed system, in terms of the total contributions to each impact category per reference unit. Displaying the normalised life cycle impact assessment results for the different impact topics next to each other shows which impact categories are affected most and least by the analysed system. Normalised life cycle impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalised results are dimensionless, but not additive.

Product LCA: a Product Life Cycle Assessment (LCA) evaluates the environmental impacts of a single product or service, across its entire life cycle — from raw material extraction (cradle) through manufacturing, use, and disposal (grave). Often used to quantify the environmental performance of a specific product and identify key impact hotspots across its life cycle stages. Often used to support eco-design, product development, labelling, or sustainability reporting as well as in Environmental Product Declaration (EPD) and in compliance with ISO 14040/14044.

Prospective LCA: Life Cycle Assessment of a product, system, or technology that does not yet exist in widespread use or is still in development. To anticipate environmental impacts under future conditions, such as future electricity mixes, materials, or production scales.

Scope of the study: the scope is defined in the first phase of the study. It encompasses issues of depth and breadth of the study. It defines the limits placed on the product life cycle (that can be infinite) and on the detail of information to be collected and analysed. It defines where the data will be coming from, how up to date the study will be, how information will be handled, and where the results will be applicable.

Secondary data: data that is not from a specific process within the supply-chain of the company performing a PEF study. This refers to data that is not directly collected, measured or estimated by the company, but rather 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 as well as other generic data. Primary data that go through a horizontal aggregation step are considered to be secondary data.

Sensitivity analysis: systematic procedures for estimating the effects of the choices made regarding methods and data on the results of a PEF study.

Social impact subcategory: subsection of a social impact category that is related to a specific stakeholder category.

Stakeholder: individual or group that has an interest in any activities or decisions of an organization. (ISO 26000, 2008)

System boundary: definition of aspects included or excluded from the study. For example, for a ‘cradle-to-grave‘ LCA analysis, the system boundary includes all activities ranging from the extraction of raw materials, through processing, distribution, storage and use, to the disposal or recycling stages.

Uncertainty: refers to the lack of certainty e.g., in the prediction of a certain outcome, in a measurement, or in an assessment's results. It is a general term used to cover any distribution of data caused by either random variation or bias. In LCA and S-LCA, evaluation or measurement of uncertainty is an on-going process and relates to all the elements of data quality as well the aggregation model used and to the general aims of the study as set in the Goal and Scope.

Weighting: a step that supports the interpretation and communication of the analysis results. PEF results are multiplied by a set of weighting factors (in %), which reflect the perceived relative importance of the impact categories considered. Weighted EF results may be directly compared across impact categories, and also summed across impact categories to obtain a single overall score.

I. Introduction

TranSensus LCA aimed to develop a baseline for a European-wide harmonised, commonly accepted and applied single life cycle assessment (LCA) approach for a zero-emission road transport system including both environmental and social aspects. In this regard, it employed a consensus-based approach (detailed in TranSensus LCA Deliverable 2.3) for the development of a life-cycle-based methodology. This included consultation processes, which engaged the consortium, associated partners, defined scientific and industry advisory boards as well as, the wider stakeholder community including the European Commission, standardisation bodies and member states.

The TranSensus LCA methodology has been built to enable the resulting studies applying this method to be:

- Understandable, providing a clear scope and results to the audience (including limitations);
- Harmonized, being one clear, unique, method fostering the possibility to compare one study results to other ones using it, even when conducted by distinct parties;
- Accurate, providing indicators close to the actual (true) value of the environmental and social performance of the systems analysed;
- Auditable, with credible verification processes overcoming the challenge of confidentiality;
- Accepted by the scientific community and industrials;
- Reliable and trustworthy, in that 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 methodology provides guidance on both environmental and social life cycle assessment. It is important to note the differences in maturity of environmental life cycle assessment (E-LCA) and social life cycle assessment (S-LCA). This is reflected in the level of guidance provided for the two methodologies. Thus, in the case of S-LCA, the guidance is provided only as a recommendation; in order to be compliant with TranSensus LCA methodology, it is not mandatory to conduct an S-LCA yet, knowing the gap in systems in place to collect primary data for social assessment.

However, it is recommended to start with a social risk assessment based on PSILCA, SHDB, or other tools (Sedex, Ecovadis, and so on) to assess possible risks in the supply chain based on the specific location or even specific suppliers of each OEM. This is also consistent with other EU policies, making mandatory for big companies to implement CSRD and the EU Taxonomy

(Minimum Safeguard), which are good sources for social data. Moreover, it is suggested to start with a collection of primary data related to ZEV´s components, which include critical raw materials such as Battery (according to the EU battery regulation) and electronics.

In TranSensus LCA, zero-emission vehicles (ZEV) are defined as vehicles without any significant tailpipe emissions including battery electric vehicles and fuel cell electric vehicles. The TranSensus LCA methodology covers four types of LCA: product LCA, prospective vehicle LCA, OEM fleet LCA and macro fleet LCA (detailed further in E-LCA Goal and Scope).

I.1 Relationships to existing standards, methodologies and legislation

As mentioned, TranSensus LCA aimed to develop a harmonized methodology for LCA and S-LCA and thus, looked towards existing guidelines, standards, and regulations.

I.1.1 Standards and guidelines

As part of the TranSensus LCA methodology, a number of guidelines and standards were reviewed (Table I-1). These included guidelines at different technical levels (e.g., batteries, complete vehicle) and from different regions. The review formed the basis of the TranSensus LCA methodology whereby harmonization efforts were made in consultation with beneficiaries and associated partners. Although not included in the table, relevant ISO guidelines were also considered including ISO 14040, 14044 and 14075.

Table I-1: List of guidelines and standards reviewed.

Name	Abbreviation	Technical level	Publisher
GBA battery passport - greenhouse gas rulebook; generic rules	GBA	battery	Global Battery Alliance
LCA research progress of CATARC	CATARC	components/vehicle	China Automotive Technology and Research Center
Catena-X product carbon footprint rulebook	Catena-X	components	Catena-X automotive network
PEFCR - product environmental footprint category rules for high specific energy rechargeable batteries for mobile applications	PEFCR-Batteries	batteries	advanced rechargeable & lithium batteries association

Pathfinder framework- guidance for the accounting and exchange of product life cycle emissions	PACT	components/vehicle	World Business Council for Sustainable Development (WBCSD)
Harmonised rules for the calculation of the carbon footprint of electric vehicle batteries	CFB-EV	Batteries	Joint Research Center of the EC (JRC)
Product category rules public and private buses and coaches	PCR-Buses and coaches	Vehicle	EPD international ab
Elcar: guidelines for the LCA of electric vehicles	eLCAr	Vehicle	E-Mobility Life Cycle Assessment Recommendations project
Life cycle assessment applied to a vehicle or a vehicle equipment - methodological recommendations	PFA	components/vehicle	Filière automobile & mobilités
LCA guidelines for electric vehicles	RISE	Vehicle	RISE Viktoria
Guidance for Conducting Life Cycle Assessment Studies of Passenger Cars	VDA-PC	Vehicle	German association of automotive industry

I.1.2 Legislation and regulations

There are a number of existing legislations and regulations that are relevant to zero-emission vehicles. The importance of TranSensus LCA is even more evident in light of the increasing adoption of LCA-based requirements in the European regulations. For example, the EU Regulation on batteries and waste batteries, where providing an LCA-based carbon footprint declaration will be mandatory for any >2kWh-capacity batteries deployed in the European market (European Parliament, 2023). Similarly, the European Commission is required to develop a European methodology to assess and report the full life-cycle CO_2 emissions of cars and vans under the regulation on CO_2 emission performance for light duty vehicles (European Parliament, 2021).

The TranSensus LCA method makes an effort to align with current European legislation, such as the EU Battery Regulation (in particular Article 7 relative to life-cycle carbon footprint calculations) and various legislation setting out vehicle type-approval and certification requirements also feeding into the CO_2 regulations for cars, vans and HDVs, and air pollutant emissions standards.

A comprehensive review of guidelines, standards and legislation and regulations considered during methodology development is available in TransSensus LCA Deliverable 1.1.

I.2 Scope of guidance book

This guidance book is limited to the provision of guidance regarding the implementation of the TranSensus LCA methodology. It does not provide the background to the decision-making processes that underpin the development of the methodology. These are available in Deliverable 2.3 on the Final Harmonised Approach of the TranSensus LCA Methodology.

I.3 Structure of guidance book

The guidance book is organized into four sections:

- Part A: focusing on environmental life cycle assessment.
- Part B: focusing on social life cycle assessment.
- Part C: focusing on reporting requirements.
- Part D: providing future research outlooks.

I.4 Terminology

The following definitions apply in the implementation of the guidelines:

Shall/Mandatory	– Required for compliance with the guidelines.
Should/Recommended	– Advisable to implement.
May/Optional	– Not required for compliance with guidelines.
Informative	– Included for information purposes only, no action required.

PART A: Environmental Life Cycle Assessment (E-LCA)

The following guidance is specific to conducting an environmental life cycle assessment according to the TranSensus LCA methodology. Although the focus is on product LCA, unless otherwise stated, the entire guide applies to other types of LCA, including prospective and fleet LCA. Where there are deviations, these are highlighted in colours corresponding to the respective LCA Type as per Table A II-1.

II. Goal and Scope

This section describes the goal of the LCA linked to different LCA types, the scope (powertrains and vehicle types), the functional unit including default values for lifetime assumptions and the system boundary including cut-off rules.

II.1 Goal

The TranSensus LCA methodology comprises four different types of LCA with different definitions, goals, users and target audience (Table A II-1). The four types are: product LCA, prospective product LCA, OEM fleet LCA and macro fleet LCA. The LCA practitioner shall pick the appropriate LCA type for their study based on the descriptions in Table A II-1. The detailed approach for the OEM fleet LCA is described in Annex A1.

Table A II-1: LCA types in TranSensus LCA.

LCA type	Definition	Reason/Goal	User of the LCA	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 product LCA	A prospective LCA is conducted in the development stage and	• Research and development (eco-design) • Target setting	• R&D department	• Internal stakeholders (decision makers, strategy developers)

	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.	• Identification of levers to reach targets • Comparison between vehicles	• Purchase department (targeting supply chain) • External consulting firms • Researchers (universities and RTOs)	• 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 single manufacturer. Typically, it is based on an extrapolation of vehicle LCAs.	• Corporate reporting of fleet emissions • Inform future decarbonisation strategy • Fleet portfolio optimisation	Same as (prospective) product LCA	• Managers for target tracking • General public (info in Annual and Sustainability report), CDP, sustainability ratings, financial ratings
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 • External consulting firms • Governmental agencies	• Policy makers • Scientific community • General public

Note: The TranSensus LCA methodology is not strictly limited to the users and target audience described in the table. Other users might, however, face challenges regarding the accessibility of the data needed to implement the method.

II.2 Scope

This section describes how, and which product system can be evaluated with this guideline.

The technology coverage includes the following powertrains:

- Battery electric vehicles (BEV)
- Fuel cell electric vehicles (FCEV)
- Fuel cell range extended vehicles (FC-REEV)
- Battery electric vehicles with dynamic charging operation on electric road systems (BEV-ERS)
- Hydrogen fuelled internal combustion engine vehicle (H_2 ICEV)

and vehicle types:

- Passenger cars
- Light commercial vehicle (LCV)
- Lorries, urban busses and coaches summarised as heavy-duty vehicles (HDV)
- Motorcycles and mopeds summarised as two-wheelers.

<u>Prospective LCA - Deviation for Technology coverage</u>

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

II.3 Functional unit

The functional unit for the different vehicle types is based on the lifetime of the vehicle in kilometres. The functional units stated in Table A II-2 shall be used:

Table A II-2: Functional unit for different vehicle types.

Vehicle Type	Functional Unit
Passenger cars and LCV*	Passenger-km with the default assumption of one passenger, which is then equivalent to vehicle-km. If available, other occupancy rates may be used.
Lorries	Tonne-km with the default assumption of average (weighted) payload from the EU's VECTO HDV fuel consumption and CO_2 emissions certification tool.
Urban busses and coaches	Passenger-km with the default assumption of average (weighted) number of passengers from the EU's VECTO HDV fuel consumption and CO_2 emissions certification tool.
Two-wheelers	Passenger-km with the default assumption of one passenger, which then equals vehicle-km.

* Light commercial vehicles – LCVs may also be used for freight applications, in which case scenario analyses based on alternative tonne-km functional units may also be relevant.

** Vehicle Energy Consumption calculation TOol - VECTO - European Commission.

II.3.1 Lifetime distance

The following hierarchy shall be applied to identify the lifetime in kilometres for passenger cars and LCV:

1) Lifetime kilometre shall be chosen on a segment basis, where applicable. However, there is currently no harmonization of vehicle segments in Europe. Therefore, for TranSensus LCA, until a harmonized segmentation and respective lifetime kilometres is available, a default assumption of 200 000 km shall be applied for passenger cars (as indicated in Table A II-3 under "All"). Comparison between vehicles and segments (for comparative LCAs) shall be made on a km basis (vehicle-km/passenger-km). The default values stated in Table A II-3 shall be used:

Table A II-3: Lifetime in kilometres for different passenger cars and LCVs.

	Passenger car					LCV
	Small (A/B)	Lower medium (C)	Upper medium (D)	Large (Others)	All*	All

All power-trains	190 000	200 000	210 000	260 000	200 000	240 000

* Relevant for 3) of the hierarchy when no segment-specific approach is taken

Source: Ricardo et. al (2018).

2) Lifetime assumptions may be different from the default values provided in step 1 if they are sufficiently justified. Comparison shall be made based on the default values in step 1. To justify deviating values, the process in Figure A II-1 should be used:

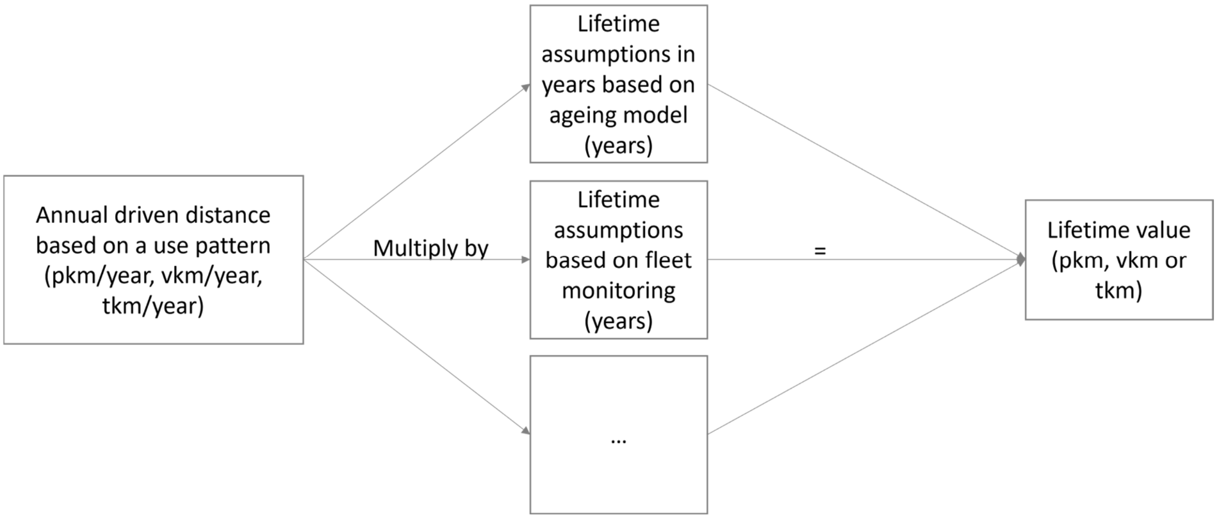


Figure A II-1: Process for deviating lifetime assumptions.

An annual driven distance should be calculated based on the specific use pattern of the 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 lifetime in years to obtain the full driven distance over the lifetime. There are different ways to justify the lifetime in years, such as ageing model or data from fleet monitoring. Other sufficiently justified lifetime assumptions in years are acceptable as well. A transparent documentation of these shall be made. The combination of a use pattern and an ageing model leads to the use of a mission profile, which 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 kilometres.

c. Define the number of times this trip is performed per year.

d. Define a typical speed profile.

e. Define the type of charging and refuelling after each trip.

f. For long trips, define the type of charging or refuelling during the trip.

g. Define the external temperature at which the trip is performed to consider the climate where the car operates.

3) OEMs may opt to use a more generic approach and assume a lifetime of 200 000 km for passenger cars of all segments. With this approach, comparisons between segments may be performed, additionally to the approach in step 1 (environmental impacts per vehicle-km), on a lifecycle basis (environmental impacts per total driven distance).

Please note: For explicitly comparative LCAs, which are aimed at making "comparative assertions", the same approach shall (step 1, 2 or 3 above) be used for all vehicles assessed.

For HDV, values consistent with VECTO-based HDV CO_2 and fuel consumption certification (European Commission, n.d.-b) shall be used to determine the lifetime in kilometres. The VECTO tool is prescribed for the calculation of HDV energy consumption for each segment and for different mission profiles 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 emissions standards for HDVs, These regulations also define standardised annual km for new HDVs and weighting factors for different mission profiles to be used to calculate a weighted average value for the assessment of compliance with CO_2 reduction targets for different HDV segments. These yearly-driven distances are scaled to the lifetime in kilometres with the default scaling values in Table A II-4. Please note that these scaling factors do not represent the lifetime of the vehicles in calendar years since the vehicles are expected to drive more in the beginning of its operating life.

Table A II-4: Scaling values for different HDVs.

Lorries	12
Urban buses	15
Coaches	18

For two-wheelers, the default values in Table A II-5 based on the SIBYL model by EMISIA shall be used (Joint Research Center of the European Commission, 2024).

Table A II-5: Lifetime in kilometres for two-wheelers.

	Motorcycles				Mopeds	
	2 stroke > 50cm³	4 stroke < 250cm³	4 stroke	4 stroke > 750cm³	2 stroke < 50cm³	4 stroke < 50cm³

			250 – 750cm^3			
Lifetime in km	75 000				45 000	

II.3.2 Lifetime years

The default values for the lifetime in years for all vehicle types in Table A II-6 shall be used. Other values may be used if they are documented and justified.

