**Towards a European-wide harmonised transport-specific LCA Approach**

# TranSensus LCA

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# EXECUTIVE SUMMARY


In recent years, automobile manufacturers have conducted a variety of LCAs on zero emission vehicles and batteries, both internally and for the public. Even for the same product, subjectivity can lead to truly diverse results depending on critical modelling choices, such as choosing the functional unit or choosing the electricity grid mix. As a consequence, these differences hinder the use of these studies for further decision making, as they complicate the comparability of results and make conclusions less reliable.

In this context, a consensus is required to establish a single European harmonized approach for applying LCA to zero emission road transport where all stakeholders can calculate, monitor, communicate, and make decisions with a common basis. In order to achieve such consensus, the TranSensus LCA project brings together a broad array of influential European stakeholders in zero-emission mobility, encompassing the entire value chain for electric vehicles and batteries. In order to address climate change and prevent burden shifting to other environmental issues, TranSensus LCA aims at enabling industry, mobility providers, and planners to provide sustainable products and optimise mobility solutions.

As a first step to create a common ontology for an LCI database for the road transport sector and the battery value chain, this report will discuss the concept of ontology. It will provide a basic overview of ontologies, their necessity, design options, languages, and tools, as well as a discussion of the current state of the art. The main chapter describes the TranSensus LCA ontology (TLCAO), starting from existing ontologies to nomenclature and taxonomy to data formats and data exchange. Providing detailed descriptions of the intended domain and scope, specific elements included like the decomposition tree, S-LCA, as well as an outline of possibilities on implementation and usage.

An ontology is a formal structure for organizing, classifying, defining, and linking data. Concepts are described and their relationships are represented in ontologies. Ontologies facilitate data integration, interoperability, and knowledge reuse. It is emphasized that building on existing ontologies would reduce workload and increase connectivity and consistency. In the ORIENTING project, environmental, social, and economic aspects are taken into account in developing a Life Cycle Sustainability Assessment. ORIENTING has developed the ORIONT ontology for structuring fundamental methodological and data elements. This ontology is used as a baseline for TLCAO and adapted where needed.

To understand how a product is related and associated with its components, hierarchical structures, or taxonomies, are of great importance. In order to ensure unambiguous identification of items within a taxonomy, a standardized nomenclature system is essential. A decomposition tree serves as a purely informational foundation, which facilitates collaboration across work packages and tasks. Ontology visualization, boundary identification, inventory data

# EXECUTIVE SUMMARY

collection, impact assessment, and sensitivity/uncertainty/scenario analysis are some of the applications of the tree. An analysis of existing vehicle decomposition approaches helped build the tree. For batteries, the JRC's Carbon Footprint of Electric Vehicle Batteries (CFB-EV) proposal was adapted, and for vehicles, the GREET model was adapted from the US Department of Energy. The decomposition tree was refined to ensure that it is as complete and accurate as possible for all OEMs after obtaining feedback from OEMs through questionnaires and meetings. Some of the reasons for these changes are adapting to zero-emission vehicles, improving clarity and detail, splitting large categories, and adding process details. Decomposition of the traction battery is based on the JRC tree, with minor modifications to list subcomponents. The decomposition tree for vehicles has several limitations: there are numerous subdivision possibilities that require adaptation and improvement, and it is largely based on the GREET structure, making certain categories like 'Powertrain' for Zero Emission Vehicles difficult to comprehend. The GREET decomposition of a vehicle and the JRC battery decomposition of a battery have inconsistencies in terms of component details and fluid classification, which are also limitations.

In addition to UNEP guidelines, the Social Life Cycle Assessment (S-LCA) ontology integrates elements from ILCD, BONSAI, and ORIONT. Incorporating a Reference Scale approach to social impact evaluation and comparison is the primary distinguishing feature of this ontology. Although the ontology was designed based on S-LCA guidelines, its definitions can be applied to other phases of S-LCA, such as Goal and Scope, and Social Life Cycle Impact Assessment (S-LCIA).

Using an automated procedure, a technical ontology was developed to streamline development and minimize errors. An Excel file listed all elements of the TLCAO, and a Python script imported the ORIONT ontology, adding classes, instances, and properties using the Owlready2 package. An OWL file was created to import the merged ontology into Protégé for querying, visualizing, and further development. Through an interactive knowledge graph, users can explore ontology components and their interrelationships in Protégé.

The maintenance of the data is a key point, which was described according to several aspects. These are the overall organization being in charge of the database, the available technical knowledge, the scope, the software capabilities in background data update, the approach on updating the datasets, and the data format. An essential decision is how or by whom the database should be set up and managed. Three cases are presented to demonstrate the benefits and drawbacks, depending on who is in charge of the overall organization.

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## Abbreviations

Battery Electric Vehicle  BEV

Battery Value Chain Ontology  *BVCO*

Bill of Materials  *BOM*

BONSAI ontology  *BONT*

Characterisation Factor  *CF*

Electric Vehicle  EV

Elementary Multiperspective Material Ontology  *EMMO*

End of Life  EoL

European Reference Life Cycle Database *ELCD*

European Union  EU

extended International Life Cycle Data format  *eILCD*

eXtensible Markup Language  *XML*

Fuel Cell Electric Vehicle  FCEV

General Process Ontology  *GPO*

Global LCA Data Access Network  *GLAD*

Greenhouse gases  GHG

Heavy Duty Vehicles  *HDV*

Hybrid Electric Vehicles  HEV

Internal Combustion Engine Vehicle  ICEV

Internal Combustion Engines  ICE

International Material Data System  *IMDS*

International Reference Life Cycle Data System  *ILCD*

Knowledge graphs  *KG*

Life Cycle Assessment  *LCA*

Life Cycle Costing  LCC

Life Cycle Data Network  *LCDN*

Life Cycle Impact Assessment  *LCIA*

Life Cycle Sustainability Assessment  *LCSA*

Ontology Inference Layer  *OEL*

ORIETING LCSA ontology  *ORIONT*

Original Equipment Manufacturer  *OEM*

Plug-in Hybrid Electric Vehicles  PHEV

Ressource Description Framework  *RDF*

State of the Art  SotA

TranSensus LCA ontology  *TLCAO*

Web Ontology Language  *OWL*

Work Package  WP

World Wide Web Consortium  *W3C*

Zero Emission Vehicle  ZEV

# I. Introduction

## I.1 Background and Context

Road transportation is a principal driver of multiple environmental problems, among which climate change. Emissions of greenhouse gases (GHGs) from transportation sector accounts for 20% of energy related GHGs globally. If emissions from fuel supply chain are considered, this percentage can be even higher (Dillman, et al., 2020). In the European Union (EU), the share of transportation's GHG emissions is around 22% excluding aviation and maritime emissions. Road transport alone emitted 77% of all EU transport GHGs in 2020 (including domestic transport and international bunkers) (European Environment Agency, 2022). Fossil fuels are currently the dominating energy carriers for transportation with around 94% of the total energy carriers (European Commission, 2016), which puts pressure on the EU to decrease this reliability on fossil fuels in mobility.