Table A II-6: Lifetime in years for all vehicle types.

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

Sources: Values for passenger cars and LCVs are based on those typically used in a range previously published studies, values for HDVs are based on an internal study of Scania/MAN, and values for two-wheelers are based on SIYBL model by EMISIA

With a dynamic approach for the use stage modelling (see Chapter III.2), the distribution of driven distance per year becomes relevant. The default distribution of the yearly driven distance for passenger cars, LCV and HDV shown in Table A II-7 should be used.

Table A II-7: Default distribution of yearly driven distance for passenger cars, LCVs and HDVs.

Year	Passenger car	Light commercial vehicle	Truck	Urban bus	Coach
1	10%	15%	10%	8%	8%
2	9%	13%	9%	8%	8%
3	9%	11%	9%	8%	8%
4	8%	9%	8%	8%	8%
5	8%	8%	8%	8%	8%
6	7%	7%	7%	8%	7%
7	7%	6%	7%	8%	7%
8	6%	5%	6%	8%	7%
9	6%	5%	6%	8%	7%
10	6%	4%	5%	8%	6%
11	5%	4%	5%	7%	6%
12	5%	4%	5%	7%	6%

13	5%	3%	4%	6%	5%
14	4%	3%	4%	-	5%
15	4%	3%	4%	-	5%
16	-	-	3%	-	-

Source: Analysis by Ricardo and Scania (2025).

Prospective LCA - Deviation for Functional Unit

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 III.4.2]. The chosen reference flows should be justified and documented.

Macro Fleet LCA - Deviation for Functional Unit

The functional unit should be adapted to reflect the aim of the study. Macro fleet LCAs may have various potential functional units. One 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.

II.4 System boundaries

The system boundary modelled shall be cradle-to-grave for product LCA. The system boundary shall include the following stages of the life cycle: production (raw material extraction; material, components (battery and fuel cell included); vehicle assembly), use (including energy use, replaced parts and maintenance) and end-of-life. Any eventual second use of the battery 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. The trailer shall be included in the use phase (e.g., based on the protocol for the EU's full vehicle certification regulations, using the VECTO tool).

The processes listed in Table A II-8 below shall be followed when defining the system boundary, including those to be included or excluded.

Table A II-8: 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, lorries, 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
Vehicle charging point or hydrogen refuelling station		Exclude
Infrastructure for electricity and hydrogen generation	This includes power plant, transmission (+ losses), transformers	Include
Auxiliary materials for production	Refers to materials directly 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	Consumable during the use phase of the vehicle. The minimum items to consider are lubricating oil, oil filters, 12V battery, engine coolant and traction battery, air conditioning gas (PFA). The full list of items is detailed in Table A III-5.	Include
Maintenance: wear parts	Replacement of **wear parts** (for example, tyres or brake linings), whose renewal depends heavily on the driver's driving mode. Reference should be made to the theoretical	Include

	change frequencies specified in the maintenance book where they exist. The minimum elements to take into account are tyres, brake linings and windscreen wipers (PFA). The full list of items is detailed in Table A III-5.	
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
Road surface wear	Wear and tear emissions due to activity of vehicles. Can be considered as part of road infrastructure.	Optional
Charging cable of the vehicle delivered with vehicle		Include
Charging losses (note 1)		Include

Note 1: Charging losses refer to the electrical energy that is not converted to stored energy in the on-board battery storage during charging, due to inefficiencies in the charging process/equipment (either external or internal to the vehicle), with the 'lost' electrical energy usually dissipated as heat. AC charging losses are already included within the standardised European WLTP energy consumption figures from LDV type-approval. However, charging losses are NOT included within EU certified energy consumption for HDVs using the VECTO certification tool, so need to be separately accounted for either using generic values or vehicle OEM-specific data, if available.

The following hierarchical process shall be used to cut off flows:

1) No intentional cut-off of flows shall be made, where these can be reasonably avoided.
2) In case a cut-off is needed, an absolute threshold based on 3% of the environmental impacts shall 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. This means if the cut-off flow impact is above 3% in even one of the mandatory impact categories, it cannot be excluded.

To use the cut-off allowance, a minimum 97% coverage (max. 3% cut-off) of environmental impacts shall be achieved and documented in a screening analysis, which shall be representative of the vehicle. 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 practitioner 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.

Prospective LCA - Deviation for System Boundary

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 exclude should be revised. Any changes shall be justified and documented.

Macro Fleet LCA - Deviation for System Boundary

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.

III. Life Cycle Inventory

This chapter is organised 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 are provided on multifunctionality and data quality assessment.

III.1 Production stage modelling

In this section, TranSensus LCA provides guidance on inventory modelling in the production stage of the vehicle. Specifically, data requirements to reach Level 3[2] LCA (as defined by the UNECE A-LCA IWG[3]), and how to model the electric energy supply.

III.1.1 Data requirements for level 3

TranSensus LCA will adopt the level 3 primary data requirements developed by the UNECE A-LCA IWG once officially published. The guidelines presented below may be considered aspirational, as during the road testing (TranSensus LCA Deliverable 3.3), the data requirements were found to be difficult to meet at the moment due to data availability constraints.

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

- The practitioner shall choose vehicle parts/materials 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 A III-1.
- The chosen parts/materials 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/materials chosen to fulfil these requirements (e.g., car body, rims) shall be provided by the practitioner.

2 Level definition: refer to TranSensus LCA Deliverable 2.3 Annex, subsection ‘Data requirements for level 3

3 UNECE (United Nations Economic Commission for Europe) work on LCA: https://unece.org/transport/documents/2023/01/informal-documents/lca-status-report-iwg-lca

- H_2 storage vessel (FCEV, FC-REEV, H_2-ICEV) may[4] be treated similarly to batteries, which means it is modelled with company-specific data apart from the generic 20%.

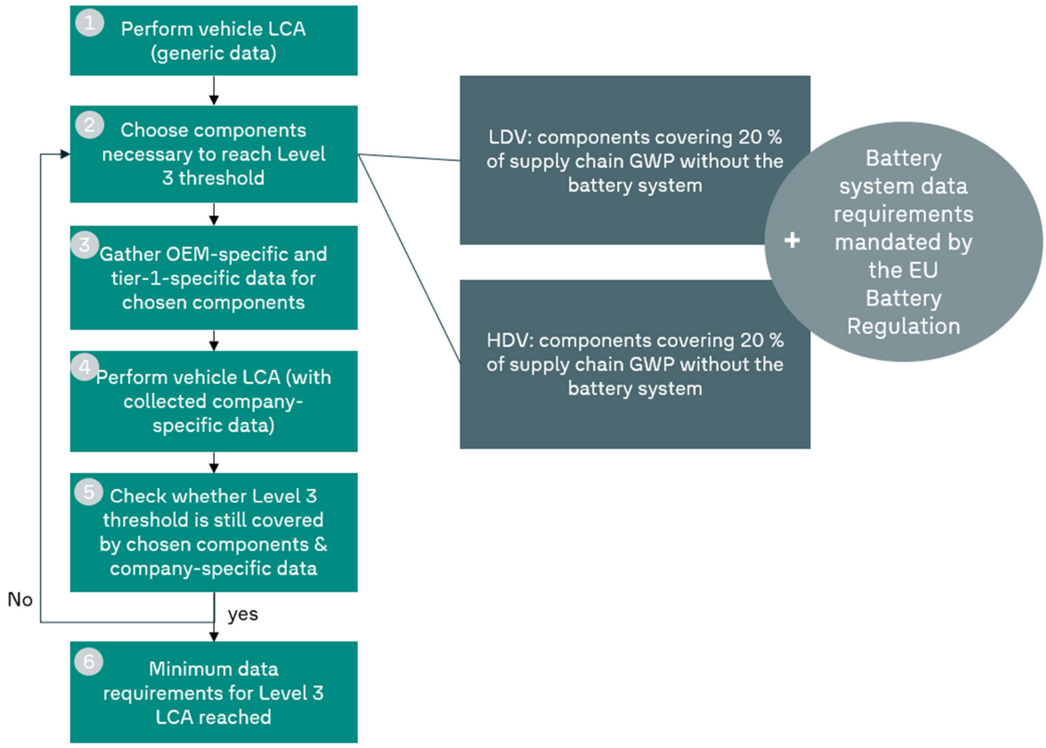


Figure A III-1: Iterative approach to fulfil the TranSensus LCA Level 3 minimum data requirements.

These level 3 data requirements only apply for the Global Warming impact category. If the supplier specific data is in the form of a full LCI (e.g., energy consumption) or as an aggregated dataset (e.g., in ILCD format), all other TranSensus LCA impact categories can be evaluated as well. If, for confidentiality reasons, the supplier will only supply PCF/GWP values, other IC cannot be modelled with supplier specific data and so instead should be modelled with secondary data.

III.1.2 Electric energy supply in manufacturing stage

III.1.2.1 Overall time consistency

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

[4] 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.

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.

III.1.2.2 General guidelines

When modelling electric energy supply, the following hierarchy shall be followed: a location-based approach (option 1), a 100% market-based approach (option 2), and a mixed-method approach (option 3). The location-based approach is the default approach, which shall be used except for when LCA practitioners want to use Energy Attribute Certificate (EACs)[5] in their LCA modelling. In that case, they should opt for the 100% market-based approach. Unless LCA practitioners do not have either enough adequate data (processes covering needed residual mixes and processes using them) or the time to develop those, they may use the mixed-method approach. These 3 options are described below in detail.

- **Option 1**: TranSensus LCA shall use a location-based approach by default.

  In this approach, each electricity consumption process is modelled using either a sub-national consumption grid mix (e.g., for the USA and China, to improve accuracy), a national consumption grid mix (i.e., country-specific), or - if neither national nor sub-national consumption grid mixes are available, a supra-national consumption grid mix (e.g., the EU average grid mix).

- **Option 2**: However, if the use of Energy Attribute Certificates (EACs) is desired, in this case LCA practitioners should apply a 100% market-based approach, whereby all electricity consumption processes are 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 shall be used. This mix may be derived at a national level, sub-national level or, -if neither is available- at a supra-national level.

  The contractual instruments that are used shall comply with the specific safeguards as stated in the following sections.

  Further, 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 up-stream value chain of the product).

[5] Common types of EACs include: Guarantees of Origin (GOs) in Europe, Renewable Energy Certificates (RECs) in the US, and International RECs (I-RECs) for global markets.

- **Option 3**: Lastly, when industries lack either sufficient data (e.g., processes covering needed residual mixes and processes using them) or the time to develop such data, they may adopt the following mixed-method approach - currently widely used in the OEM industry - to model production-stage impacts:
  - Use the available location-based electricity consumption mixes for 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.

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.

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 either a 100% market-based approach with time, or, when possible, location-based.

Prospective LCA – Deviation for electric energy supply in production stage – General guidelines

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 Power Purchase Agreements (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.

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.

III.1.2.3 Safeguards for the use of EACs in TranSensus LCA market-based approaches

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. The LCA practitioner shall document the adherence to these safeguards by making the EACs used in the foreground system available to a third-party verifier. In the OEM's background system (i.e., by the suppliers), the safeguards shall be part of the contract between OEM and tier-1 supplier.

III.1.2.3.1 Safeguard on additionality

The general definition of "additionality" is that the installation would not have been built without the financial intervention of, in this case, the OEM. Here, the additionality safeguard refers to all EACs being used shall be issued only for installations that have been recently built, and that started to produce electricity and were connected to the grid less than 15 years ago.

III.1.2.3.2 Safeguard on geographical consistency

For geographical consistency, 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 where it is difficult to verify that the electricity-producing asset associated with the used EAC is located within the same bidding zone as the value chain site consuming the electricity, a simple distance checking may be applied: the asset must be no more than 500 km away in a straight line from the consumption site of the electricity.

III.1.2.3.3 Safeguard on time consistency

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 (within 12 months) 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 with the vehicle production timeline (general meters dedicated to entire production lines or facilities complemented with justified and documented allocation procedure can be used).

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

III.1.2.3.5 Other safeguards

In addition, 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.

III.1.2.4 Guidance for residual mixes modelling in market-based approaches

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 Association of Issuing Bodies (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 removed (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, the residual mixes that may be used within the mixed approach (e.g., in a transition period towards 100% mixed approach should 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).

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 out in the best possible manner according to available resources (available time, data and software).

Prospective LCA – Deviation for electric energy supply in manufacturing stage – Residual mixes modelling

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)).

III.1.2.5 On-site electricity production processes

When 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 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, compliance shall be verified using the following hierarchy:

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

For produced electricity that is not consumed during the production stage and is either wasted or fed to the grid as grey electricity (no EACs associated with it), 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).

Secondary data from default electricity processes from databanks, which include infrastructure can be used during modelling.

Prospective LCA type – Deviation for electric energy supply in manufacturing stage – On-site electricity production processes

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).

III.2 Use stage modelling

This section provides guidance on 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.

III.2.1 Estimating the energy requirements of vehicles

For all vehicles, the minimum acceptable approach for defining the energy consumption shall be the EU regulatory type-approval/certification values. For LDVs, this shall be average 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 (discussed in E-LCA Interpretation).

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.

Equation1 : Calculating use stage vehicle energy consumption.

Real World (RW) adjustment factors and degradation factors are discussed in the proceeding sections.

III.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, called WLTP-RW. The different options are listed in order of accuracy and preference in Table A III-1, 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.

Table A III-1: Proposed prioritization for the real-world adjustment factor to apply to WLTP-based energy consumption.

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)[6]	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 A III-2 below).	Level 3 and below.

Table A III-2: 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
Passenger cars	Small (A, B)	BEV	115%
Passenger cars	Medium (C, D)	BEV	113%
Passenger cars	Large (Other segments)	BEV	112%
Passenger cars	Small (A, B)	FCEV	115%
Passenger cars	Medium (C, D)	FCEV	113%
Passenger cars	Large (Other segments)	FCEV	112%
LCVs	All	BEV	120%
LCVs	All	FCEV	120%

Source: (Ricardo et al., 2018)

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

III.2.1.2 Degradation factor for Fuel Cells

For all vehicle types, 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%

6 For example based on On Board Fuel Consumption Monitoring (OBFCM) or similar data provided by operators with a suitably wide/significant sample size across the European region, or alternatively data based on Real Driving Emissions (RDE) testing for the specific model.

average 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:

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

Equation2 : 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 relevant VECTO-based fuel consumption and CO_2 emission certification cycles 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 (Equation3).

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 (Equation4)

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:

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

Equation3: 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-based fuel consumption and CO_2 emission certification cycles for HDVs

EnConConversion = conversion factor for converting MJ to kWh

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

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

Equation4: 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.

The following prioritisation shall be followed for the underlying assumptions of fuel cell life and average operational efficiency (Table A III-3). 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.

Table A III-3: Proposed prioritisation for the underlying assumptions of fuel cell life and average operational efficiency.

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 power/voltage), 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)[7], an efficiency of 55%/52% (at the start of the fuel cell life for LDVs/HDVs)[8], with efficiency loss of 10% over the life of the fuel cell, and running at an average of 25%[9]/25%[10] (for LDVs/HDVs) of the peak power rating.	Level 3 and below.

[7] Based on 2025 targets from FCH2JU KPIs FCH 2 JU - MAWP Key Performance Indicators (KPIs) - European Commission (europa.eu)

[8] Based on Ricardo review of typical fuel cell efficiency for LDV and HDV applications

[9] Based on Fuel Cell Electric Vehicle Durability and Fuel Cell Performance (nrel.gov)

[10] Average approximation based on Ricardo analysis of VECTO simulation results for different HDVs and cycles.

III.2.2 The Well to Tank (WTT) modelling

III.2.2.1 Electricity energy supply

The electricity supply modelling methodology for the vehicle use stage shall comply with the following hierarchy:

1. 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 – 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 occurring over the full-service life of the vehicle.
2. 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.

The following step-by-step methodological approach shall be used for the “dynamic” modelling approach:

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)[11]. 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.

[11] 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. 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[12]. 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 A III-2.

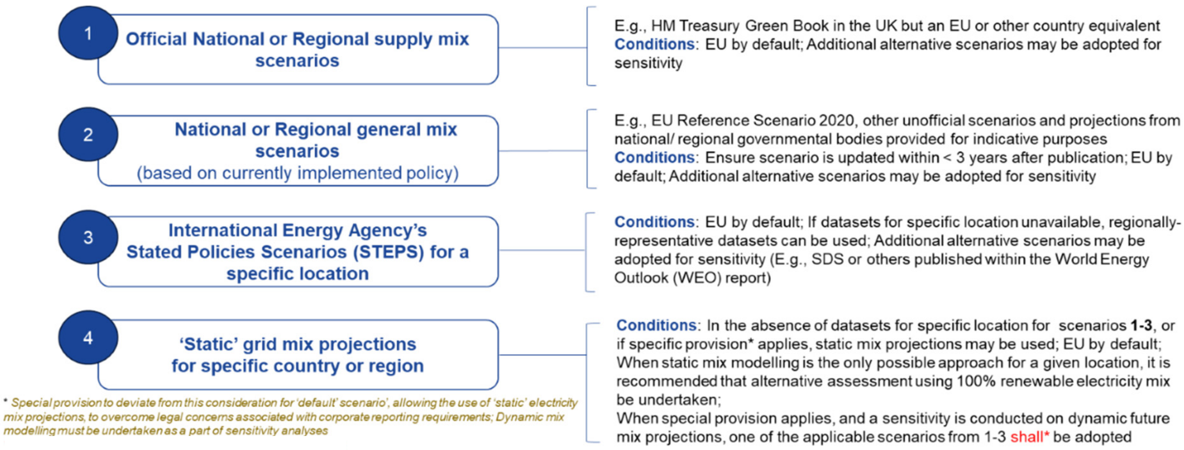


Figure A III-2: Mandatory hierarchy for the selection of appropriate datasets for use-stage dynamic mix electricity modelling.

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:

   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

[12] 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.

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[13,14].

A hypothetical example of how to apply these steps is available in the TranSensus LCA Deliverable 2.3 Annex.

Prospective LCA type – Deviation for electric energy supply in use stage – General Guidance

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

[13] 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/.

[14] 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.

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 PRospective EnvironMental Impact asSEment (PREMISE) project, which offers a streamlined approach to producing databases for prospective Life Cycle Assessment using Integrated Assessment Models.

III.2.2.2 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.

Fleet Level LCA – Deviation for electric energy supply in use stage – On-site electricity production processes

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).

Prospective LCA – Deviation for electric energy supply in use stage – On-site electricity production processes

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).

III.2.2.3 Hydrogen

The following step-by-step methodological approach shall be followed for the modelling of hydrogen supply mixes feeding into the use stage of FCEVs, which is analogous to that used for electricity. As of the development of these guidelines (2024), there are 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 (directly agreed by the relevant authority to be the one to be used for vehicle LCA studies or related analyses) 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 (even if not specifically agreed for use for vehicle LCA studies or related analyses), 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 (provided this has been updated within less than 3 years)[15].

      iii) Stated Policies Scenario (STEPS) from the most recent International Energy Agency's World Energy Outlook (IEA WEO) report, for the geographical region

[15] 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.

of interest[16]. 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.

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 $S_{i,n}$ 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 predefined time horizons in the scenario selected at point 1 above. To clarify, for each year of operation n, both the share $S_{i,n}$ 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).

16 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.

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 $S_{i,n}$ of hydrogen supplied by each technology i in the year n, i.e.

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

4) A custom 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[17,18].

III.2.3 Non-exhaust emissions

III.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.

   For hydrogen leakage in the use stage, appropriately verified vehicle OEM-specific leakage rates may also be used, where these are available.

2) In the absence of official governmental estimates (or supplier-specific or vehicle OEM information) on fugitive hydrogen emissions, include estimated H_2 supply chain emission rates based on Table A III-4, derived and simplified from (Cooper, Dubey, Bakkaloglu, & Hawkes, 2022)

[17] 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/

[18] 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.

Table A III-4: Proposed default H_2 supply chain emission rates for hydrogen produced from (i) steam reforming of natural gas, (ii) electrolysis of water.

	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 LH_2)	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 LH_2)	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) and Cooper, Bakkalohlu & Hawkes (2022). In the absence of other information, a similar rate is assumed also for hydrogen vehicles using fuel cells.

III.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 emissions if the GWP100 of the used refrigerant is equal to or greater than 150 kg CO_2 eq./kg. Refrigerant with GWP less than 150 kg CO_2 eq./kg may be included as non-exhaust emissions. TranSensus LCA 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.

III.2.3.3 Tyres and Brake wearing

Non-exhaust emissions from tyre and brakes wear shall be included in the inventory as elementary flows. Official data for 2023 are available from EMEP guidebook [19] (EEA, 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 acknowledges that the 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.

III.2.4 Maintenance

All maintenance, wear and consumable items listed in Table A III-5 should be considered in all studies.

The 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.

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 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).

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

Table A III-5: 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	H_2 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		✓	✓	✓	✓	✓
	Traction/storage battery (See below)	**Yes**	N/A	✓	✓	✓	✓
	Fuel cell stack (See below)	**Yes**	N/A	N/A	N/A	✓	✓
	Other auxiliary batteries[20]	**Yes**	(✓)	(✓)	(✓)	(✓)	(✓)

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

20 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 set-ups). 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.

III.2.4.1 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.

III.2.4.2 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.

   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 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 complete battery replacement is likely to be needed):

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

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, 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.

For the simplified methodology to decide the need for fuel cell system replacement(s) if no specific data is available, refer to subsection III.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.

III.3 End-of-life stage modelling

III.3.1 Data Choices

The entity that carries out the study shall use company-specific data 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.

III.3.2 Electric energy supply in the End-of-Life stage

III.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.

Prospective LCA – Deviation for electric energy supply in the End-of-life 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 project, which offers a streamlined approach to producing databases for prospective Life Cycle Assessment using Integrated Assessment Models.

III.3.2.2 Guidance for on-site electricity production

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

III.4 Multifunctionality problems

This section is mainly based on work by Guinée et al., (2021); J. B. Guinée et al., (2002, 2004)

Important definitions:

- **Economic flow**: a flow of goods, materials, services, energy or waste from one unit process[21] to another, with either a positive (e.g., steel, transportation) or zero or negative (e.g., waste) economic value.
- **Good/product flow**: an economic flow between two processes with an economic value higher than or equal to zero
- **Waste flow**: an economic flow between two processes with an economic value smaller than zero.
- **Functional flow**: any of the (economic) flows of a unit process that constitute its goal (or part of its goal). This can be:
    1. The **product outflows** (including services) of **any process** (e.g., press shop producing a car door frame & valuable iron scrap) and
    2. The **waste inflows** of a **waste treatment process** (e.g., EoL car tyre going to incineration as input).

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

- **Non-Functional flows**: any of the flows of a unit process that are not a functional flow. These include **product inflows** (e.g., steel coils feeding the press shop) and **waste outflows** (e.g., residual mixed waste from factories), as well as elementary inflows and outflows (natural resources and pollutants).
- **Multifunctional process**: a unit process yielding more than one functional flow.

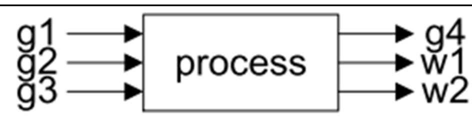
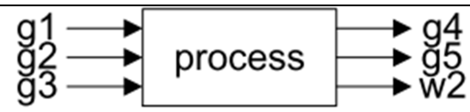
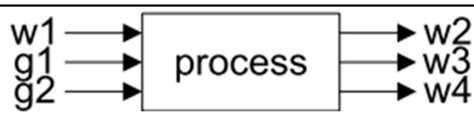
Note that any other criterion to distinguish between products and wastes may be applied as long as it can be consistently applied over different product systems.

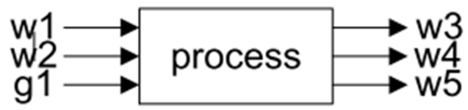
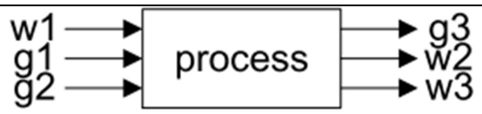
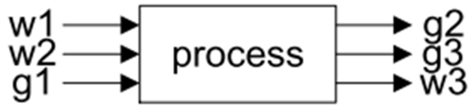
III.4.1 Identifying multifunctional unit processes:

1. The identification of each flow between two processes as either a good/product or a waste.
2. The identification of a process' functional flow(s). Note that every process needs at least one functional flow.
3. The identification of multi-functional processes. i.e., unit processes yielding more than one functional flow.

The following table summarizes the different typologies of multi-functional processes that can be obtained (Number 2, 4, 5 and 6). It also includes a mono-functional production process (Number 1) as well as a mono-functional waste process (Number 3) only to show the difference between a mono-functional and a multifunctional process considering the aforementioned definitions.

Table A III-6: Typologies of mono- and multi-functional processes (based on Guiinée et. Al. 2021).

Typology #	Typology	Graphical representation (g=good/product flow, w=waste flow)	Functional Flow(s)	#Functions	To solve?
1	Mono-functional production process		g4	1	No issue to solve.
2	Co-production process		g4;g5	**2**	Section III.4.2
3	Mono-functional waste process		w1	1	No issue to solve.

4	Combined waste processing		w1;w2	2	Section III.4.3
5	Recycling Or energy recovery		w1;g3	2	Section III.4.3
6	Combined waste processing and recycling (or energy recovery)		w1;w2;g2;g3	4	Section III.4.3

III.4.2 Solving multifunctionality in co-production cases

This is typology number 2 in Table A III-6. The following hierarchy shall be used to solve any multifunctionality problem encountered in case of co-production multifunctional unit processes. For example, a press shop producing both a car door frame and some valuable iron scrap.

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 A III-3).

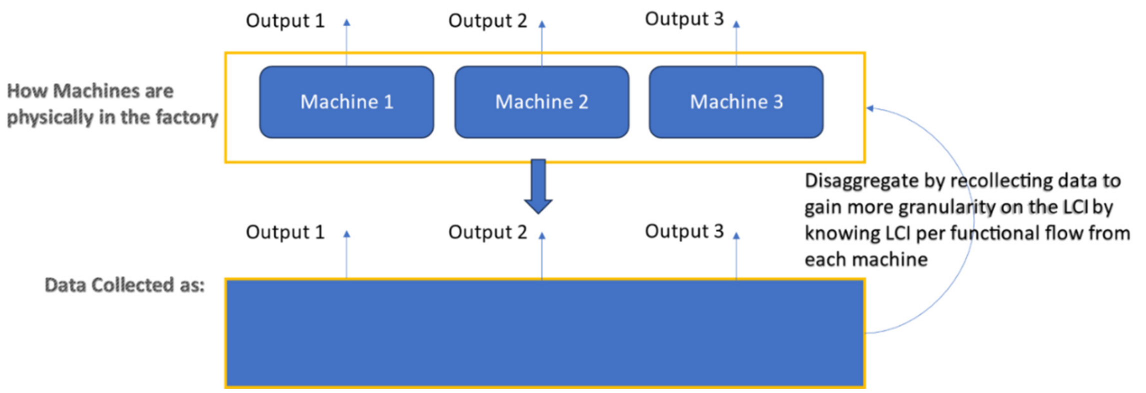


Figure A III-3: Illustrative example on subdivision.

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[22] 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 A III-4). Thus, if the aim of the study is to assess the environmental impacts related to just one of the functional flows (which is often the case), system expansion is not the right approach, and the practitioner shall proceed to the next step in the hierarchy.

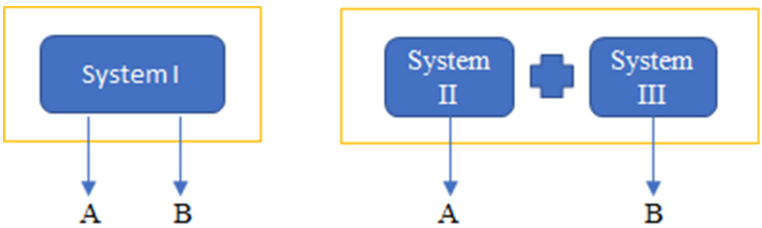


Figure A III-4: Illustration of system expansion. The LCA results of system 1 are the combined impacts of product A + B. In a comparative LCA, system 1 needs to be compared to another (set of) system(s) that provides the same basket of products as system 1.

3-Substitution (avoided burdens)[23]

When a functional flow (here the co-product that has a positive economic value) of a multifunctional 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

[22] 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.

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

the entire burdens of the multifunctional process and then subtracting the burdens of the substituted processes (Figure A III-5).

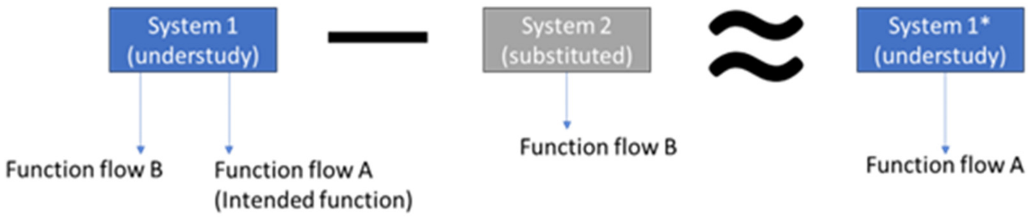


Figure A III-5: Illustration of substitution (avoided burdens approach).

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

1) There is a real, measurable substitution effect[24]: for each co-product (functional flow B in Figure A ***III-5*** 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[25] 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 A ***III-5*** 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. This substituted system shall be represented (in the model) by market average. This is to prevent any attempts to substitute the worst technology, and to have a common reference.

4) Cascaded multifunctionality is avoided: there shall be an identifiable primary monofunctional production path that produces the co-product (functional flow B in Figure A ***III-5*** 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.

[24] 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.

[25] 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 for 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, and substitution cannot be applied."

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 (main product and co-products). The economic value is calculated as:

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

Equation 6: Calculating economic value.

For the calculation of economic values, the following hierarchy shall be followed to determine the "economic factor" in Equation 6:

1. Global market price[26]
2. Regional market price
3. Processing cost[27]
4. Other factors (e.g., Sales price)

[26] Note that global market prices are usually only available for commodities.
[27] 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.

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 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. The economic value ratio between the functional flows (higher or lower than four) shall determine which type of allocation to apply.

If the calculated economic value ratio between any of the functional flows is higher than four[28], 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.

In the case of metal scrap from steel and aluminum processing by OEMs, the economic value ratio between the produced component (e.g., car door) and the scrap is expected to be way bigger than 4, which will lead to economic allocation with probably close to 100:0 allocation factors according to OEMs expectations. For simplification, the allocation factors here may be assumed to 100:0 so the entire burden is allocated to the produced component or piece. The simplification here is justified by:

1. The effort and resources needed to calculate the allocation factors accurately is not compensated by the impact it would have on the results given the big gap in the economic value. So if allocation factors are to be calculated accurately, it will be for example 98% to 2%.
2. The intermediate components (e.g., car door) is not a commodity (no global or regional declared price) and allocation based on processing price is the least realistic and is not possible in most cases according to OEMs (due to unavailability of necessary data).
3. A 100:0 allocation is the most conservative approach.

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

[28] 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).

- Produced masses
- Contained exergy
- Contained energy

Table A III-7 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.

Table A III-7: 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, piece perimeter
Vehicle Assembly	Pieces time, mass
Welding	Welding length
Quality checks	Time, pieces
Storage	Volume, 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 6 and 7 to calculate allocation factors.

Prospective and Fleet-level LCA - Multifunctionality

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.

Prospective LCA - Multifunctionality

Additionally, for prospective LCA, additional considerations that LCA practitioners may **pay attention** to are provided (Table A III-8). These considerations can be translated into parameters and combined into scenarios to be explored within a prospective LCA. The parameters and scenarios are to be defined by the practitioner as deemed relevant.

Table A III-8: 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	Could the multiple functions provided by the system change in the future?	Could 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?
	• Could the substitution ratio change due to:
	  ○ Quality changes of the output product?
	  ○ Up-scaling of the process under research?
	  ○ Changes of the input(s) in future?
		• Could the process efficiency of the reference process(es) might change in a future scenario?
		• Could the environmental burdens of the reference process change in a future scenario?

Economic allocation	• Could 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	• Could the future technology setup change the physical flows? • Could upscaling change the physical flows?	N.A.

III.4.3 Solving multifunctionality resulting from waste treatment

Multifunctionality arising from waste treatment activities can take many forms as illustrated in Table # (i.e., Typologies 4,5, and 6).

Typology (4):

In case of combined waste treatment without any sort of material or energy recovery, allocation as shown in previous section (III.4.1) shall be followed if subdivision is not possible (the economic factor for allocation here would be the cost of treatment of each waste flow). This type of multifunctionality problem might not be apparent to the practitioner if databases (e.g., ecoinvent) are used to model waste treatment processes (e.g., in studies where waste treatment is not the focus of the study). This is because these waste treatment datasets are provided to the practitioner already after allocation.

EXAMPLE: A unit process in a facility that treats both plastic and metal waste streams with no further details about the fate of each waste stream inside the facility (i.e., the facility is a black box). Allocation must be applied in this case to partition the burden of the waste treatment process between the two waste streams.

Typology (5 and 6)

These typologies encompass material or energy recovery. Multifunctionality here shall be dealt with using the cut-off approach, which is also referred to as “recycled content” or “100:0” approach. This is to be applied whenever a multifunctional unit process of these types occurs (at any of the vehicle life stages).

This applies to open-loop reuse, recycling, and energy recovery systems. Recovered material or energy from 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 of typology 6, this means that the burden is distributed only between the two (or more) treated waste streams after the cut-off of the functional flows in the outflow side (recovered material and energy), which practically makes typology 6 identical to typology 4 in this case.

Since this type of multifunctionality is expected to exist more frequently at the end-of-life of the vehicle, the step-by-step guide that shall be followed is:

1. Model EoL of the product (vehicle in this case) until sufficient sorting leads to distinct waste streams (incl. all transportation). Namely: collection, pretreatment, dismantling and shredding.

2. After having clearly labelled 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 A III-6 to determine the cut-off point for typical streams.
4. If 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 properties of the material (for example in terms of quality or form) for the new vehicle is obtained. Datasets documentation from data providers should be read carefully to reduce omission or double counting risks.
5. Only in case of typology 6, after the elimination of the recovered material and energy, the burden of the combined treatment shall be allocated between the waste inflows following the allocation rule in section III.4.1 if subdivision is not possible to apply.