From the policy perspective, the European Green Deal, adopted by the Commission in December 2019, has at its core tackling climate change, including more ambitious action in the coming decade, and reaching the objectives of the Paris agreement and other environmental issues. As one of the key elements of the European Green Deal, the European Climate Law enshrines the EU's commitment to reaching climate neutrality by 2050 together with the intermediate target of reducing net GHG emissions by at least 55 percent by 2030, compared to 1990 levels.

Road vehicle electrification and Zero Emission Vehicles (ZEVs) have become one of the most significant climate change mitigation options in Europe, manifested by the rapid growth of ZEVs market in recent years, since they have been associated with promising environmental gains. The EU's Sustainable and Smart Mobility Strategy (European Commission, 2020) calls for an irreversible shift to zero-emission mobility. Given transport's high proportion of total EU GHG emissions, the EU's climate goals will be reached only by introducing more ambitious policies to reduce transport's reliance on fossil fuels without delay.

However, it is acknowledged that focusing only on direct GHG emissions during vehicles use has the potential to lead to burden shifting to other environmental impacts like toxicity and resources depletion or to other life phases of vehicles. A very pronounced example here are the concerns around rechargeable batteries supply chains which are a core element of Electric vehicles (EVs) supply chain. (Xia, et al., 2022)

Methodologies like Life Cycle Assessment (LCA), Social LCA, and Life Cycle Costing (LCC), can play a paramount role in helping assess the sustainability of certain strategic choices in a more holistic way, to help identify options to prevent or mitigate for hotspots. LCA (the most mature methodology among the three aforementioned methodologies) is an established environmental assessment methodology supported by ISO standards (ISO, 2006; ISO, 2012; ISO,

2020) which takes into account all the life cycle of products and services and a wide spectrum environmental concerns.

A plethora of LCA on ZEVs and batteries have been researched and reported in the literature and applied by automobile manufacturers (for both internal use and public reporting). However, subjectivity in critical modelling choices, such as choosing the functional unit, or the electricity grid mix can lead to truly diverse results even for the same product. (Bouter, et al., 2022; Marmiroli, et al., 2018; Nordelöf, et al., 2014; Xia, et al., 2022)

This divergence hampers the utilization of these studies in further decision making as it complicates the comparability between results and diminishes the reliability of conclusions for policy making and strategic planning on corporate, country, or regional level. In the public-forum, the lack of standardization can at best lead to confusion on the relative performance of different options, or at worst be used as a tool to provide a biased or deliberately misleading picture to support a particular viewpoint or interest. For example, choices could be deliberately made to promote products in a certain way (e. g. a battery manufacturer claiming “zero burdens” when using recycled materials, while an end of life (EoL) battery treatment company claiming benefits for providing recycled materials).

Therefore, there is a need for a consensus on a single European harmonized approach of applying LCA for zero emission road transport where all stakeholders can calculate, monitor, communicate, and make decisions starting from a common ground. This becomes even more urgent in the light of the increasing adoption of LCA-based requirements in the European regulations. The proposal of batteries and waste batteries is a clear example, where providing an LCA-based carbon footprint declaration will be mandatory for any >2kwh-capacity batteries deployed in the European market (European Commission, 2020), which is a legislation now. Similarly, the new life cycle-based emissions reporting was proposed in the new regulation on $CO_2$ emission performance for light duty vehicles. (European Parliament, 2021)

## I.2 Aims of the TranSensus LCA Project

The TranSensus LCA project (funded under the EU’s Horizon Europe programme) is a promising attempt to achieve such consensus by gathering a wide spectrum of influential European stakeholders in the zero-emission mobility sector ranging from academia and research to industry which covers the whole value chain of ZEVs and batteries. As also indicated above, such a single European LCA approach is seen as a key element in achieving the Green Deal targets, making Europe the first digitally enabled circular, climate-neutral and sustainable economy. By consensus, TranSensus LCA aims to enable industry, mobility providers and planners to provide sustainable products and to optimise mobility solutions as needed to combat climate change and prevent burden shifting to other environmental concerns.

The project is structured into six content-related work packages (WPs), plus one work package related to project management as illustrated in Figure 1 below. The aim of Work Package 1 (WP1) is to account for the study's context and objectives (e.g., product environmental reporting, possible application for regulatory compliance/assessment, or policy/strategic analysis), and how these influence decisions on scope/boundary, methodology and data, subsequently implying different knowledge gaps and needs. WP1 has been subdivided into an assessment of the current state-of-the art of LCA concepts and approaches (Task 1.1) and a subsequent assessment of the needs and gaps in the current LCA practice in ZEV field (Task 1.2). S-LCA and LCC are also addressed similarly in Task 1.1 yet with less emphasis since LCA is the focal point of the project. The identification of needs and gaps should partly build on the outcomes of Task 1.1 and pave the road to WP2 where these needs for harmonization and gaps in current practices will be addressed to eventually achieve a harmonized methodology.

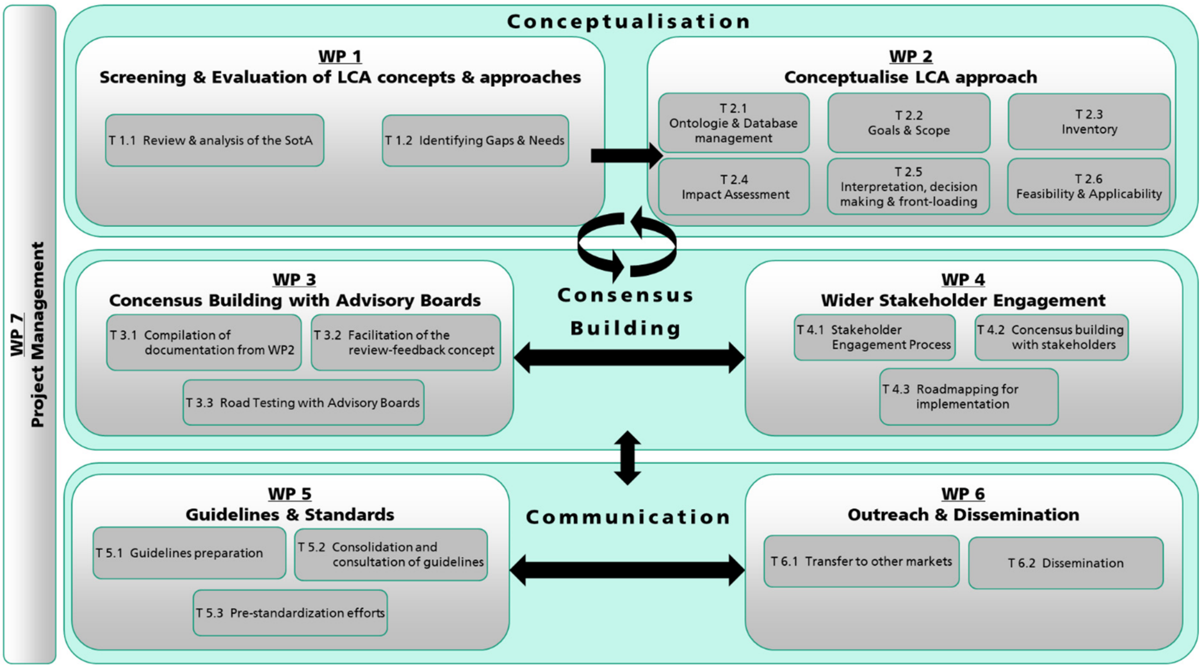


**Figure 1:** TranSensus LCA project structure

Deliverable 1.1 covers all Zero Emission Vehicles, however a strong emphasis is placed on battery electric vehicles (BEVs) and traction batteries for electric powertrain vehicles (which also include Fuel Cell Electric Vehicles – FCEVs) since most of the state of the art (SotA) and guidelines available are related to these topics. Furthermore, the LCA practices are not expected to differ substantially for other powertrain types from a methodological perspective. Any differences that would emerge will be addressed in detail in WP2.

WP2 aims at conceptualising an LCA approach for zero emission road transport. This is divided into three main topics: 1) Creation of a common ontology and management approach for an

LCI database (Task 2.1), 2) Elaborating a common LCA approach integrating environmental and social aspects (Task 2.2 – 2.5), and 3) Test the feasibility and applicability of the approach (Task 2.6).

## I.3 Aims and Structure of this Report

This report will cover the creation of a common ontology for an LCI database for the road transport sector and battery value chain.

The report will start with the fundamentals of ontology, to outline the concept itself. By giving basic descriptions of ontologies and their necessity, possible design approaches and visualization options, languages and tools the reader is to be introduced to the general topic.

Chapter III. will reflect the current SotA. Starting with already existing ontologies, to nomenclature and taxonomy to data format and data exchange.

In the following section, you will find a description of the main chapter of our upcoming TranSensus LCA ontology. Giving detailed explanations about the intended domain and scope, the specific elements included, S-LCA and economic factors and outlining a possible implementation and usage.

# II. Fundamentals of Ontology

**Summary of key findings**

Ontologies…

- … are formal structures that organize, classify, define, and link information.
- … describe concepts and their relationships, serving as data models for semantic networks and taxonomies.
- … enable data interoperability, knowledge reuse, and facilitate data integration.
- … are widely used in various fields including artificial intelligence, semantic web, software engineering, and more.
- … are commonly structured into classes, attributes, individuals and relationships.
- … should respect criteria of clarity and coherence, allow extendibility, be based on knowledge and their definition minimalistic, be reusable.
- … can be designed in numerous ways. An example is a 7-step approach proposed by the Protégé project.
- … can be visualized through a knowledge graph.
- … can be created with several languages (e.g., XML, RDF or OWL) and in different tools (e.g., OilEd, OntoEdit or Protégé)

## II.1 Basic Description of Ontologies and their Necessity

An ontology is a description of concepts and their relationships (Gruber, 1995). In information science, ontologies provide a formal structure where information/knowledge/data are organized, classified, defined, named, and linked to each other. It is "a way of showing the properties of a subject area and how they are related, by defining a set of concepts and categories that represent the subject" (Wikipedia, 2023). In other words, these general semantic data models define and classify the type of information/data that exist and the properties that describe them (Schrader, 2020). They are closely linked to semantic network and taxonomies.

Ontologies are commonly structured into **classes** (type of objects that exist in the data), **attributes** (properties describing a class), **individuals** (instances) and **relationships** (properties connecting two classes).

If we take the example of the automotive sector, vehicle-related data could be classified into the following classes (non-exhaustive list): Car, Original Equipment Manufacturer (OEM), Client. Each of these classes can be described by several properties, called attributes, and can be linked to each other. For example:

**OEM** produces **Car** – OEM and Car are linked together, it is a relationship

**Client** buys **Car** – Client and Car are linked together, it is a relationship

**Car** has a **Colour** – the Colour is a specific attribute of the Car class

**SUV** is a **Car** – SUV is a subclass of Car

**Car** has **Age** and is produced in **Year –** Age and Year are attributes of the Car class

**Red** is an individual of the class **Colour**

Ontologies provide a common understanding of information structures and explicate domain assumptions. Doing so, it enables the reuse of domain knowledge: data identification, interpretation and integration are facilitated (Fridman Noy, et al., 2001). Ontologies are powerful models that allow data interoperability, harmonization, and consistency among one or several domains.

Ontologies are widely used in artificial intelligence, semantic web, software engineering, biomedical information, library science, information architecture, etc. (Maniray, et al., 2010)

## II.2 Design Approach for Ontologies

Ontology engineering is a multidisciplinary field which studies methodologies for building ontologies, including representation, formal naming, category definitions but also ontology exploitation, maintenance, and management. Interestingly, ontologies can be considered as living objects and described through their life cycle (Gandon, 2006). Figure 2 represents a six steps life cycle composed of: 1) the evaluation of the needs (why do we need an ontology), 2) the conception of the ontology, 3) the diffusion, 4) use of the ontology, 5) its evaluation and improvement, but also 6) its maintenance. Model validation is at the centre of this life cycle, designing ontologies is an iterative process.