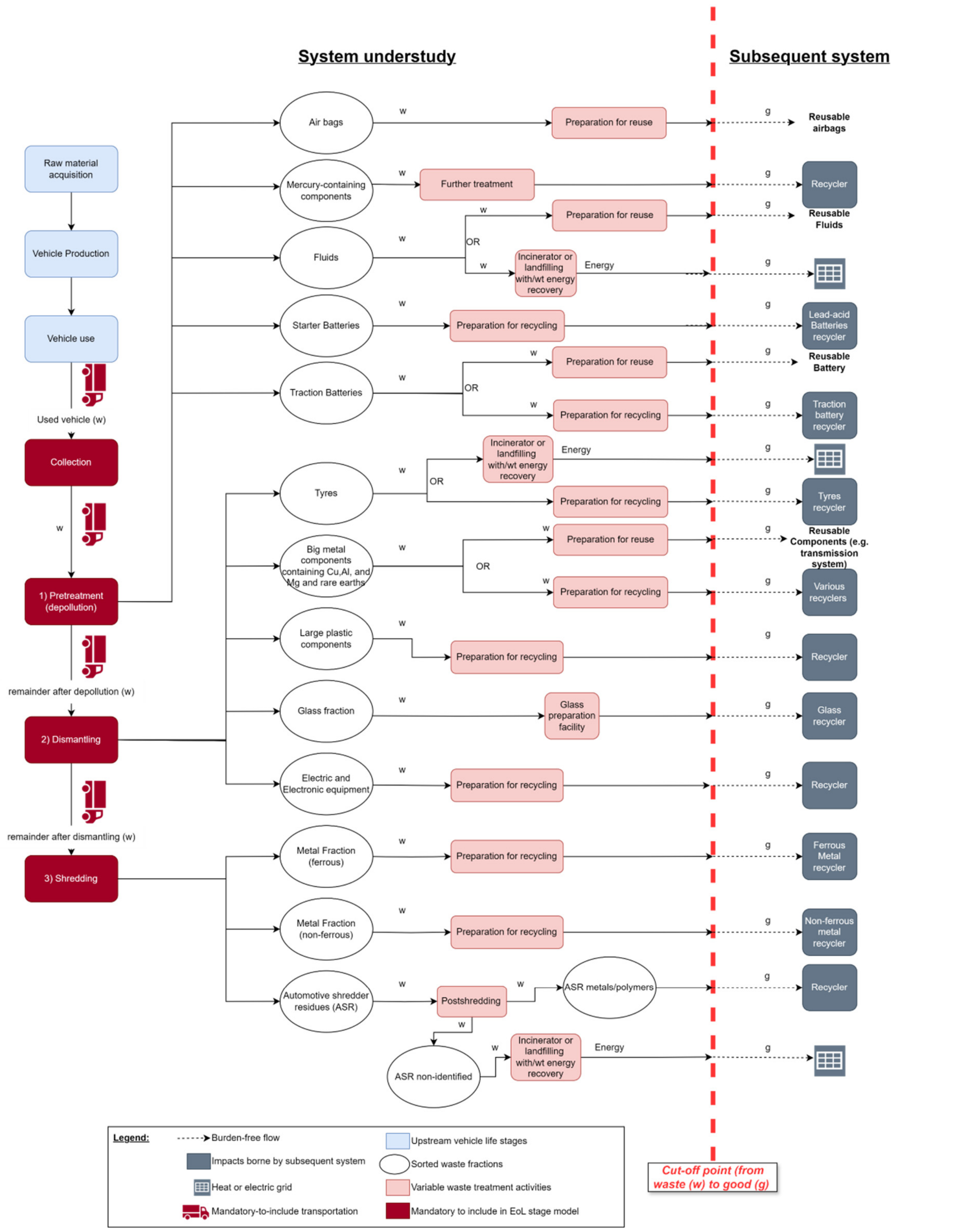


Figure A III-6: A reference vehicle EoL model (a guide for waste streams whose market values are untraceable).

It is important to note that TranSensus LCA does not mandate Figure A III-6 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 in Figure A III6 that plastic/polymer fraction of Automotive shredder residues (ASR) go to recycling, this does not mean that the LCA practitioner must model it this way.

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.

Figure A *III-6*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 A III-6. Following the cut-off method and the system boundary in TranSensus LCA, 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 (cut-off point is positioned as explained above to consider all preparation processes). In case of remanufacturing, this is modelled by using a burden-free or partially burden-free (depending on the cut-off point) remanufactured traction battery instead of a brand-new traction 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).

Prospective LCA – Deviation for Multifunctionality in the EoL

Regarding the EoL in prospective LCA, the cut-off method should be used as indicated in subsection III.4.3, however, 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 A III-7).

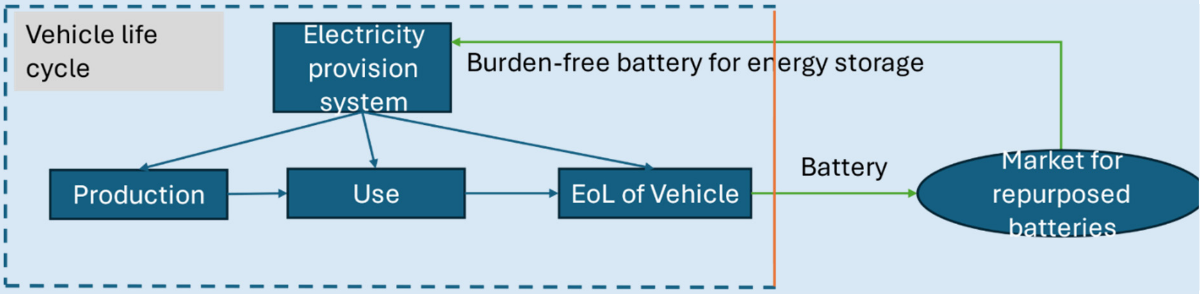


Figure A III-7: A way to consider the benefits of traction battery repurposing (for stationary applications) in the vehicle prospective life cycle assessment (pLCA for a vehicle).

III.5 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. TranSensus LCA does 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)).

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.

IV. Life Cycle Impact Assessment

The TranSensus LCA methodology standardizes key elements of Life Cycle Impact Assessment (LCIA), including impact categories, impact indicators, impact assessment methods, and normalization. The following sections provide a Mandatory and Optional list of impact categories and related assessment methods. This is followed by guidance on how to approach normalisation.

IV.1 Mandatory set of Impact Categories

The following list of mandatory environmental impacts categories, indicators and LCIA methods shall be applied and calculated, without exclusion (Table A IV-1). For those impact categories included in the EF methodology, the latest method must be used.

Table A IV-1: Mandatory environmental impact category list from TranSensus LCA.

Mandatory Impact Category	Impact Category Indicator	Unit	Characterization model	Present in EF
Climate change, total (see note 1 and note 2 below)	Radiative forcing as global warming potential (GWP100)	kg CO_2eq	Baseline model of 100 years of the IPCC 2021	Yes
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq.	LOTOS-EUROS model (Van Zelm *et al.*, 2008) as implemented in ReCiPe 2008	Yes
Acidification	Accumulated Exceedance (AE)	mol H^+ eq.	Accumulated Exceedance (Seppälä *et al.* 2006, Posch *et al.*, 2008)	Yes
Particulate matter (see note 3)	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP 2016)	Yes
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq.	EUTREND model (Struijs *et al.*, 2009) as implemented in ReCiPe	Yes
Cumulative Energy Demand (see note 4 and 5 below)	Renewable and non-renewable cumulative energy demand (CED)	MJ	Hischier *et al.*, 2010 Frischknecht *et al.*, 2015	No
Resource use, minerals and metals	Abiotic resource depletion for elements (ADP ultimate reserves)	kg Sb eq.	CML 2002 (Guinée *et al.*, 2002) and van Oers *et al.* 2002	Yes

Note 1: 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.

Note 2: It should be noted the biogenic climate change is currently not included in the EF methodology however should future iterations of the methodology include it this should be followed.

Note 3: There are three categories of PM which always include the smaller particles e.g., PM2.5 is a subset of PM10. So in order to avoid double counting a subtraction of PM values needs to be done.
Note 4: 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.
Note 5: 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 of TranSensus Deliverable 2.3.

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 (see section V.1.2).

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

1. 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 Table A III-4.
2. Use of GWP100 of 11.6 for characterising the impacts of hydrogen emissions for the sensitivity analysis (Sand et al., 2023).

In the future, if and when a formalised global warming potential (GWP) for hydrogen is adopted by the IPCC, within the EF method, or through the UNECE IWG, hydrogen emissions and their associated impacts are expected to be included by default in the Climate Change impact category. As a result, it may no longer be necessary to report hydrogen emissions as a mandatory indicator or to conduct a supplementary sensitivity analysis.

IV.2 Optional set of Impact Categories

The following list (Table A IV-2) of optional environmental impacts categories, indicators and LCIA methods may be applied. The latest version of EF should be used as relevant.

Table A IV-2: 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)
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte *et al.*, 2017)
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 (Frischknecht *et al.*, 2000)
Eutrophication, terrestrial	Accumulated Excedance (AE)	mol N eq.	Accumulated Exceedance (Seppälä *et al.*, 2006, Posch *et al.*, 2008)
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq.	EUTREND model (Struijs *et al.,* 2009) as implemented in ReCiPe
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fankte *et al.*, 2017)
Land use	- Soil quality index24 - 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 and Bos *et al.*, 2016)
Water use	User deprivation potential (deprivation-weighted water consumption)	m^3 world eq.	Available WAter REmaining (AWARE) as recommended by UNEP, 2016
Criticality	GeoPolRisk	kg Cu eq.	(Santillán -Saldivar *et al.*, 2022 and Koyamparambath *et al.*, 2024 [24])
Dissipation (See Note below)	Average Dissipation Rate (ADR) Environmental Dissipation Potential (EDP)	kg Fe eq. kg Cu eq.	Charpentier Poncelet *et al.*, 2021 and van Oers *et al.*, 2020

Note: 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 TranSensus LCA Deliverable 2.3.

As of the development of the TranSensus LCA guidelines (2024), biodiversity and circularity indicators are not yet be 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.

IV.3 Normalisation

Normalisation may be used in LCAs following the TranSensus LCA methodology. Global Planetary Boundary based normalisation factors, based on the scientific article by Sala, 2020, shall be used to perform normalisation. 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.

V. Interpretation

In the interpretation phase, the results of the LCA are analyzed, evaluated, and contextualized to derive clear conclusions in line with the study's goal and scope. This includes identifying key contributing processes, evaluating trade-offs between impact categories, and assessing the completeness, consistency, and relevance of the findings. To assess the robustness of the results, sensitivity and scenario analyses are also conducted to examine how methodological choices and input uncertainties may influence the outcomes. By integrating these insights, the interpretation phase ensures that the study supports informed decision-making and contributes to environmental improvements in the ZEV supply chain and product development.

V.1 Scenario analysis and sensitivity analysis

V.1.1 Definitions and methodology

Definitions are provided in Table A V-1.

Table A V-1: Definition of scenarios and sensitivity analysis in TranSensus LCA.

Analysis type	Definition	Example
Scenario analysis	Evaluation of storylines that determine variations in key parameters/assumptions of the model, typically in cases where parameters are correlated.	Exploring different energy mix scenarios.
Sensitivity analysis	Determines the influence of each parameter on the result, identifying the key drivers of change.	One-at-a-time (OAT) analysis on grid location.

1. Methodology for Analysis

To ensure robust LCA results, parameters are first categorized as mandatory, recommended, or optional. The appropriate analysis type—scenario, or sensitivity analysis—is then assigned. While mandatory and recommended parameters follow specific requirements, optional parameters remain at the practitioner's discretion.

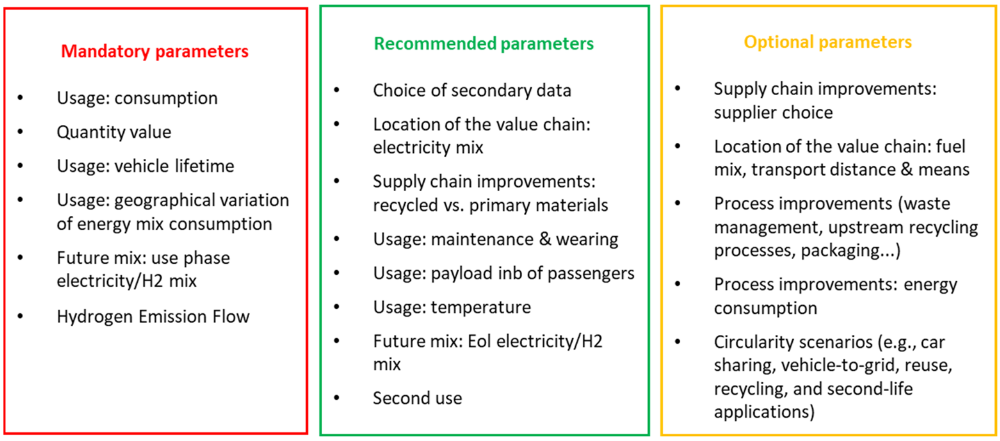


Figure A V-1 : Categorization in mandatory, recommended, and optional analysis of parameters.

Details on classifications and analysis methods are provided in the following subsections.

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.

V.1.2 Mandatory analysis of parameters

The five mandatory parameters shall be assessed as per the requirements. Table A V-2 summarizes the type of analysis that shall be followed for each, with detailed definitions and approaches provided in the following paragraphs.

Table A V-2: Summary of mandatory parameters with definitions, analysis types, and recommended approaches.

Parameter	Definition of Parameter	Analysis Type	Analysis Approach
IV.1.2.1 **Usage: Consumption**	The amount of energy consumed during the use phase of a vehicle	**Sensitivity analysis**	Assess how alternative values for energy consumption during vehicle usage affect LCA results. Consider real-world ranges for LDVs (e.g., WLTP vs. default) and drive cycles for HDVs (e.g., urban delivery, long haul). Follow guidance on dynamic electricity consumption modeling in Chapter II.2.
IV.1.2.2 **Quantity Value**	The amount of any LCI flow (e.g., material, energy input, or emissions) associated with foreground data[1]		Evaluate impact of minimum and maximum ranges for critical flows identified as hotspots. Derive ranges from literature or measurements. Certain activities or flows may be excluded if values are fixed, provided justification is given (e.g., vehicle-specific BOM).
IV.1.2.3 **Usage: vehicle lifetime**	The total operational lifespan of the vehicle, affecting cumulative environmental impacts.		Compare low and high values based on company data or literature. Ensure proper documentation of data sources. *For example, low values (e.g., 150,000 km for passenger cars) may be based on literature, while high values assume a 20% increase.*
IV.1.2.4 **Usage: Geographical variation of energy mix consumption**	Changes in the energy mix used during the vehicle's operational phase.	**Scenario analysis**	Explore scenarios with different national or renewable energy mixes, focusing on key markets or contrasting regions like Norway and Poland. *See Transensus LCA Deliverable 2.3 Annex, Table IV.3, for an example of sensitivity analysis on vehicle ifetime activity.*

Parameter	Definition of Parameter	Analysis Type	Analysis Approach
IV.1.2.5 **Future mix: use phase electricity/H_2 mix**	The projected electricity and hydrogen mix used in vehicle operation and EoL processes, considering the future national grid composition at the time of EoL.		Test scenarios with future projections (e.g., IEA's SDS). Account for evolving decarbonization trends for electricity and hydrogen. Estimation methodologies shall be based on Chapter II.2.2.2.
IV.1.2.6 **Hydrogen Emission Flow**	Emissions related to hydrogen production, distribution, and usage in the vehicle system, including potential hydrogen leakages throughout these stages.	**Sensitivity analysis**	Assess how variations in hydrogen emission flows influence the overall environmental profile. The H_2 supply mix composition under the alternative scenarios shall be estimated based on the methodology outlined for this (see chapter II.2.2.2).

V.1.3 Recommended analysis of parameters

The following seven parameters should be assessed to enhance the robustness of the LCA outcomes. These parameters address aspects such as data selection, geographic and operational variations, and evolving material flows. Table A V-3 summarizes the parameters, their definitions, recommended analysis types, and corresponding approaches for practitioners.

Table A V-3: Summary of recommended parameters, analysis types, and approaches.

Parameter	Definition of Parameter	Analysis Type	Analysis Approach
IV.1.3.1 Choice of secondary data	Selection from multiple datasets to represent LCI flows, where the decision is often arbitrary and adds uncertainty to results.	**Sensitivity analysis**	Perform a one-at-a-time sensitivity analysis by changing datasets for significant contributors (e.g., cobalt sulfate in battery manufacturing). Identify hotspots and justify dataset selection.
IV.1.3.2 Location of value chain: electricity mix	Evaluates how electricity mix variations in supply chains affect Life cycle environmental impacts, especially in average datasets.	**Scenario analysis**	Model alternative supply chains based on potential production locations (e.g., synthetic graphite from China vs. USA) by varying country-specific electricity mixes.
IV.1.3.3 Supply chain improvements: recycled vs. primary materials	Assessing the influence of recycled content in input materials on LCA results, as higher recycled content often reduces environmental impact intensity.		Compare scenarios with varying recycled content rates. Define minimum (regulatory targets or 0%) and maximum (industry best practices) scenarios. Justify material inclusion based on relevance and hotspot analysis.
IV.1.3.4 Usage: maintenance & wearing	Assessing how intensive use impacts maintenance and replacement needs.		Create scenarios for low vs. high maintenance. Include battery replacement scenarios if durability is estimated using simplified methods. Use lifecycle data (e.g., from Table II 3) to guide assumptions.
IV.1.3.5 Usage: payload/number of passengers	Evaluating the impact of payload (freight) or occupancy rate (passenger cars, buses, coaches) on functional unit and energy consumption.		Analyze scenarios with low and high payloads or occupancy rates (e.g., 1 vs. maximum passengers). Consider secondary effects like increased energy consumption due to higher payloads. Use typical ranges (e.g., 25%-100%) for freight vehicles and justify chosen scenarios.

Parameter	Definition of Parameter	Analysis Type	Analysis Approach
IV.1.3.6 Usage: temperature	Assessing the impact of ambient temperature effects on efficiency, range, and performance of components (e.g., battery)		Compare scenarios for different locations (e.g., Norway vs. Italy). Account for temperature effects on range, energy consumption, and inventory flows. Document assumptions transparently, such as annual average temperatures for key regions.
IV.1.3.7 Future mix: EoL electricity/ H_2 mix	Accounting for the effect of future electricity grid mixes at vehicle EoL on results, considering temporal evolution.		Model future electricity grid mixes based on official scenarios (e.g., EU Reference Scenario). Apply interpolation to estimate grid mix for EoL year. Build bespoke grid mix models in LCA tools (e.g., SimaPro) for critical EoL processes.
IV.1.3.8 Second use	Evaluating the effects of repurposing batteries for stationary applications.		Define best- and worst-case scenarios for the percentage of reusable cells (e.g., 10%-100%). Consider alternative approaches to default multifunctionality (e.g., substitution approach) to evaluate avoided emissions. Clearly document chosen methods and assumptions.

V.1.4 Optional analysis of parameters

The following parameters (Table A V-4) are optional and may be analysed based on stakeholder interest or relevance to the business context. These analyses aim to provide additional insights but require additional effort and may involve various methods (scenario or sensitivity analysis).

Table A V-4: Summary of optional parameters.