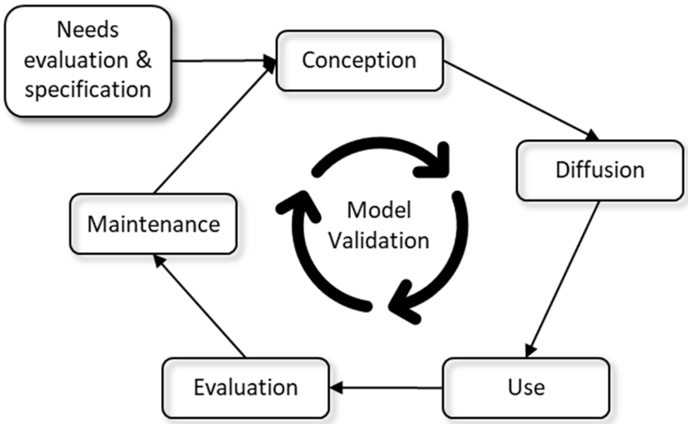


**Figure 2:** Ontology Life Cycle – adapted from (Gandon, 2006) & (Baneys, 2007)

Gruber described the most important criteria when building ontologies. First, the ontology design should depend on the purpose of the ontology and its utility for the domain of application. Second, the ontology should respect criteria of **clarity** and **coherence**: definitions should be objective, independent from other contexts, and complete. The design of ontology should allow **extendibility** (new terms can be added without changing existing concepts), the concepts should be **based on knowledge** and their **definition minimalistic** (minimal ontological commitment). It is also important to highlight that ontology should be **reusable**, allowing to build on it. (Gruber, 1995)

Several approaches can be found in the literature to build an ontology:

- some ontologies extend existing ontologies,
- some used a text corpus or dictionary as a baseline (the ontology covers every relevant concept mentioned in a text reference),
- some define motivating scenario (problems to solve) and propose a set of intended solutions.

When building the concepts of an ontology, several approaches can be used as well:

- bottom-up approach starting from the most specific concepts and grouping them in categories,
- top-down approach identifying the most general concepts and creating categories,
- the middle-out approach starting from middle layer concepts and building up and down. (Fridman Noy, et al., 1997)

There is no "correct" way of designing ontologies. Several approaches have been developed in the past 30 years, manual (human made) or automatic (through machine learning, data mining, etc.) (Xu, 2021). The Protégé project (Fridman Noy, et al., 2001) proposed a 7-step process to guide ontology developers, highlighting this is an iterative process. An example is given in **Table 1**.

Step 1: **Determine the domain and scope of the ontology**, identifying who will use and maintain the ontology, what types of questions and problems the ontology should answer.

Step 2: **Consider reusing existing ontologies** or controlled vocabularies.

Step 3: **Enumerate the important terms in the ontology**, giving definitions and properties.

Step 4: **Define the classes and their hierarchy** (closely intertwined with step 3).

Step 5: **Define the properties** (also called slots or attributes) **of classes** (closely intertwined with step 3).

Step 6: **Define the facets of the properties**: A slot/attribute (= the property of a concept) can have one or several values. These values can be classified per type. The most common value types are: "string" value (the value is a simple string), number, Boolean (yes/no value), enumerated (the value can be one of the values listed), and instance type (the value is a relationship, translated by a verb).

Step 7: **Create instances**, to have an individual representative of a specific class.

**Table 1:** Knowledge-Engineering Methodology (Fridman Noy, et al., 2001)

| Step | Example on vehicles |
|---|---|
| 1) Determine domain and scope | Representation of vehicles is the domain of the ontology. We plan to use this ontology for the applications that suggest good combination of vehicles and clients. |
| 2) Consider reusing existing ontologies | A list of vehicle types, properties and characteristics already exist and could be used as a baseline. A knowledge base of client profiles may already exist, as well as results of surveys. |
| 3) Enumerate important terms | Important vehicle-related terms could include passenger car, bikes, trucks, buses, vehicle's color, year of production, vehicle's mass, consumption, mileage driven per day/year, driving type, in which topology the client lives, etc. |
| 4) Define the classes and class hierarchy | Three approaches:<br>Top down: we start with the general concept of vehicle, specializing classes and sub-classes. E.g., the passenger class is composed of four segments sub-classes A, B, C, D.<br>Bottom up: we start by listing all vehicles (Renault ZOE, BMW X7, VW Polo, SCANIA XX …), we then define common classes. It could be the BEV vs ICE classes or the M1 and N1 vehicles categories. |

| | |
|---|---|
| | Combination: we start from general classes like passenger car, and we try to connect it through middle-level concept to specific concepts such as the Renault ZOE model. A middle-level concept could be “BEV” class. |
| 5) Define the properties of classes – slots | For each class defined in step 4), properties of the classes are defined. For example, the powertrain, the mass, the color, etc. |
| 6) Define the facets of the slots/attributes | A car can have one or several colors, but a car has only one mass value. The OEM produces a car, the attribute “produces” defines a relationship between classes. |
| 7) Create Instances | If we have a class for BEVs, a sub-class could be Renault Zoe e-tech. An instance for this class is created and has to be filled with the necessary property values. A specific make of a Zoe e-tech would thus be a representative. |

## II.3 Ontology Visualization, Languages, and Tools

Several formalisms can be found in the literature to represent knowledge and ontologies. In this section, we will describe two formalisms: the **knowledge graph** and the **logic of description** (Baneys, 2007).

Knowledge graphs (KGs) have been introduced by (Sowa, 1984). They model knowledge networks, where nods are concepts and edges are relationships. An example of an ontology graph is given in Figure 3 where Renault ZOE as an individual of the concept “Car” is linked to Color, OEM, Client, and Year concepts/classes.