Parameter	Definition	Analysis type	Analysis approach
1. Supply chain improvements: supplier choice	Linked to decisions by OEMs to change suppliers for specific parts, materials, or components, potentially impacting LCA results.	**Scenario analysis**	Model alternative supplier scenarios based on variations in production methods, energy sources, and transport distances. Focus only on suppliers with significant impacts as identified in hotspot analyses.
2. Location of the value chain: fuel mix, transport distance & means	Changes in supplier location or factory location affecting transport means, distances, and fuel types.		Evaluate scenarios for relocating suppliers or factories. Consider impacts from new transport modes, distances, and regional fuel mixes. Adjust hotspot contributors and quantify the effects of changes on logistics emissions.
3. Process improvements (waste management, upstream recycling processes, packaging, etc.)	Optimizations related to renewable energy use, waste reduction, improved recycling, and material consumption reductions in manufacturing.		Assess energy and material savings from implementing process optimizations (e.g., installing solar panels, reducing packaging waste). Focus analysis on processes with high energy use or material intensity.
4. Circularity scenarios	Exploring circular economy strategies such as car-sharing models, vehicle-to-grid applications, enhanced recycling, or second-life applications.		Model scenarios for circular practices. For example, simulate avoided impacts from second-life applications by using substitution approaches. Justify assumptions and document potential avoided emissions or resource savings.

Parameter	Definition	Analysis type	Analysis approach
5. Process improvements: energy consumption	Energy efficiency improvements in manufacturing processes, which can significantly reduce environmental impacts.	**Sensitivity analysis**	Analyze the effects of reduced energy consumption in key processes. Use a one-at-a-time sensitivity analysis on energy-intensive steps and quantify the change in LCIA impacts.

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

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 development V-Model.

In the automotive industry, the V-model is a well-established development framework used to guide the design, integration, and validation of complex vehicle systems. It is particularly useful for managing the growing complexity of modern vehicles, which combine mechanical, electrical, software, and environmental aspects. The V-model represents the development process in a V-shaped diagram, where the left side of the "V" focuses on system design and decomposition, while the right side focuses on integration, testing, and validation.

The development process begins on the left side of the V, with high-level activities such as defining customer needs, regulatory requirements, and overall system specifications. From there, the system is gradually broken down into subsystems and components through successive levels of functional and architectural design. This process continues until the lowest level of detail is reached, such as the design of individual sensors, actuators, control units, or structural elements.

At the bottom of the V, the system enters the implementation phase, where individual components and subsystems are physically realized, manufactured, or coded. Moving up the right side of the V, each system element is then verified and validated in a bottom-up fashion.

In recent years, the V-model has also been expanded to incorporate sustainability assessments, such as Life Cycle Assessment (LCA). This integration of environmental assessment within the V-model helps ensure that sustainability is considered throughout the vehicle development lifecycle.

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

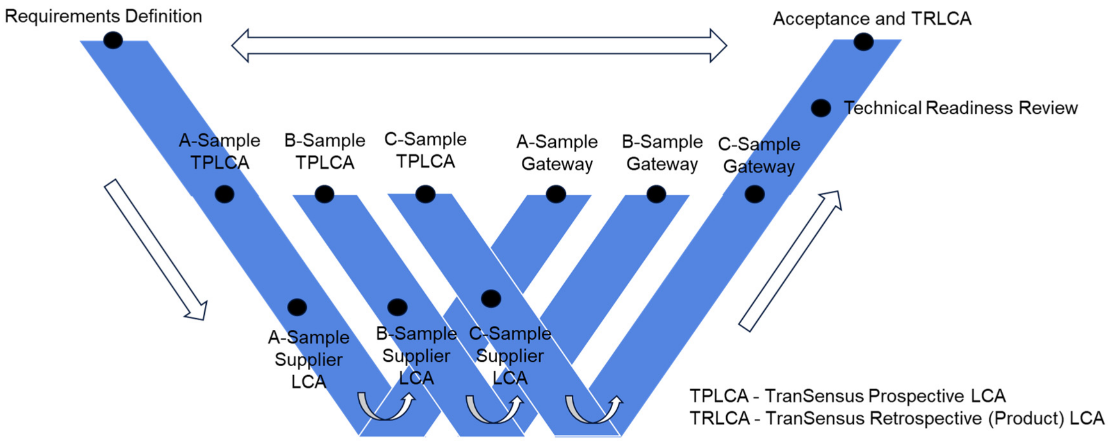


Figure V-1: TranSensus-LCA Calculations within Product Development Process.

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 be 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.

PART B: Social Life Cycle Assessment (S-LCA)

While the primary focus of TranSensus LCA is on environmental LCA (E-LCA), the project has also developed recommendations for the application of Social LCA (S-LCA) as a complementary methodology. The S-LCA framework follows four key phases: Goal and Scope, Inventory Analysis (S-LCI), Impact Assessment (S-LCIA/S-LCPA), and Interpretation, each defining essential steps for evaluating social impacts following ISO 14075. However, it is important to note that Prospective S-LCA and Fleet S-LCA are outside the scope of TranSensus LCA discussions.

TranSensus LCA developed the foundational elements of TranSensus S-LCA primarily based on:

- The UNEP Guidelines for Social Life Cycle Assessment of Products and Organization's (2020) as the primary reference.
- ISO 14075, where applicable, as it provides additional principles and frameworks for S-LCA.

The TranSensus guideline for S-LCA provides a framework that references the four phases of S-LCA but does not offer detailed, step-by-step procedures for conducting S-LCA of ZEVs. To gain a comprehensive understanding of the step-by-step processes, practitioners should thoroughly study and comprehend the recommended standards and guidelines, as well as documentation from S-LCA databases and related software. This approach ensures that users have a solid foundation in S-LCA methodology before applying the TranSensus framework to their specific ZEV assessments.

Whilst the S-LCA is not mandatory, should the practitioner choose to follow it, then they must apply the requirements as defined (mandatory, recommended, optional).

VI. S-LCA Goal and scope

In this phase, the overall objectives for the S-LCA are clearly defined. These objectives guide the entire study, focusing on key aspects like the application of S-LCA, stakeholder identification, and system boundaries.

The definitions listed in the Goal and Scope of Part A: E-LCA (Part A: II) for the Goal, Functional Unit, System Boundary, and Technology Coverage should be used for S-LCA as well. Functional unit description includes vehicle types, default lifetime km, full-service lifetime in years. These definitions must be comparable to or equivalent to those in LCA to create consistency between both methodologies.

VI.1 Application of S-LCA

S-LCA studies related to ZEVs can serve various purposes, including:

- Assessing social performance, social impacts or social risks in the product life cycle.
- Informing decision-making for stakeholders.
- Identifying social hotspots in the product life cycle.
- Enhancing sustainability reporting of products by companies.
- Comparing alternatives in vehicle design, materials, or technologies.
- Improving supply chain management to address social risks.
- Supporting policy development and regulations for sustainable mobility.

VI.2 Selection of Activity Variable

Worker hours should be used as the activity variable for S-LCA studies following the TranSensus LCA methodology. While this choice provides methodological advantages, it also has limitations. Therefore, any future adaptation of the activity variable should be monitored and properly documented. Different results attributed to the choice of the activity variable can allow further analysis as part of the interpretation.

VI.3 Defining the Geographical Scope

S-LCA studies should adopt a global geographic scope, rather than a regional focus, for several key reasons:

- Complexity of international supply chains involved in ZEV production.
- Sourcing of raw materials from diverse global locations.
- Comprehensive assessment of social impacts across stakeholders.

For ZEVs in Europe, the S-LCA geographical scope should still be defined as global, ensuring that all upstream and downstream impacts are considered in a harmonized way.

VII. Social Life Cycle Inventory Analysis

The focus of this phase is to gather data on the social inventory across the ZEV life cycle, from raw material extraction to the end-of-life. Key areas to consider in Social Life Cycle Inventory (S-LCI):

- Collecting data related to Stakeholder Categories, which can include Workers, Local Communities, and Society and corresponding Impact Subcategories (see section III.1.1 for mandatory impact subcategories).
- Data Sources: Primary data or using reliable databases such as PSILCA and SHDB to gather data on possible social risk assessment and collect data specific to worker hours across the lifecycle.
- Collecting complementary data for the Reference Scale Approach

In parallel to the LCI section for E-LCA, modelling for production, use and end-of-life stages should be followed (See subsections II.1, II.2 and II.3 in Part A respectively). For the production stage (subsection II.1), the guideline highlights on data requirements for Level 3 analysis and electric energy supply in manufacturing. This includes detailed instructions on collecting primary data from manufacturers and using secondary data, when necessary, as well as emphasizing the importance of region-specific grid mixes and accounting for renewable energy sources.

The use stage modelling (subsection II.2) addresses estimating energy requirements for vehicles, WTT modelling, maintenance, and non-exhaust emissions. This section focuses on inventory data associated to a product's operational life, including energy consumption patterns and potential component replacements. End-of-life stage modelling (subsections II.3) covers data choices and electric energy supply specific to this phase. It outlines approaches for modelling different scenarios.

It is also recommended that, in the future, a system to collect primary data for social LCA shall be put in place at least for the most critical components of ZEVs, such as Batteries and electronics, consistent with Regulation (EU) 2023/1542.

VII.1 Collecting inventory data for Impact subcategories and related Indicators

A diverse range of data is required to assess various impact subcategories. As an example, for Workers Stakeholder Category, data may consider data for indicators related to subcategories such as: health and safety, fair wage, forced labour, child labour, discrimination, working hours and so on (UNEP, 2020). This could involve quantitative data such as the number of workplace accidents or qualitative data like the presence of formal equal opportunity policies. The data collection process for S-LCA could involves a combination of site-specific information, generic data from databases, and both quantitative and qualitative inputs. This may include company records, stakeholder interviews, industry reports, and government statistics. It's important to note that while some data can be quantitative (e.g., number of jobs created), many social impacts require qualitative assessment, which need qualitative definition in the reference scale. The data collected should align with the defined subcategories and indicators for each stakeholder group, as outlined in the S-LCA guidelines and UNEP methodological sheet.

VII.2 Data Collection to create the Reference Scales

For reference scale assessments, data is needed to establish social performance of indicators and subcategories, those are defined as performance reference points (PRPs). These PRPs are often based on international standards, local legislation, or industry best practices. The data collection process should be designed to gather information needed for creating the reference scales, which typically use a multi-point system (e.g., a 5-point scale) to assess social performance or social risks.

For S-LCA studies, practitioners should prioritize using general RSs derived from best practice and scientific literature. When available, product- or sector-specific reference scales tailored to ZEVs or related industries should be employed, as they account for unique social risks and stakeholder concerns inherent to specialized sectors. If such tailored RS frameworks do not exist (which is currently the case), new reference scales should be developed by aligning with international regulations (e.g., ILO conventions, UN Guiding Principles on Business and Human Rights) and national laws governing labor rights, health and safety, and community engagement, as well as industry-specific standards and norms. This ensures compliance with legal requirements and ethical benchmarks while addressing the full scope of the ZEV value chain—from raw material extraction and manufacturing to use-phase operations and end-of-life management. The hierarchy of using general RS frameworks first, followed by sector-specific ones, and finally developing custom scales grounded in regulatory frameworks promotes methodological consistency and enhances the credibility of S-LCA outcomes.

For Social Risk Assessment, databases such as SHDB and PSILCA can be used.

VII.3 Multifunctionality

The hierarchy proposed in Part A: section III.4.2 shall be used to solve any multifunctionality problem encountered in the model except for the multifunctionality that might arise in the EoL of the product. The proposed hierarchy for addressing multifunctionality in LCA establishes a clear order of preference for different methodological approaches. Subdivision is given the highest priority, recognizing its ability to separate processes and avoid allocation issues altogether. System expansion is recommended as the second-best option, followed by substitution as the third choice. Allocation methods are positioned as the last resort, to be used only when the other approaches are not feasible. See more details regarding each method use in section II.4.1.

The EoL stage of vehicles and batteries often presents multifunctionality challenges in S-LCA. To address this complexity, the cut-off method, also known as the “recycled content” or “100:0” approach shall be used (see more details in Part A: section III.3).

VII.4 Data for activity variable stakeholders and impact subcategory

To establish worker hours as the activity variable in S-LCA, three types of data are required:

- Modelling Data: Ensures that the life cycle is fully covered and provides the basis for defining study boundaries and scope.
- Working Time Data: Determines the number of worker hours per process, a critical metric in S-LCA.

TranSensus LCA follows three approaches to collect data for activity variables:

1. Site-specific data collection for direct measurement.
2. Use of S-LCA-specific databases when a risk assessment is performed (e.g., SHDB, PSILCA).

3. Input-output or other general databases (World Bank, UNICEF, Eurostat) to supplement missing data.

Whenever possible, site-specific data should be used, as it provides the most accurate and relevant information for assessments.

To evaluate the activity variable for S-LCA, various types of data are needed. The activity variable serves as a quantitative weighting for each process in the product's life cycle. This data is crucial when proxy of social inventory data at company level are only available to scale them to the functional unit of the study.

For example, when assessing the social impacts of a BEV life cycle, data on working hours in mining raw materials and components manufacturing would be required. These activity variables help in quantifying the relative importance of each process in the overall life cycle. The data needed for activity variables can be both generic and site-specific. Generic data might come from industry averages or national statistics, while site-specific data would be collected directly from the processes involved in the product system. For instance, a company producing electronics might use industry-average worker hours for raw material extraction but collect precise data on worker hours in their own manufacturing facilities.

VII.5 Data Quality Assessment

The quality of data obtained should be assessed based on criteria such as reliability, timeliness, geographic and technical compliance, and completeness. These indicators may be scored using ordinal evaluation rules (e.g., 1 to 5). TranSensus LCA recommends using the Pedigree Matrix from the Guidelines for Social Life Cycle Assessment of Products and Organisations 2020 to ensure a structured and standardized data quality evaluation.

VIII. Social Life Cycle Impact Assessment

The third phase focuses on translating the inventory data into social impacts and/or social performance. Similarly to E-LCA, there are two levels of impact categories: mandatory (Table B VIII-1) and optional (Table B VIII-2).

VIII.1 Calculation of S-LCIA results

The Reference Scale Approach (RS S-LCIA) is the most used method for hotspot analysis, risk assessment, and performance evaluation in S-LCA and should be used for TranSensus LCA. Practitioners using databases such as PSILCA and SHDB in assessing risk assessment can utilize the reference scales provided within these tools.

For a TranSensus-compliant S-LCA study, all mandatory subcategories shall be calculated using the corresponding assessment method, with no exclusions. The detailed, step-by-step process for evaluating individual indicators within each impact subcategory falls beyond the scope of this guideline. For a comprehensive understanding of these procedures, practitioners are advised to read and understand the previously mentioned guidelines and standards. Impact pathway approach should be used once it is mature.

For a practical application of S-LCA in the context of BEVs, readers should refer to the case study presented in TranSensus LCA Deliverable 3.3. This document provides a real-world example of how these frameworks are applied in the assessment of BEVs.

VIII.1.1 Mandatory set of Impact Subcategories

The mandatory impact subcategories, as specified in Table B VIII-1, shall be used.

Note: All data sources in this table are from PSILCA, except for the Stakeholder Category: Society, which is sourced from Social Hotspots Database (SHDB). If these databases are unavailable, select equivalent indicators from alternative sources.

Table B VIII-1: Mandatory social impact subcategory list from TranSensus LCA.

Stakeholder Category	Mandatory Impact Subcategory	Impact Subcategory Indicator	Unit	Reference Scale Model
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

	Child Labour	Children in employment, total	% of all children ages 7-14 in employment	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
	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
	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
	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
	Working Hours	Weekly hours of work per employee	hr/week and person	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
	Health and Safety	Rate of fatal accidents at workplace and Rate of non-fatal accidents at workplace	No. fatal No. non-fatal	
Local Community	Respect of Indigenous Rights	Presence of indigenous population	Y/N	0 = no = no risk: 1 = yes = medium risk
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)

VIII.1.2 Optional set of Impact Subcategories

The optional subcategories enhance analysis flexibility. While not required, their inclusion provides broader insight into social impacts. Table B VIII-2 lists these optional subcategories. As these subcategories are optional practitioners may choose appropriate indicators as relevant.

Table B VIII-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

IX. Social Life Cycle Interpretation

The final phase focuses on analysing results, identifying significant issues, and drawing actionable conclusions. For ZEVs, this includes:

- Comparing social impacts of different ZEV technologies.
- Assessing the social sustainability of transitioning to electric mobility.
- Providing recommendations to enhance social performance across the ZEV life cycle.

TranSensus LCA suggests the following parameters for result interpretation in the following table:

- 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 phase.

The interpretation of S-LCA results for zero-emission vehicles, involves several key parameters as suggested by TranSensus LCA as mentioned above. These parameters help identify hotspots and provide a comprehensive understanding of the social impacts across the vehicle's life cycle.

Quantity values for specific components, materials, or flows are crucial in pinpointing hotspots in the supply chain. For BEVs, this could involve examining the social impacts associated with, for example, battery production, including raw material extraction and processing. For BEVs, this could involve analysing the social impacts of cobalt mining for battery production. For instance, as an example, a study might find that 60% of the child labour risks in the product life cycle are associated with cobalt extraction in the Democratic Republic of Congo.

The geographical variation of the value chain can be particularly important, as it highlights how social risks differ across regions involved in vehicle production, from mining locations to manufacturing sites. As an example, an S-LCA study might reveal that while final assembly of a BEV in Germany has low social risks, the lithium mining in Chile for battery production presents significant concerns regarding certain impacts on local communities.

The choice of activity variable, such as working hours versus value added, can significantly influence the assessment results, potentially altering the perceived importance of different life cycle stages. As an example, using working hours as the activity variable might emphasize the social impacts of labour-intensive processes like vehicle assembly, while using value added might highlight the importance of high-value components like the battery management system.

Variations in assumptions regarding social data can affect the overall assessment, emphasizing the need for robust and consistent data sources. As an example, changing assumptions about working conditions in rare earth element mining for electric motors (e.g., from "average" to "poor" conditions) could significantly alter the overall social risk profile of the BEV.

Price-related factors for processes or materials play a role in understanding the economic context of social impacts. As an example, fluctuations in the price of lithium could affect the economic stability of mining communities. A price increase might lead to better wages but could also intensify exploitation of resources.

For BEVs, the geographical variation of energy consumed during usage, including electricity mix considerations, is crucial in assessing the social implications of vehicle operation in different regions. As an example, a BEV charged in Norway (with its predominantly hydroelectric grid) would have a different social impact profile compared to one charged in Poland (with a coal-dominated grid), potentially affecting issues like occupational health in energy production.