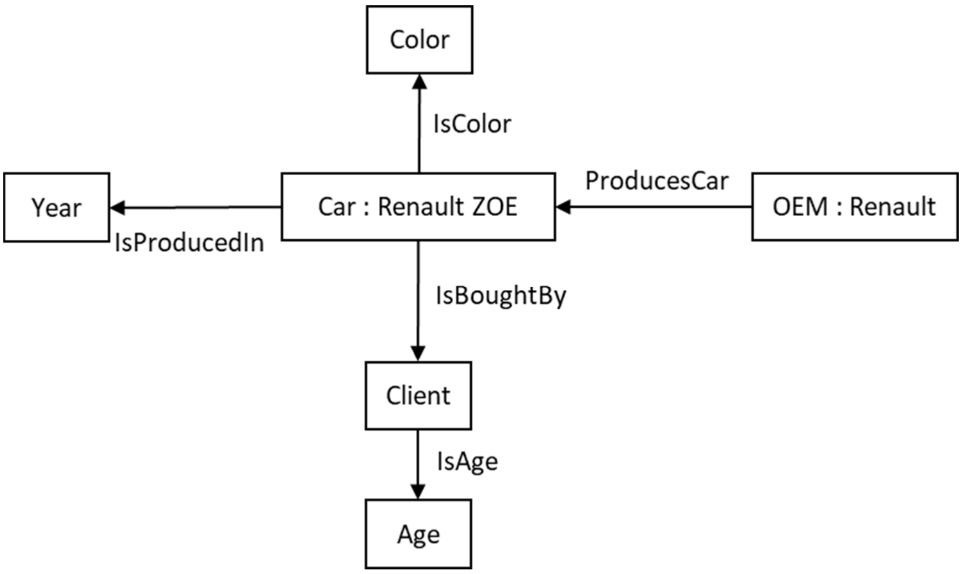


**Figure 3:** Example of a knowledge/ontology graph

The ontology designer has the responsibility to choose the language in which the ontology will be expressed and used. This language should be **readable**, **understandable** by human (in continuity with the natural language), **standardized** (to be reusable), and should allow **data treatment** to create knowledge graphs or other representations. Several languages can be found in the literature: XML (eXtensible Markup Language), RDF (Resource Description Framework), or OIL (Ontology Inference Layer) (Maniray, et al., 2010). In 2004, the World Wide Web Consortium (W3C) published the standard language **OWL** (Web Ontology Language) based on the XML syntax– (OWL2 is an extension and revision of  OWL) (W3C, 2013). This standard is widely used today.

Ontology editors are software tools for ontology building. Several tools can be found in the literature: OilEd, OntoEdit, WebODE and Protégé can be named (University of Manchester, 2008; Ontology Engineering Group, 2015; Stanford University, 2020). Protégé, has been developed by Stanford Medical Informatics in 1995 and has become a reference in the ontology field. Easy to handle, it can integrate plugins (for knowledge graph representation for example), compare and merge different ontologies. (Stanford University, 2020)

# III. State-of-the-Art

In this chapter, a review of the current state of the art in science and practical application is presented to show the basis on which this report is based. The main topics are as follows: 1) Existing ontologies, 2) Nomenclature and Taxonomy, and 3) Data format and data exchange.

## III.1 Existing Ontologies

**Summary of key findings**

- The importance of building on existing ontologies to reduce workload and increase connectivity and consistency was emphasized.
- Several ontologies, such as BONSAI, KIproBatt_v1, LCA methodology ontology, and ORIONT are examined for their suitability in the project's domain and scope.
- The ORIENTING research project focuses on developing a Life Cycle Sustainability Assessment methodology encompassing environmental, social, and economic aspects. The ORIONT ontology from ORIENTING is created for structuring crucial methodological and data elements from previous sustainability assessment ontologies and public databases.

As shown in Chapter II.2, it is of high importance to build on existing ontologies. On the one hand the workload can be reduced, on the other hand they are often compatible with existing applications, which increases the connectivity and consistency. Therefore, we examined several existing ontologies to determine a conformance with the intended domain and scope of this project.

BONSAI ontology: This will be partly covered in the following sub-chapter.

KIproBatt_v1: Describes the process of manufacturing battery cells (Fraunhofer ISC, 2022). While this is too specific for the overall scope of this report, this ontology could potentially be implemented in the future.

LCA methodology ontology: This ontology is too broad and high-level for the scope of this report. Elements that are additionally covered in this ontology are e.g., Organization & Assignment, Decision Making or Process Design. (Chungoora, 2019) In case the TranSensus ontology should cover these elements as well, the LCA methodology ontology can be used as a foundation.

In the following three sub-chapters additional ontologies will be explained in more detail.

It should be further noted that several guidelines/standards/reports were analyzed as well. While they partly cover certain elements that can be linked to an ontology, none of them contains the word ontology itself. These documents were for example: EN15804, Batteries PEFCR, GBA Battery Passport, CFB-EV, GreenNCAP, PCR Buses and Coaches, PFA French, eLCAr, Rise, Draft PCR Passenger Cars, Draft PCR Passenger Cars China, and Catena-X Rulebook.

### III.1.1 Orienting Ontology ORIONT

The ORIENTING research project, funded from the European Union's Horizon 2020 research and innovation programme, aims to develop an operational methodology for product Life Cycle Sustainability Assessment (LCSA). This should include environmental, social, and economic aspects. For structuring the most important methodological and data elements and their relationships, the ORIENTING LCSA ontology (ORIONT) was created. (ORIENTING, 2021) The deliverables D3.1 of this project "Data ontologies: Documentation of the ORIENTING LCSA ontology (ORIONT)" and D3.2 "Data specification: Specifications for a future LCSA data format" have not been published yet but were provided to the TranSensus LCA project.

**Generic description of an ontology**

"An ontology is a description of concepts and their relationships. Ontologies simplify the complexity of an application domain (for example LCSA in the ORIENTING case) and organize data into information and knowledge concepts. They allow keeping an easy and consistent communication among experts by providing the necessary structure to link one piece of information to other pieces of information and facilitate data linking and interpretation. Furthermore, because ontologies are used to specify common modelling representations of data from various systems, databases, and information sources, they enable interoperability of data sources, cross-database search, and smooth knowledge management. This is ensured by providing a controlled, formal vocabulary that consists of naming and defining categories in, properties of, and relations between the concepts, data and entities that substantiate one or several domains." (ORIENTING, 2022)

**Tailored definition of ontology**

"ORIONT aims at fulfilling the definition that 'an ontology encompasses a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse' (Wikipedia, 2022a), the domain obviously being LCSA." (ORIENTING, 2022)

### The BONSAI ontology (BONT)

The very core of ORIONT forms the BONSAI ontology (BONT), as seen in Figure 4. The BONSAI ontology unites previous sustainability assessment ontologies, with two main applications: Firstly, integration of relevant data from the publicly available databases, such as the EXIOBASE and the Yale Stock and Flow Database, and secondly querying the resulting integrated database. (Ghose, et al., 2021) Descriptions and examples of the different BONSAI elements are given in Figure 4 and Table 2. See also appendix A3. for a visualization of the ontology.

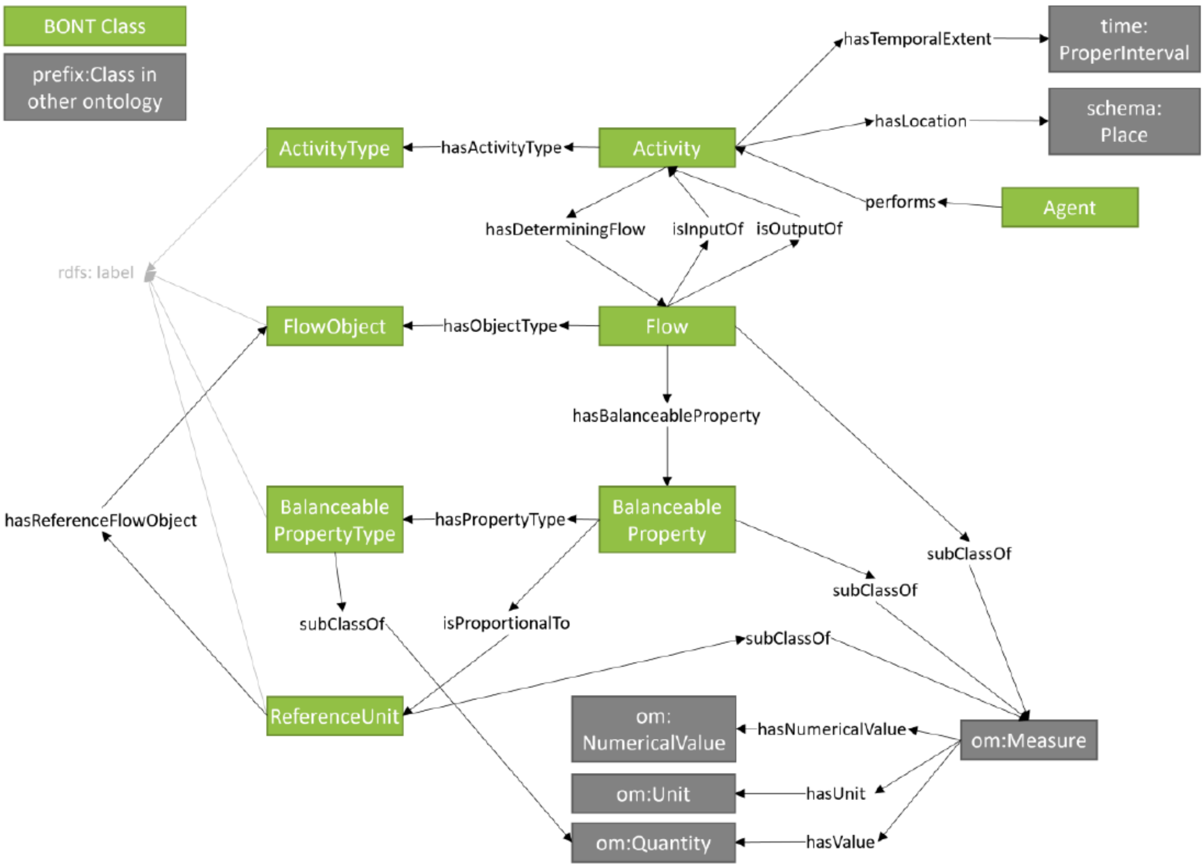


**Figure 4:** The BONSAI ontology (Ghose, et al., 2021) rdfs: Resource Description Framework Schema; om: Ontology of units of Measure

**Table 2:** Description and examples from the BONSAI ontology (Ghose, et al., 2021) & (ORIENTING, 2022)

| Description | Example |
|---|---|
| **Activity** | |

| | |
|---|---|
| Making or doing something within a spatial and temporal delimitation. | "Cultivation of wheat" in Germany in the year 2020 or "Aluminium production" in China in the year 2020. |
| **Activity Type** | |
| This class includes the labels of activities. | "Cultivation of wheat" or "Aluminium production". |
| **Agent** | |
| An entity (person or thing) that performs an activity. An agent may have a location that may be different from the location of an Activity performed by it. | Within an activity, agents can perform different roles, for example, laborer, owner, purchaser, consumer. |
| **Flow** | |
| An input or output of an entity to or from an instance of an Activity or a directional exchange of an entity between two instances of Activity. A flow can be unidirectional, that is, a flow can be defined as an input or output of an activity without defining its origin or destination. The determining flow is a specific flow of an activity for which a change in demand or supply will affect the activity level. | Input of 2393 tonnes of "Aluminium and aluminium products" (FlowObject) to "Manufacture of motor vehicles" (ActivityType) in Germany in the year 2011. |
| **Flow Object** | |
| This class includes the labels of entities that are produced or consumed by an activity or added to or removed from a stock accumulation. | "Wheat" or "Aluminium and aluminium products". |
| **Balanceable Properties** | |
| Properties of Flows. | Dry mass, wet mass, energy, elemental mass, monetary value (when measured in the same valuation) (non-balanceable properties: volume, number of units, Becquerel (unit to measure radioactivity). |
| **Balanceable Property Type** | |
| The property/"quantity" that is quantified. | Mass |
| **Reference Unit** | |
| A measure to which the numeric value representing the measure of a flow is expressed in proportion to, e.g. CO2-emissions per kg-km transport covered. "Functional Units" are reference units, but not all reference units are "Functional Units." | Amount of CO2 emitted from a transport activity may be expressed in proportion to the quantity of another flow of this activity (e.g., 1 km of distance covered) or to a time period (e.g., CO2 emissions per year from transport). |
| **Numerical Value** | |

| | |
|---|---|
| | 1 |
| **Unit** | |
| | kg |
| **Quantity** | |
| | Mass |

**Product system and BONT classes**

As "BONT is rather generic/macro-level, it was deemed necessary to adapt it with the aim to be more specific and to cover all sustainability topics" (ORIENTING, 2022). To reach this, several additional elements were added, which are based on the extended International Life Cycle Data format (eILCD). The aspects central for this report are the product system and the BONT classes, which can be seen in Figure 5.