The quantity of energy consumed during the use phase directly relates to the vehicle's efficiency and its long-term social impacts. As an example, a more efficient BEV consuming less energy over its lifetime might reduce the social impacts associated with electricity generation, such as reduced exposure to health risks for power plant workers and the society at large.

PART C: Reporting

Transparent and consistent reporting is essential to ensure the understandability and indirect comparability of studies following TranSensus LCA. The following subsections outline the key reporting requirements, covering LCA results, methodological choices, and supporting information. By adhering to these guidelines, practitioners can provide clarity on the assumptions, data, and decisions that shape their assessments, maintaining alignment with the TranSensus LCA framework.

X. TSLCA Adherence statement

A product LCA shall claim adherence to the TranSensus LCA methodology at one of two levels: A or B. Based on a full LCA report, Practitioners are encouraged to target profile A, which represents full adherence, but profile B is available for cases where external constraints limit reporting capabilities; the profiles are presented in Table C X-1.

X.1 Adherence Levels

Table C X-1: Adherence Levels and Compliance Criteria in TranSensus LCA.

Adherence Level	Criteria
Level A – "Following the full TranSensus LCA methodology".	- All mandatory requirements (*including* those on public reporting) shall be followed. - Requirements with no choices shall be strictly followed. - Requirements with choices shall have their selection publicly reported, with results, documentation, and justifications provided for verification. - Recommended requirements may or may not be followed.
Level B – "Following the TranSensus LCA methodology, reporting excluded".	- All mandatory requirements from TSLCA (*excluding* those on public reporting) shall be followed. - Requirements with no choices shall be strictly followed. - Requirements with choices shall have their selection documented, with results, documentation, and justifications provided for verification. - At least one mandatory public reporting requirement is not followed. - Recommended and optional requirements may or may not be followed.

X.2 Compliance Summary

Table C X-2 details the criteria for TranSensus-LCA adherence levels A and B, outlining the percentage of mandatory and recommended/optional requirements that must be met for each phase.

Table C X-2: Description of two levels of adherence, A and B, to TSLCA that can be claimed.

	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< T< 100%	0% to 100%

("%" refers to % of TSLCA requirements that are strictly followed, and for which any methodological choices (where allowed) are made transparently and with justification)
(Bmin is the minimum required for B adherence level. For each item, requirement or not for B adherence level is described in the list of all reporting requirements Chapter XI.4)

Note: Public reporting includes both a full LCA report and a public summary.

X.3 Exceptions & Best Practices

Mandatory requirements to claim "Using best practices from TranSensus LCA methodology" when neither Level A nor Level B is met are:

- The methodology **shall** be cited,
- A list of best practices followed and/or deviations **shall** be included in a public annex.

This applies to all cases, including Prospective LCA, OEM fleet LCA, and Macro fleet LCA, where strict adherence to Level A or B is not feasible.

XI. Result display and public reporting

To ensure clarity and indirect comparability of studies claiming with TranSensus LCA, the following types of information must be reported:

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

XI.1 Results of the LCA study

The TSLCA methodology provides:

- Absolute impact values scaled to the functional unit (FU).
- Normalization results (if applicable).
- Contribution analysis (sources of impacts).
- Comparisons and scenario analysis.
- Sensitivity analysis.

XI.2 Choices made along the application of TranSensus LCA methodology

The TranSensus LCA methodology includes mandatory, recommended, and optional requirements, some allowing practitioner choices or deviations. This variability prevents direct comparisons but enables indirect comparisons through normalization to a chosen reference. Transparency in these choices is essential to ensure clarity and comparability.

XI.2.1 Requirements for Reporting Choices

Practitioners must publicly report all required choices in public communications, such as LCA reports or summaries. Each choice must be justified ("why?") and documented ("how?") for verification, although justification/documentation may only be shared with verifiers unless otherwise stated. Table C XI-1 details the content of the information to be publicly reported for some key requirements.

Table C XI-1: Detailed content for some reporting requirements for TranSensus LCA choices.

Category	Content of Reporting
Functional Unit (FU) lifetime values	Report choice of default or deviation for lifetime kilometers per segment for passenger cars and LCVs. Specify if segment-based or generic values were used. Explicitly disclose deviations from default values. ***Recommended:*** Include additional rationale for deviations to improve report understanding.
System Boundary: cut-off	Report the choice between default (no intentional cut-off) or a cut-off approach allowing less than 3% impacts.
Production Stage Modelling	Identify tier-1 company specific data as requested for a level 3 LCA. Report the parts (e.g., car body, rims) contributing to 20% of the supply chain GWP, excluding the detailed BOM. Disclose the choice of modelling approach for electric energy supply: location-based, 100% market-based, or mixed. Detail safeguards used for EACs, including synchronization frequency (hourly, monthly, yearly). Specify whether residual mixes are modelled using coordinating entity-prescribed characteristics or national mixes excluding renewables/nuclear. State whether on-site electricity production processes were verified hourly or yearly. ***Recommended:*** Provide simplified diagrams illustrating production stage modelling choices. ***Optional:*** Include detailed energy use for production sub-processes.

Use Stage Modelling	Report the choice of energy requirement calculations: OEM-specific data or default values from LDV CO_2 regulations or UNECE A-LCA. Specify the choice of degradation factor calculation methodology. For WTT electricity, report the use of dynamic or static modelling and the selected future grid scenario including supply mix. For WTT hydrogen, disclose the chosen supply mix scenario and composition. For non-exhaust hydrogen emissions, report whether official, supplier-specific, or default estimates were used.
End-of-Life Stage Modelling	Report the choice of data source: company-specific or generic secondary data.
Multifunctionality Problems	Report the approach for production and use stage multifunctionality. Provide a table summarizing the chosen methods without including allocation factors or economic values. For end-of-life, disclose whether market value or preset cut-off points were used for typical waste streams.
Hydrogen Emission Flow	Report the choice between using a default approach or integrating H_2 emissions into the GWP indicator. If H_2 emissions are integrated into GWP, provide supporting references. Disclose whether a sensitivity analysis was conducted or integrated directly into the GWP indicator.

XI.3 Supporting information

In addition to reporting the results and methodological choices made in the implementation of TranSensus LCA, additional supporting information of the LCA is also expected to be publicly disclosed to ensure clarity and indirect comparability of studies claiming compliance with TranSensus LCA.

XI.4 List of all reporting requirements

A full list of reporting requirements for LCA results, methodological choices, and supporting information is summarized in Table C XI-2. Each requirement is categorized as mandatory (M), recommended (R), or optional (O).

Information type: Specifies whether the information relates to LCA results (Re), methodological choices (Ch), or supporting information (Si).

- Type: Indicates the requirement level (M, R, or O).
- Reference: The specific TranSensus LCA reference code for traceability (e.g, Si-M1: is the first mandatory supporting information requirement).

Table C XI-2: 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
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, standing passenger capacity), 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

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
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	H_2 storage capacity (kg H_2)	M	x		Supporting Information (Si)	Si-M21
Vehicle description	H_2 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
Functional unit (FU)	Lifetime km per segment (Passenger car & LCV) – Choice: default or other values – 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
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
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
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-/exclusion 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
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
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
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
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
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 CO_2 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
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
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

Use stage modelling	WTT - Hydrogen - general guidance - Choice: scenario selection for the future evolution of H_2 supply (official published, official based on current policy, H_2 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 H_2 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
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
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

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
Multifunctionality problems	Approach for production and use stage - Choice:- The multifunctionality choices based on the hierarchy (substitution/system expansion/economic/ physical allocation) for each multifunctional processes reported above in the foreground system (table format recommended, no need of details like allocation factor 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 calculation economic value for allocation	M	x	x	Choice within TSLCA (Ch)	Ch-M18

Multifunctionality problems	Approach for end-of-life - Choice: use of market value determined or preset cut-off points for typical waste streams	M	x	x	Choice within TSLCA (Ch)	Ch-M19
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
Mandatory set of impacts categories	Hydrogen (H_2) emission flow- Choice: default approach or integration into GWP indicator and reference supporting it	M	x	x	Choice within TSLCA (Ch)	Ch-M20
Mandatory set of impacts categories	Hydrogen (H_2) emission flow - Choice: Sensitivity analysis of the impact of H_2 emissions on GWP of H_2 fuelled ZEVs or direct integration	M	x	x	Choice within TSLCA (Ch)	Ch-M21

Mandatory set of impacts categories	Hydrogen (H_2) 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
Normalization	Normalization results	O			LCA results (Re)	Re-O2
Normalization	Confirmation of planetary boundaries NF used if normalised results are shown	M	x		Supporting Information (Si)	Si-M57
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	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
Contribution analysis	Main hotspots by life cycle stage contribution to mandatory impacts results (like battery+electricity for production, electricity/H_2 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, and sensitivity (s.) analysis	Brief description of type and parameters studied through sensitivity and scenario analysis.	M	x		Supporting Information (Si)	Si-M58
Sc. and s. analysis	Qualitative summary of influence of all mandatory parameters on mandatory impact results	M	x		LCA results (Re)	Re-M5
Sc. and s. analysis	Variability (quantification expected) induced by all mandatory parameters on all mandatory impact results	M	x		LCA results (Re)	Re-M6

Sc. and s. analysis	Qualitative summary of influence of all mandatory parameters on relevant optional impact results	R			LCA results (Re)	Re-R5
Sc. 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
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

XII. Verification process

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

XII.1 Verification Levels

Verification is aligned with the UNECE Level Concept and is tailored based on the complexity and intended use of the study, as detailed in the table below.

- Level 3 or 4 (UNECE):
  - Requires 3rd party verification.
  - Must follow the ISO 14040/44 type and format for extensive reporting.
  - A detailed checklist must accompany the verification process, aligned with TSLCA adherence principles.
- Level 1 or 2 (UNECE):
  - May use 1st party or 2nd party verification (as per Catena-X definition)

XII.2 Definitions of Verification Parties

The following definitions of 1st, 2nd and 3rd party (Catena-X, adaptation from ISO 17029[29]) shall be used:

- 1st Party: Conducted by personnel from the same organization (e.g., supplier's in-house verification).
- 2nd Party: Conducted by personnel from an organization that is a customer of the supplier.
- 3rd party: Conducted by personnel from an organization or company that is neither a supplier, customer, nor competitor.

Additionally, prospective LCA, OEM fleet LCA, and macro fleet LCA may also undergo 1st, 2nd, or 3rd party verification to ensure alignment with the methodology.

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

XIII. Summary of all TranSensus LCA requirements

Table C *XIII-1* provides a summary of the E-LCA TranSensus LCA requirements, categorized by LCA phase and topic. It outlines whether each requirement is Mandatory (M), Recommended (R), Optional (O), or Informational (I), and specifies if deviations are allowed with Documentation & Justification (D&J).

- Requirement Type: Indicates the level of obligation (M, R, O, I).
- Deviation Allowance: Specifies whether deviations are permitted and under what conditions (D&J means deviations are allowed only if properly documented and justified).
- Reference: Links each requirement to a specific identifier for easy tracking.

This table serves as a quick reference for users to understand and apply the TranSensus LCA framework effectively.

Table C XIII-1: List of TranSensus LCA requirements.

				Type of requirement: (✓)choice required Mandatory (M), Recommended (R), Optional (O) or Informational (I)		Documentation for verification		
#	**Phase of LCA**	**Topic**	**Requirement**	**Type**	**Deviation allowance**		**Reference**	**Document Link**
1	Goal & scope	Goal definition	LCA types	I			I1	II.1
2	Goal & scope	Technology coverage	List of powertrains	I			I2	II.2
3	Goal & scope	Technology coverage	List of vehicle types	I			I3	II.2
4	Goal & scope	Functional unit	Functional units according to vehicle types	M			M1	II.3
5	Goal & scope	Functional unit	Default lifetime km per segment (Passenger car & LCV)	M✓	Process to justify other values Segmentation deviation	(D&J)	M2	II.3.1

					allowed for OEMs			
6	Goal & scope	Functional unit	Default lifetime km per segment (HDV)	**M**			M3	II.3.1
7	Goal & scope	Functional unit	Default lifetime km per segment (two-wheelers)	**M**			M4	II.3.1
8	Goal & scope	Functional unit	Default full-service lifetime in years per vehicle type	**M**✓	Other values allowed if documented & justified	(D&J)	M5	II.3.2
9	Goal & scope	Functional unit	Default distribution of yearly driven distance for passenger cars, LCVs and HDVs in case dynamic modelling is chosen for use stage	R	Not to be used in case of static modelling for use stage		R1	II.3.2
10	Goal & scope	Functional unit	Deviations for Prospective LCA	R		D&J	R2	II.3
11	Goal & scope	Functional unit	Deviations for Macro-fleet LCA	R		D&J	R3	II.3
12	Goal & scope	System boundary	Cradle-to-grave	**M**			M6	II.4
13	Goal & scope	System boundary	List of default processes to include and exclude	**M**			M7	Table A II-8
14	Goal & scope	System boundary	Default Cut-off	**M**✓	If <3% of impacts & screening LCA documented	(D)	M8	II.4
15	Goal & scope	System boundary	Deviations for Prospective LCA	R		D&J	R4	II.4
16	Goal & scope	System boundary	Deviations for Macro-fleet LCA	R		D&J	R5	II.4
17	Goal & scope	OEM fleet LCA	Passenger cars	R		D&J	R6	A1.
18	Goal & scope	OEM fleet LCA	HDV	R✓	Adaptation allowed if justified and documented	D&J	R7	A1.
19	Goal & scope	OEM fleet LCA	Two-wheelers	R✓	Adaptation allowed if justified and documented	D&J	R8	A1.
20	LCI	Production stage modelling	Data requirements for level 3	**M**✓	- Allowance to choose which parts to model	D&J	M9	III.1.1

					with company-specific data with an iterative approach. - H_2 storage vessel (FCEV, FC-REEV, H_2-ICEV) may be treated similarly to batteries			
21	LCI	Production stage modelling	Electric energy supply - time consistency	**M**		D&J	M10	III.1.2.1
22	LCI	Production stage modelling	Electric energy supply - modelling approach choice	**M**✓	For industries wanting to use their EACs	(D&J)	M11	III.1.2.2
23	LCI	Production stage modelling	Electric energy supply - same modelling approach for comparative LCAs	**M**			M12	III.1.2.2
24	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA - general approach	R		D&J	R9	III.1.2.2
25	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA - Use of PREMISE to model future electricity mixes	O		D&J	O1	III.1.2.2
26	LCI	Production stage modelling	Electric energy supply - follow all safeguards for EACs use	**M**			M13	III.1.2.3
27	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - additionality	**M**		D&J	M14	III.1.2.3.1
28	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - geographical consistency	**M**		D&J	M15	III.1.2.3.2
29	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - time consistency	**M**✓	Synchronization frequency	D&J	M16	III.1.2.3.3
30	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - excess of production	**M**		D&J	M17	III.1.2.3.4
31	LCI	Production stage modelling	Electric energy supply - safeguards for EACs use - others	**M**		D&J	M18	III.1.2.3.5

32	LCI	Production stage modelling	Electric energy supply - every safeguards for EACs use - verification by practitioner along its LCA	R			R10	III.1.2.3
33	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	III.1.2.4
34	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA of guidance for residual mixes modelling	R		D&J	R11	III.1.2.4
35	LCI	Production stage modelling	Electric energy supply - on-site electricity production processes	M✓	Frequency basis of the consumption proof	D&J	M20	III.1.2.5
36	LCI	Production stage modelling	Electric energy supply - deviations for Prospective LCA for on-site electricity production processes	R		D&J	R12	III.1.2.5
37	LCI	Use stage modelling	Energy requirements of vehicles - default approach	M	Other cycles to estimate energy consumption allowed in additional sensitivity analysis		M21	III.2.1
38	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	III.2.1.1
39	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	III.2.1.2

40	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	III.2.2.1
41	LCI	Use stage modelling	WTT - Electricity - same modelling approach for comparative LCAs	M			M25	III.2.2.1
42	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	D&J	R13	III.2.2.1

					approach allowed if there is a hypothesis of use of PPAs			
43	LCI	Use stage modelling	WTT - Electricity - deviation for prospective LCA - Use of PREMISE to model future electricity mixes	O			O2	III.2.2.1
44	LCI	Use stage modelling	WTT - Electricity - on-site electricity production processes excluded	**M**			M26	III.2.2.2
45	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	R14	III.2.2.2
46	LCI	Use stage modelling	WTT - Electricity - on-site electricity production processes - deviation for prospective LCA	R		D&J	R15	III.2.2.2
47	LCI	Use stage modelling	WTT - Hydrogen - general guidance	**M**✓	- Allowance to choose between 4 prioritized scenario selection for the future evolution of H_2 supply - Allowance to use a H_2 produced with natural gaz compared to low-carbon H_2 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	III.2.2.3
48	LCI	Use stage modelling	Non-exhaust emissions - hydrogen leakage	**M**✓	Allowance to use default H_2		M28	III.2.3.1

					supply chain emission rates in the absence of official governmental or supplier-specific information			
49	LCI	Use stage modelling	Non-exhaust emissions - refrigerant with GWP≥150kgCO₂eq/kg	**M**		D	M29	III.2.3.2
50	LCI	Use stage modelling	Non-exhaust emissions - refrigerant with GWP<150kgCO₂eq/kg	O		D	O3	III.2.3.2
51	LCI	Use stage modelling	Non-exhaust emissions - tyres and Brake wearing	**M**	Allowance to other data than EMEP if justified	D&J	M30	III.2.3.3
52	LCI	Use stage modelling	Maintenance - mandatory items to include	**M**	Allowance to exclude if no replacement needed	J	M31	Table A III-5
53	LCI	Use stage modelling	Maintenance - recommended items to include	R			R16	Table A III-5
54	LCI	Use stage modelling	Maintenance - mandatory items to include - battery or fuel cell replacement calculation method	**M**✓	- 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	M31b	III.2.4.1
55	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	III.3.1