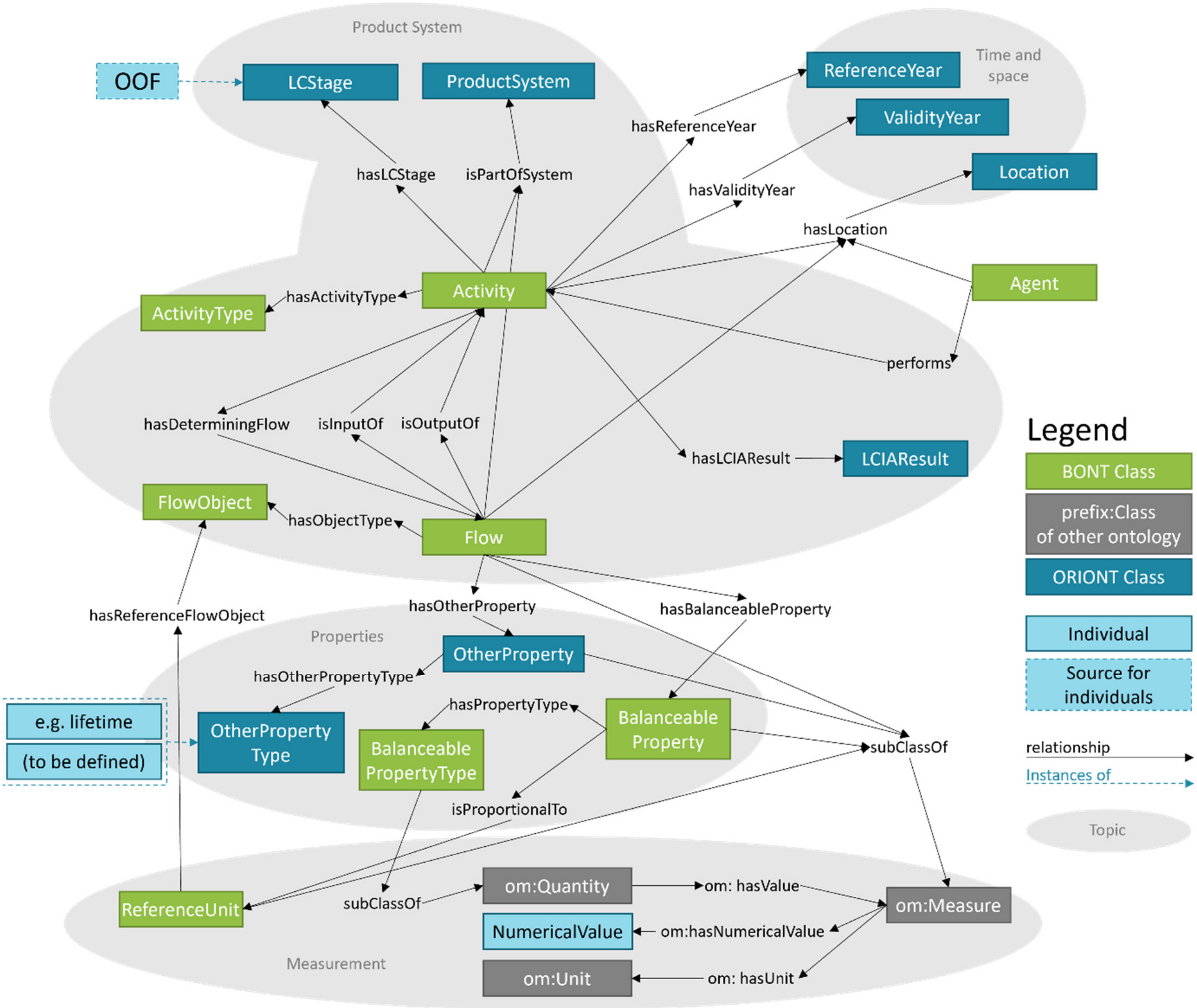


**Figure 5:** Selection of the main topics from ORIONT (ORIENTING, 2022)

Activities can be grouped in life cycle stages (LCStages) in eILCD, to enable having Life Cycle Impact Assessment (LCIA) results per life cycle stage. Different life cycle stages implemented in ORIONT are given in the ORIENTING Output Format (OOF). (ORIENTING, 2022)

It should be highlighted, that while temporal and spatial information can also be given in BONT, ORIONT uses the implementation according to eILCD. Additionally, they added the possibility to assign a location to a flow, which was not possible in BONT. While in most cases, the flow should have the same location as the respective activity, in special cases they must differ (European activity, with the flow having a specific country linked). An especially useful addition in ORIONT are two classes (conform to the eILCD format) for the reference year and the validity year. (ORIENTING, 2022)

### Classification of Flows

Another relevant aspect is the classification of flows, as seen in Figure 6. This is based on eILCD as well.

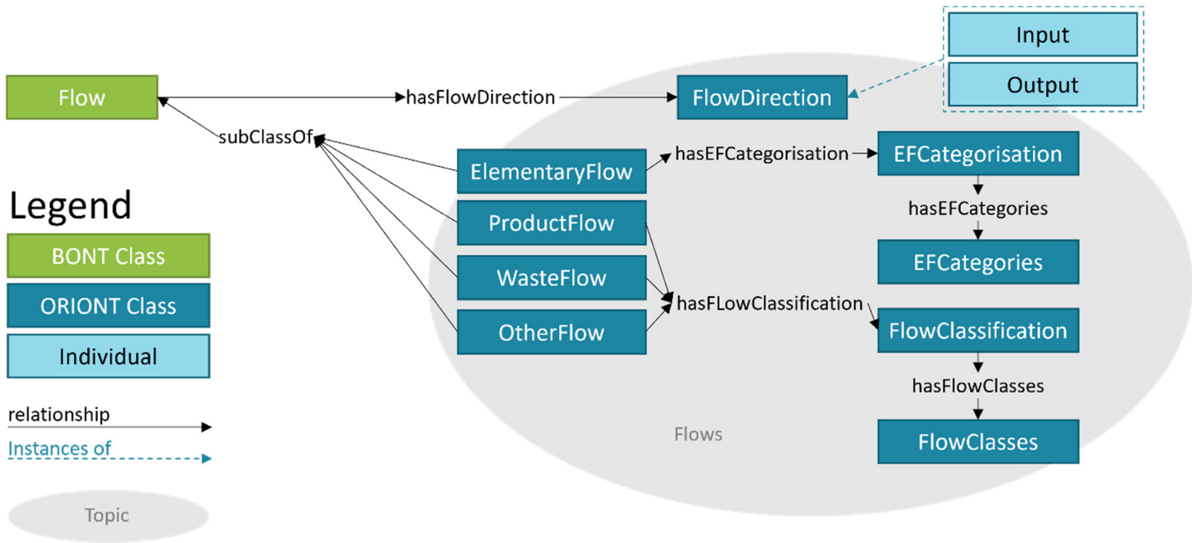


**Figure 6:** Classification of Flows (ORIENTING, 2022)

### LCIA Part of ORIONT

The third big part of ORIONT deals with LCIA, as seen in Figure 7. In the report detailed information is given on specific elements within this part. The basic building block is the class "Method". This class is linked to the class "Characterization Model," which can be used to quantify impacts indicators. "Method" is also a part of a certain methodology, being a set of different methods to assess different impact categories. (ORIENTING, 2022)