56	LCI	End-of-life stage modelling	Electric energy supply for EoL - general guidance	M		D&J	M33	III.3.2
57	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	R18	III.3.2.1
58	LCI	End-of-life stage modelling	Electric energy supply for EoL - use of PREMISE to model future electricity mixes	O			O4	III.3.2.1
59	LCI	End-of-life stage modelling	Electric energy supply for EoL - on-site electricity production excluded	M			M34	III.3.2.2
60	LCI	Multifunctionality problems	Three-step approach to identify multifunctionality problems	R			R19	III.4
61	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	D&J	M35	III.4.2

					global/regional market prices are unavailable. - Physical relationship based allocation if economic value ration ≤ 4 and relevant			
62	LCI	Multifunctionality problems	Approach for production and use stage - deviation for both fleet-level LCA	R			R20	III.4.2
63	LCI	Multifunctionality problems	Approach for production and use stage - deviation for prospective LCA	O			O5	III.4.2
64	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	0
65	LCI	Multifunctionality problems	Approach for end-of-life - deviation for prospective LCA	R			R21	0
66	LCI	Multifunctionality problems	Approach for end-of-life - deviation for both fleet-level LCA	R			R22	0
67	LCI	Data quality rating (DQR)	Conduct a data quality assessment	**M**			M37	III.5
68	LCI	Data quality rating (DQR)	Apply same DQR method as background database	R			R23	III.5
69	LCIA	Mandatory impact categories	Climate change, total	**M**			M38	Table A IV-1
70	LCIA	Mandatory impact categories	Photochemical ozone formation, human health	**M**			M39	Table A IV-1
71	LCIA	Mandatory impact categories	Acidification	**M**			M40	Table A IV-1
72	LCIA	Mandatory impact categories	Particulate matter	**M**			M41	Table A IV-1
73	LCIA	Mandatory impact categories	Eutrophication, freshwater	**M**			M42	Table A IV-1

74	LCIA	Mandatory impact categories	Cumulative Energy Demand	M			M43	Table A IV-1
75	LCIA	Mandatory impact categories	Resource use, minerals and metals	M			M44	Table A IV-1
76	LCIA	Mandatory impact categories	Hydrogen (H_2) emission flow	M✓	Until a formalised GWP is available according to IPCC/within the EF method		M45	IV.1
77	LCIA	Mandatory impact categories	Default estimated H_2 supply chain emission rates	M✓	Supplier-specific information available		M46	Table A III-4
78	LCIA	Mandatory impact categories	Sensitivity analysis of the impact of H_2 emissions on GWP of H_2 fuelled ZEVs	M✓	Until a formalised GWP is available according to IPCC/within the EF method		M47	IV.1
79	LCIA	Optional Impact Categories	Ozone depletion	O			O6	Table A IV-2
80	LCIA	Optional Impact Categories	Human toxicity, cancer	O			O7	Table A IV-2
81	LCIA	Optional Impact Categories	Human toxicity, non-cancer	O			O8	Table A IV-2
82	LCIA	Optional Impact Categories	Ionising radiation, human health	O			O9	Table A IV-2
83	LCIA	Optional Impact Categories	Eutrophication, terrestrial	O			O10	Table A IV-2
84	LCIA	Optional Impact Categories	Eutrophication, marine	O			O11	Table A IV-2
85	LCIA	Optional Impact Categories	Ecotoxicity, freshwater	O			O12	Table A IV-2

86	LCIA	Optional Impact Categories	Land use	O			O13	Table A IV-2
87	LCIA	Optional Impact Categories	Water use	O			O14	Table A IV-2
88	LCIA	Optional Impact Categories	Criticality	O			O15	Table A IV-2
89	LCIA	Optional Impact Categories	Dissipation	O			O16	Table A IV-2
90	LCIA	Optional Impact Categories	Biodiversity indicators not recommended	R✓	Robust indicator available		R24	IV.2
91	LCIA	Optional Impact Categories	Circularity indicators not recommended	R✓	Robust indicator available		R25	IV.2
92	LCIA	Normalisation	Normalisation	O			O17	IV.3
93	LCIA	Normalisation	Global Planetary Boundary based normalization factors	R			R26	IV.3
94	LCIA	Normalisation	Normalized values reported after midpoints values	R			R27	IV.3
95	Interpretation	Scenario (Sc.) analysis, uncertainty (u.) analysis and sensitivity (s.) analysis	Definition of scenario, sensitivity and uncertainty analysis	I			I4	V.1.1
96	Interpretation	Sc., u. and s. analysis	Deviations for Prospective LCA and fleet LCA	O			O18	V.1.1
97	Interpretation	Sc., u. and s. analysis	List of parameters to analyse with the type of requirement (mandatory, recommended or optional)	I			I5	Figure A V-1
98	Interpretation	Mandatory analysis of parameters	Summary of manadatory parameter with mandatory type of analysis	I			I6	Table A V-2
99	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Usage: consumption"	**M**			M48	Table A V-2
100	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Usage: consumption"	R			R28	Table A V-2

101	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Quantity value"	**M**			M49	Table A V-2
102	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Quantity value"	R	Fixed LCI values may be excluded if justified	(J)	R29	Table A V-2
103	Interpretation	Mandatory analysis of parameters	Sensitivity analysis of "Usage: vehicle lifetime"	**M**		D	M50	Table A V-2
104	Interpretation	Mandatory analysis of parameters	Approach for the sensitivity analysis of "Usage: vehicle lifetime"	R			R30	Table A V-2
105	Interpretation	Mandatory analysis of parameters	Scenario analysis of "Usage: variation of energy mix consumption"	**M**			M51	Table A V-2
106	Interpretation	Mandatory analysis of parameters	Approach for the scenario analysis of "Usage: variation of energy mix consumption"	R		D&J	R31	Table A V-2
107	Interpretation	Mandatory analysis of parameters	Future electricity/H_2 mix for the use stage	**M**			M52	Table A V-2
108	Interpretation	Mandatory analysis of parameters	Approach for the scenario analysis of "Future electricity/H_2 mix for the use stage "	R			R32	Table A V-2
109	Interpretation	Recommended analysis of parameters	Summary of recommended parameter with recommended type of analysis	I			I7	Table A V-3
110	Interpretation	Recommended analysis of parameters	Sensitivity analysis of "Choice of secondary data"	R			R33	Table A V-3
111	Interpretation	Recommended analysis of parameters	Approach for the sensitivity analysis of "Choice of secondary data"	R	Data availability	J	R34	Table A V-3
112	Interpretation	Recommended analysis of parameters	Scenario analysis of "Location of the value chain: electricity mix"	R			R35	Table A V-3
113	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	R36	Table A V-3

114	Interpretation	Recommended analysis of parameters	Scenario analysis of "Supply chain modifications: recycled vs primary materials"	R			R37	Table A V-3
115	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Supply chain modifications: recycled vs primary materials"	R		D&J	R38	Table A V-3
116	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: maintenance & wearing"	R			R39	Table A V-3
117	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Usage: maintenance & wearing"	R	Data availability		R40	Table A V-3
118	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: payload or number of passengers"	R			R41	Table A V-3
119	Interpretation	Recommended analysis of parameters	Minimal approach for the scenario analysis of "Usage: payload or number of passengers"	R			R42	Table A V-3
120	Interpretation	Recommended analysis of parameters	Advanced approach for the scenario analysis of "Usage: payload or number of passengers"	O	Data availability		O19	Table A V-3
121	Interpretation	Recommended analysis of parameters	Scenario analysis of "Usage: temperature"	R			R43	Table A V-3
122	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Usage: temperature"	R		D	R44	Table A V-3
123	Interpretation	Recommended analysis of parameters	Scenario analysis of "Future mix: EoL electricity mix"	R			R45	Table A V-3
124	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Future mix: EoL electricity mix"	R			R46	Table A V-3
125	Interpretation	Recommended analysis of parameters	Scenario analysis of "Second use"	R			R47	Table A V-3
126	Interpretation	Recommended analysis of parameters	Approach for the scenario analysis of "Second use"	R	Alternatives to cut-off approach allowed		R48	Table A V-3
127	Interpretation	Optional analysis of parameters	Summary of recommended parameter with recommended type of analysis	I	Approach left open to practitioner		I8	Table A V-4

128	Interpretation	Integration into the product development process with Prospective LCA	Frontloading LCA approach	R			R49	V.2
129	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 'List of all reporting requirements'. More information allowed.		M53	Table C XI-2
130	Interpretation	Result display and public reporting	Recommended results of the LCA study to report publicly (Re-R1 to Re-R6 of reporting list)	R			R50	Table C XI-2
131	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	Table C XI-2
132	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	Table C XI-2
133	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	Table C XI-2
134	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	Table C XI-2

135	Interpretat ion	Result display and public reporting	Public reporting of recommended choices along TSLCA application	R			R51	Tabl e C XI-2
136	Interpretat ion	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.		M5 6	Tabl e C XI-2
137	Interpretat ion	Result display and public reporting	Public reporting of recommended supporting information per LCA phase (Si-R1 to Si-R13 of reporting list)	R			R52	Tabl e C XI-2
138	Interpretat ion	Result display and public reporting	Public reporting of optional supporting information per LCA phase (Si-O1 to Si-O7 of reporting list)	O			O22	Tabl e C XI-2
139	Interpretat ion	Adherence to TSLCA	Adherence levels to target	R			R53	X
140	Interpretat ion	Adherence to TSLCA	Conditions to claim adherence levels for Product LCA	**M**			M5 7	X
141	Interpretat ion	Adherence to TSLCA	Adherence statement for prospective and fleet LCA	R			R54	X
142	Interpretat ion	Verification process	3rd party verification for Level 3 or 4 (UNECE) product LCA	**M**			M5 8	XII
143	Interpretat ion	Verification process	1st or 2nd party verification for Level 1 or 2 (UNECE) product LCA	R			R55	XII
144	Interpretat ion	Verification process	Verification process for prospective and fleet LCA	O			O23	XII

XIV. Result display and Public Reporting S-LCA

S-LCA reporting shall follow common aspects with LCA reporting (e.g., FU or MF) and include the following recommendations:

- The type and format of the report shall be defined during the scope phase.
- S-LCA results must be conveyed clearly, accurately, and without bias.
- Conclusions, data, techniques, assumptions, and limitations shall be presented transparently, with enough detail for understanding.
- Graphical representations of S-LCI and S-LCIA data may be included but be cautious of inferred comparisons.
- Confidential data may be included in study documentation, with third-party reports referencing it.

The third-party report shall include:

1. **General Aspects:**
   - S-LCA commissioner and practitioner.
   - Date and confirmation of adherence to TranSensus LCA approach.
   - Modifications to Goal and Scope with justification.
2. **Goal of the Study:**
   - Reasons, applications, target audiences, and whether it supports public social comparative assertions.
3. **Scope of the Study:**
   - Performance characteristics, functional unit, system boundaries, inputs/outputs, and assumptions.
4. **Inputs and Outputs:**
   - Criteria for including mass, energy, and environmental cut-off criteria.
5. **Social Life Cycle Inventory (S-LCI) Analysis:**
   - Data collection procedures, data validation, sensitivity analysis, and allocation methods.
6. **Reference Scale Assessment (if applicable):**
   - Procedures, calculations, limitations, impact categories, and value-choices.

7. **Social Life Cycle Impact Assessment (S-LCIA) (if applicable):**
    - Procedures, calculations, impact categories, assumptions, and results interpretation.
8. **Life Cycle Interpretation:**
    - Results, assumptions, limitations, value-choices, and expert judgments.
9. **Critical Review (if applicable):**
    - Reviewers, reports, and responses to recommendations.

By following these guidelines, reporting shall ensure transparency, clarity, and consistency in presenting the S-LCA results.

XV. Summary of TranSensus requirements for S-LCA

A summary of the TranSensus LCA requirements for S-LCA is presented in Table C XV-1.

Table C XV-1: List of TranSensus LCA requirements for S-LCA.

				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**	**Document Link**
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	VI
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	VI
147	S-LCA Goal & Scope	Activity variable	Worker hours	R			R58	VI.2
148	S-LCA Goal & Scope	Guideline	ISO 14075	R	when accessible		R59	
149	S-LCA Goal & Scope	Geographical scope	Global geographical scope	R			R60	VI.3
150	S-LCI	Modelling	Same production phase modelling, use stage modelling, EoL stage modelling as for TSLCA E-LCA	R			R61	VII

151	S-LCI	Reference scales	Reference scales established by PSILCA and SHBD. In the future: product or sector-specific reference scale	R			R62	VII.2
152	S-LCI	Multifunctionality	Co-products to be handled with the same TSLCA procedure as for E-LCA	R			R63	VII.3
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	VII.4
154	S-LCI	DQR	Specify certain relevant characteristics of data quality to evaluate the quality of data obtained	O			O24	VII.5
155	S-LCI	DQR	Rating of the defined indicators and criteria	O			O25	VII.5
156	S-LCI	DQR	Pedigree Matrix based on Guidelines for S-LCA of products and organisation 2020	R			R65	VII.5
157	S-LCIA	Mandatory Impact subcategory	Workers/Freedom of association and collective bargaining	**M**			M59	Table B VIII-1
158	S-LCIA	Mandatory Impact subcategory	Workers/Child Labour	**M**			M60	Table B VIII-1

159	S-LCIA	Mandatory Impact subcategory	Workers/Fair salary	**M**			M61	Table B VIII-1
160	S-LCIA	Mandatory Impact subcategory	Workers/Social Benefits/Social Security	**M**			M62	Table B VIII-1
161	S-LCIA	Mandatory Impact subcategory	Workers/Forced Labour	**M**			M63	Table B VIII-1
162	S-LCIA	Mandatory Impact subcategory	Workers/Working Hours	**M**			M64	Table B VIII-1
163	S-LCIA	Mandatory Impact subcategory	Workers/Health and Safety	**M**			M65	Table B VIII-1
164	S-LCIA	Mandatory Impact subcategory	Local community/Respect of Indigenous Rights	**M**			M66	Table B VIII-1
165	S-LCIA	Mandatory Impact subcategory	Society/Corruption	**M**			M67	Table B VIII-1
166	S-LCIA	Optional Impact subcategories	Workers/Equal opportunities/discrimination	R			R66	Table B VIII-2
167	S-LCIA	Optional Impact subcategories	Workers/Sexual harassment	R			R67	Table B VIII-2
168	S-LCIA	Optional Impact subcategories	Local community/Cultural Heritage	R			R68	Table B VIII-2
169	S-LCIA	Optional Impact subcategories	Local community/Delocalization and migration	R			R69	Table B VIII-2
170	S-LCIA	Optional Impact subcategories	Local community/Community engagement	R			R70	Table B VIII-2
171	S-LCIA	Optional Impact subcategories	Value chain actors/Fair competition	R			R71	Table B VIII-2
172	S-LCIA	Optional Impact subcategories	Value chain actors/Supplier relationships	R			R72	Table B VIII-2

173	S-LCIA	Optional Impact subcategories	Value chain actors/Respect of intellectual property rights	R			R73	Table B VIII-2
174	S-LCIA	Optional Impact subcategories	Value chain actors/Wealth distribution	R			R74	Table B VIII-2
175	S-LCIA	Optional Impact subcategories	Consumer/Health and safety	R			R75	Table B VIII-2
176	S-LCIA	Optional Impact subcategories	Consumer/Consumer privacy	R			R76	Table B VIII-2
177	S-LCIA	Optional Impact subcategories	Consumer/Transparency	R			R77	Table B VIII-2
178	S-LCIA	Optional Impact subcategories	Society/Prevention and mitigation of armed conflicts	R			R78	Table B VIII-2
179	S-LCIA	Optional Impact subcategories	Society/Ethical Treatment of Animal	R			R79	Table B VIII-2
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	VIII.1
181	S-LCIA	Normalization and weighting	Not to be applied	R			R81	VIII
182	S-LCA Interpretation	Results display	Quantity value for certain components/materials/flows leading to hotspots	R			R82	IX
183	S-LCA Interpretation	Results display	Geographical variation of the value chain	R			R83	IX

184	S-LCA Interpretation	Results display	Choice of the activity variable (e.g., working hour vs. value added)	R			R84	IX
185	S-LCA Interpretation	Results display	Variation of assumptions on social data	R			R85	IX
186	S-LCA Interpretation	Results display	Price related to process or materials	R			R86	IX
187	S-LCA Interpretation	Results display	Geographical variation of the energy consumed (electricity mix or H_2 mix) during usage	R			R87	IX
188	S-LCA Interpretation	Results display	Quantity of energy consumed during the use phase	R			R88	IX
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 for the reader to understand the intricacies and trade-offs	**M**			M70	

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	

PART D: Perspectives

XVI. Perspectives

This section briefly outlines areas for future improvement and further research.

XVI.1 Functional unit

The default values for lifetime distance are based on data for ICEV since data for ZEV is not available yet. The default values must be reviewed and updated when robust data specific to ZEV becomes available.

The default values for lifetime years 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).

XVI.2 Tyre and break wear

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.

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).

.

XVI.3 Electricity Modelling

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.

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.

XVI.4 Multifunctionality

The Circular Footprint Formula (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 Vehicle to Everything (V2X) cases since these technologies are expected to become more relevant in the future.

References

Accardo, A., Dotelli, G., Miretti, F., Spessa, E., 2023. End-of-Life Impact on the Cradle-to-Grave LCA of Light-Duty Commercial Vehicles in Europe. Appl. Sci. 13, 1494. https://doi.org/10.3390/APP13031494/S1

AR5 Climate Change 2013: The Physical Science Basis — IPCC

Beck, T., Bos, U., Wittstock, B., Baitz, M., Fischer, M. & Sedlbauer, K., 2010. LANCA Land Use Indicator Value Calculation in Life Cycle Assessment - Method Report.

Beddows, D.C.S., Harrison, R.M., Gonet, T., Maher, B.A. & Odling, N., 2023. Measurement of road traffic brake and tyre dust emissions using both particle composition and size distribution data. Environmental Pollution, Volume 331, Part 1. https://doi.org/10.1016/j.envpol.2023.121830

Bos, U., Horn, R., Maier, S., Beck, T., 2016b. LANCA® - Characterization Factors for Life Cycle Impact Assessment, Version 2.3. November 2016. Available at: http://ibpgabi.de/files/lanca_characterisation_factors_v2-3.pdf.

Boulay, A.-M., Pfister, S., Motoshita, M., Schenker, U., Benini, L., Gheewala, S. H., … Harding, K., 2016. Global Guidance for Life Cycle Impact Assessment Indicators, Chapter 5a: Water scarcity. UNEP SETAC Life Cycle Initiative.

Charpentier Poncelet, A., Helbig, C., Loubet, P., Beylot, A., Muller, S., Villeneuve, J., Laratte, B., Thorenz, A., Tuma, A. & Sonnemann, G., 2021. Life cycle impact assessment methods for estimating the impacts of dissipative flows of metals. Journal of Industrial Ecology, 10.1111/jiec.13136

Cooper, J., Dubey, L., Bakkaloglu, S. & Hawkes, A., 2022. Hydrogen emissions from the hydrogen value chain-emissions profile and impact to global warming. Science of The Total Environment.

DeRousseau, M., Gully, B., Taylor, C., Apelian, D., Wang, Y., 2017. Repurposing Used Electric Car Batteries: A Review of Options. JOM 69, 1575–1582. https://doi.org/10.1007/s11837-017-2368-9

Dreicer, M., Tort, V. & Manen, P. ExternE, Externalities of Energy, Vol. 5. Nuclear, Centre d'e´tude sur l'Evaluation de la Protection dans le domaine Nucle´aire (CEPN), edited by the European Commission DGXII, Science, Research and Development JOULE, Luxembourg, 1995

Dun, C., Horton, G., & Kollamthodi, S. (2015). Improvements to the definition of lifetime mileage of light duty vehicles – Report for European Commission – DG Climate Action. Report for European Commission – DG Climate Action, 1. https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ldv_mileage_improvement_en.pdf

EC-JRC, 2010. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment – Detailed Guidance. Publications Office. https://doi.org/10.2788/38479

EEA, 2023. EMEP/EEA air pollutant emission inventory guidebook 2023. European Environment Agency. https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023

European Commission, 2023. Vehicle Energy Consumption calculation TOol - VECTO. https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/vehicle-energy-consumption-calculation-tool-vecto_en

European Parliament, 2021. Setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (pp. 1–50)

European Parliament, 2023. Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC.

European Union, 2021. EN 15804+a2: Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products Vervangt NEN-EN 15804:2012+A1:2013; NEN-EN 15804:2012+A1:2013/Ontw. A2:2018 ICS 91.010.99 november 20 2.

Fantke, P., Bijster, M., Guignard, C., Hauschild, M., Huijbregts, M., Jolliet, O., Kounina, A., Magaud, V., Margni, M., McKone, T.E., Posthuma, L., Rosenbaum, R.K., van de Meent, D. & van Zelm, R., 2017. USEtox® 2.0 Documentation (Version 1), http://usetox.org

Frischknecht R., Wyss F., Knöpfel B. S., Lützkendorf T. & Balouktsi M. (2015) Cumulative energy demand in LCA: the energy harvested approach. International Journal of Life Cycle Assessment, 20:957–969

Frischknecht, R., Braunschweig, A., Hofstetter, P. & Suter, P., 2000. Human health damages due to ionising radiation in life cycle impact assessment. Environmental Impact Assessment Review, 20(2).

Giechaskiel, B., Grigoratos, T., Dilara, P., Karageorgiou, T., Ntziachristos, L. & Samaras, Z., 2024. Light-Duty Vehicle Brake Emission Factors. Atmosphere, 15. https://doi.org/10.3390/atmos15010097

Giechaskiel, B., Grigoratos, T., Mathissen, M., Quik, J., Tromp, P., Gustafsson, M., Franco, V. & Dilara, P., 2024. Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution. SUSTAINABILITY, 16(2).

Guinée, J.B., Heijungs, R., Huppes, G., 2004. Economic Allocation: Examples and Derived Decision Tree. International Journal of Life Cycle Assessment, 9, 23–33. https://doi.org/10.1007/BF02978533

Guinée, J.B., Marieke, Gorrée; Reinout, H.:, Huppes, G., Kleijn, R., Van Oers, L., Koning, A. de;, Anneke, W.S., Suh, S., De, H.A.U., de Bruijn, H., & Huijbregts, M., 2002. Handbook on Life Cycle Assessment: Operational Guide to the ISO standards.

Guinée JB, Heijungs R, Frischknecht R (2021) Multi-functionality in Life Cycle Inventory Analysis: Approaches and Solutions. In: LCA Compendium – The Complete World of Life Cycle Assessment Ciroth A, Arvidsson R (eds).

Hicks, W., Green, D.C. & Beevers, S., 2023 Quantifying the change of brake wear particulate matter emissions through powertrain electrification in passenger vehicles. Environmental Pollution. https://doi.org/10.1016/j.envpol.2023.122400

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T., 2010. Implementation of Life Cycle Impact Assessment Methods. Ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf

ISO, 2006. ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework. International Standards Organisation.

ISO, 2006. ISO 14044:2006 Environmental mangement - Life cycle assessment - Requiremenets and guidelines. International Standards Organisation.

ISO, 2024. ISO 14075:2024 Environmental management - Principles and framework for social life cycle assessment. International Standards Organisation.

Joint Research Center of the European Commission. (2024). *Model SIBYL*. https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-sibyl/

Koffler, C. & Finkbeiner, M., 2018. Are we still keeping it “real”? Proposing a revised paradigm for recycling credits in attributional life cycle assessment. International Journal of Life Cycle Assessment, 23:181–190. https://doi.org/10.1007/s11367-017-1404-x

Koyamparambath, A., Loubet, P., Young, S.B. & Sonnemann, G., 2024. Spatially and temporally differentiated characterization factors for supply risk of abiotic resources in life cycle assessment. Resources, Conservation and Recycling. https://doi.org/10.1016/j.resconrec.2024.107801

Posch, M., Seppälä, J., Hettelingh, J.P., Johansson, M., Margni, M. & O. Jolliet, O., 2008. The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. International Journal of Life Cycle Assessment 13(6): 477-486.

Provost-Savard, A., Majeau-Bettez, G., 2024. Substitution modeling can coherently be used in attributional life cycle assessments. Journal of Industrial Ecology, 28:410–425. https://doi.org/10.1111/JIEC.13480

Ricardo, TEPR & E3M Lab, 2018. Assessing the impacts of selected options for regulating CO2 emissions from new passenger cars and vans after 2020. https://climate.ec.europa.eu/system/files/2018-03/ldv_post_2020_co2_en.pdf

Ricardo. (2019). Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles.

Sacchi, R., Terlouw, T., Siala, K., Dirnaichner, A., Bauer, C., Cox, B., Mutel, C., Daioglou, V., Luderer, G., 2022. PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2022.112311

Sand, M., Skeie, R.B., Sandstad, M., Krishnan, S., Myhre, G., Bryant, H., Derwent, R., Hauglustaine, D., Paulot, F., Prather, M. & Stevenson, D. 2023. A multi-model assessment of the Global Warming Potential of hydrogen. Communication Earth & Environment.

Santillán-Saldivar, J., Gemechu, E., Muller, S., Villeneuve, J., Young, S. B. & Sonnemann, G., 2022. An improved resource midpoint characterization method for supply risk of resources: integrated assessment of Li-ion batteries. International Journal of Life Cycle Assessment, 27:457–468. https://doi.org/10.1007/s11367-022-02027-y.

Schrijvers, D.L., Loubet, P., Sonnemann, G., 2016. Critical review of guidelines against a systematic framework with regard to consistency on allocation procedures for recycling in LCA. International Journal of Life Cycle Assessment, 21:994–1008. https://doi.org/10.1007/s11367-016-1069-x

Seppälä, J., Posch, M., Johansson, M. & Hettelingh, J.P., 2006. Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. International Journal of Life Cycle Assessment 11(6): 403-416.

Sala, S., Crenna, E., Secchi, M. & Sanyé-Mengual, E., 2020. Environmental sustainability of European production and consumption assessed against planetary boundaries. Journal of Environmental Management. doi:https://doi.org/10.1016/j.jenvman.2020.110686

Struijs, J., Beusen, A., van Jaarsveld, H., Huijbregts, M.A.J., 2009. Aquatic eutrophication. Chapter 6. In: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (Eds.), ReCiPe 2008 a Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level. Report I: Characterisation factors, first edition).

The European Parliament, 2000. Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.

Charbouillot, T., Cettour Janet, D., Schaal, P., Beynier, I., Boulat, J-M., Grandchamp, A. & Biesse, F., 2023. Methodology for the direct measurement of tire emission factors. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2022.160853

UNEP Annual Report 2016 | UNEP - UN Environment Programme

van Oers, L., Koning, A de, Guinée, J.B. & Huppes, G., 2002. Abiotic resource depletion in LCA - improving characterisation factors fro abiotic depletion as recommended in the new Dutch LCA Handbook

van Oers, L., Guinée, J.B., Heijungs, R. et al., 2020. Top-down characterization of resource use in LCA: from problem definition of resource use to operational characterization factors for dissipation of elements to the environment. International Journal of Life Cycle Assessment, 25:2255–2273. https://doi.org/10.1007/s11367-020-01819-4 van Zelm, R. and Huijbregts, M.A.J. and den Hollander, H.A. and van Jaarsveld, H.A. and Sauter, F.J. and Struijs, J. and van Wijnen, H.J. and van de Meent, D., 2008. European characterization factors for human health damage of PM10 and ozone in life cycle impact assessment. Atmospheric Environment, 42(3):441-453, 10.1016/j.atmosenv.2007.09.072.

Volvo Cars, 2024. Carbon footprint report: EX30 [WWW Document]. URL https://www.volvocars.com/images/v/-/media/Project/ContentPlatform/data/media/sustainability/volvo_ex30_carbonfootprintreport_A4.pdf

Zink, T. & Geyer, R., 2017. Circular Economy Rebound. Journal of Industrial Ecology. 21, 593–602. https://doi.org/10.1111/JIEC.12545

Zink, T., Geyer, R., Startz, R., 2018. Toward Estimating Displaced Primary Production from Recycling: A Case Study of U.S. Aluminum. Journal of Industrial Ecology. 22:314–326. https://doi.org/10.1111/JIEC.12557

Zink, T., Geyer, R., Startz, R., 2016. A Market-Based Framework for Quantifying Displaced Production from Recycling or Reuse. Journal of Industrial Ecology. 20:719–729. https://doi.org/10.1111/JIEC.12317

Appendix

A1. 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.

Passenger cars and light commercial vehicles

The OEM fleet LCA should be used by OEMs to report the life cycle carbon emissions of their fleet in a specific year and geographical area. It should be tracked and reported in absolute CO_2 equivalent emissions (tonne CO_2 eq.) or in tonne CO_2 eq./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. 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_2 eq./km, conventional ICEVs with e.g., 103 g CO_2 eq./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, i.e. vehicles that have been sold before the reporting period. 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 tonne CO_2 eq./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 found 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 (see Figure A1-1).

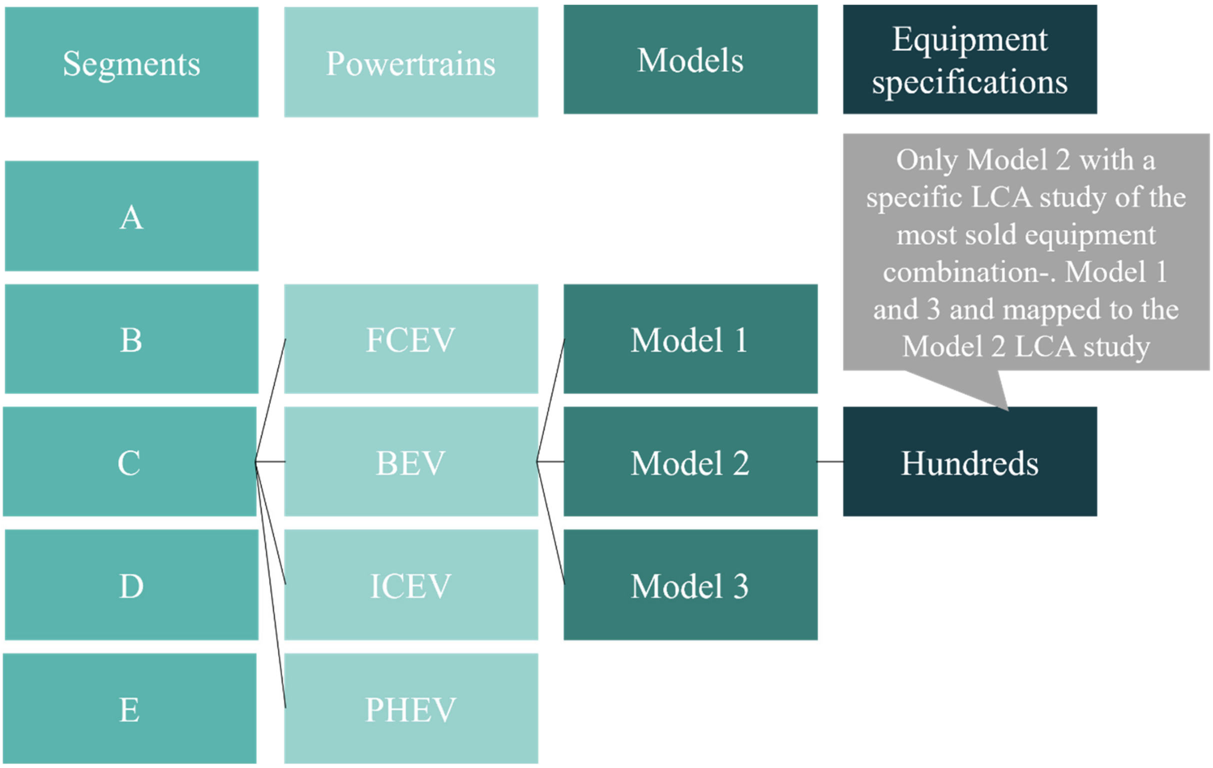


Figure A1-1: Minimum criterion for performed OEM fleet LCAs: one vehicle LCA per powertrain-segment combination of the most sold model with respective equipment.

Vehicles without a specific LCA are mapped to existing ones with the following hierarchy:

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

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.

The modelling results for the production and EoL stages are then adjusted based on curb weight differences, as shown in an example in Figure A1-2:

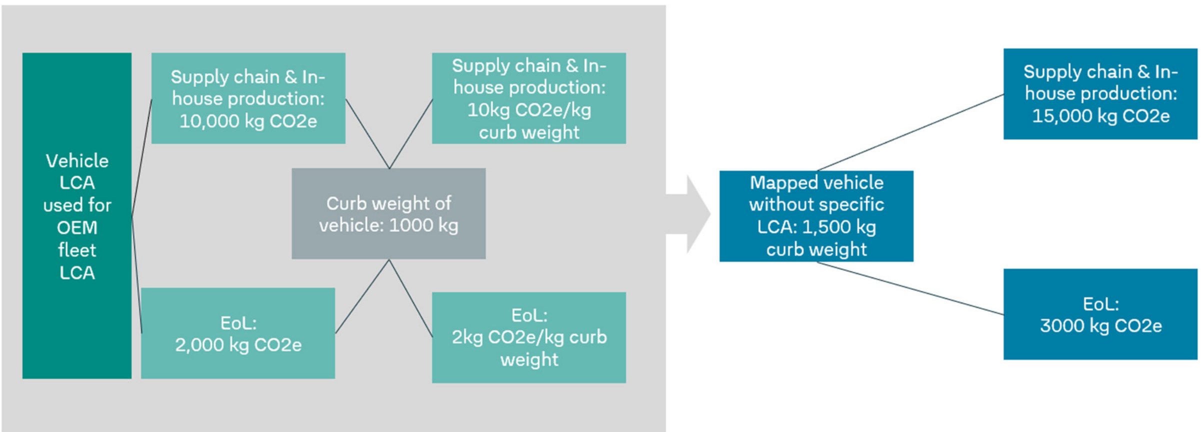


Figure A1-2: Process to adjust vehicle LCAs based on the curb weight.

To sum it up, the process shown in Figure A1-3 is used to reach the OEM fleet level (example given for GWP). Data sources and assumptions should be sufficiently documented and justified.

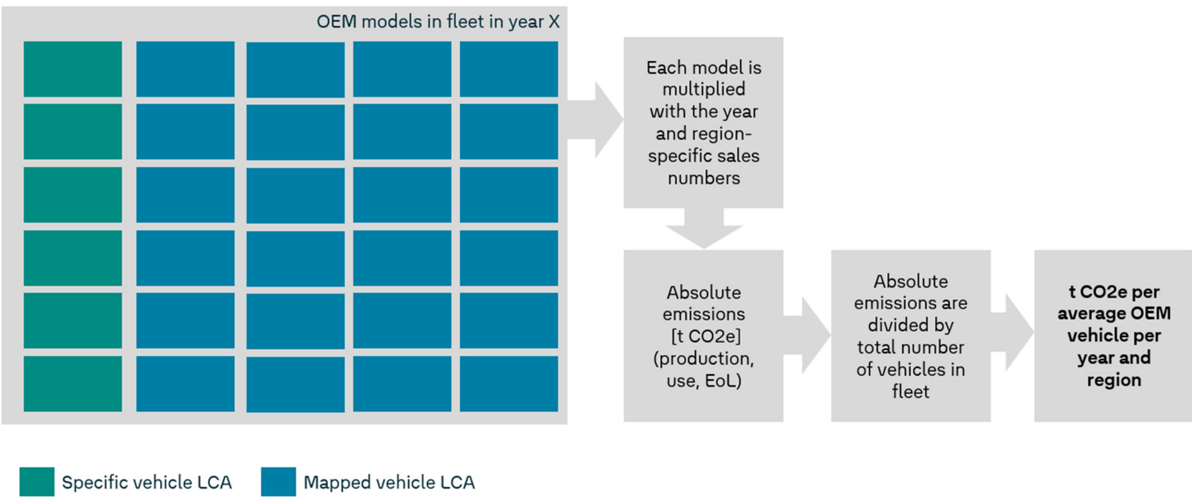


Figure A1-3: Summary of process for the OEM fleet LCA for passenger cars and LCVs.

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. Results from the VECTO tool (used for EU fuel consumption and CO_2 emission certification) can be for example used for this second option. However, a vehicle should never be presented in comparison with a vehicle from another/different VECTO vehicle certification group. Adaptions may be made where necessary with sufficient documentation and justification.

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.