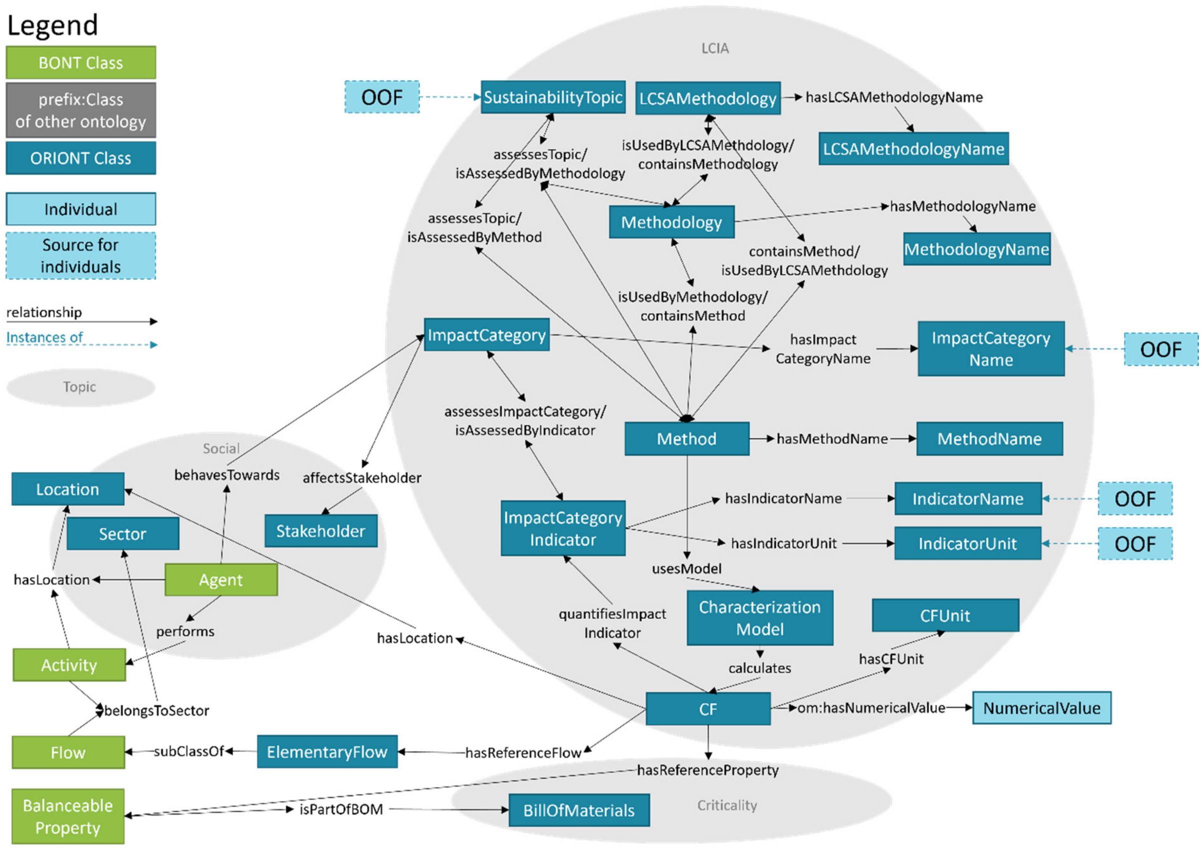


**Figure 7:** LCIA part of ORIONT (ORIENTING, 2022)

ORIONT classes, instances of classes, object properties, and data properties are given in appendix A5. to A8.

There are three basic takeaways from the analysis of ORIONT and discussions with its main author:

1) The development process including discussions is as valuable as the result as it forces to think about an aligned data structure from different perspectives.
2) ORIONT is not perfect (same for eILCD), and it should not be considered to be finished.
3) The integration into the world of ontologies and the semantic web would mean a huge technical effort and the need for more ontology expertise.

### III.1.2 Battery Value Chain Ontology

The Battery Value Chain Ontology (BVCO) is a cross-project development coordinated by Fraunhofer ISC (both EU and national research projects). The purpose of this ontology is to describe processes within the value chain of batteries. A process is a holistic perspective element that transforms inputs and outputs (matter, energy, information) into outputs and products through the application of tools (devices, algorithms). They may be decomposed into sub-processes and have predecessor and successor processes may exist. The ontology is based on the General Process Ontology (GPO) and the Elementary Multiperspective Material Ontology (EMMO). In comparison to BattINFO, BVCO manages the higher-level process chains for material processing and manufacturing, while BattINFO focuses on the internal components and chemical processes. The two ontologies are therefore complementary. (Stier, et al., 2023)

BVCO is focused on the production processes of a battery and does not specifically include the aspects of Life Cycle Assessment. The ontology only covers lithium-ion batteries and no further technologies. It is therefore out of scope for this project. See appendix 0for the ontology visualization.

### III.1.3 Catena-X Ontology

The Catena-X ontology aims to be an integrative framework, focusing on automotive manufacturing. Building a federated virtual knowledge graph enabling data access across companies in the automotive industry. (Catena-X, 2023) While there are different ontologies (packages) available, the two main ontologies are the Common (see Fig. 8) and the Core ontology (see Fig. 9):

**Common ontology**

“The common ontology describes the Dataspace connectors in detail. On the one hand, this includes the information from which Catena-X business partner the connectors are deployed. On the other hand, with which contracts which assets provide the connectors. All this information is provided in the Catena-X main repository so that the connectors are findable.” (Catena-X, 2023)

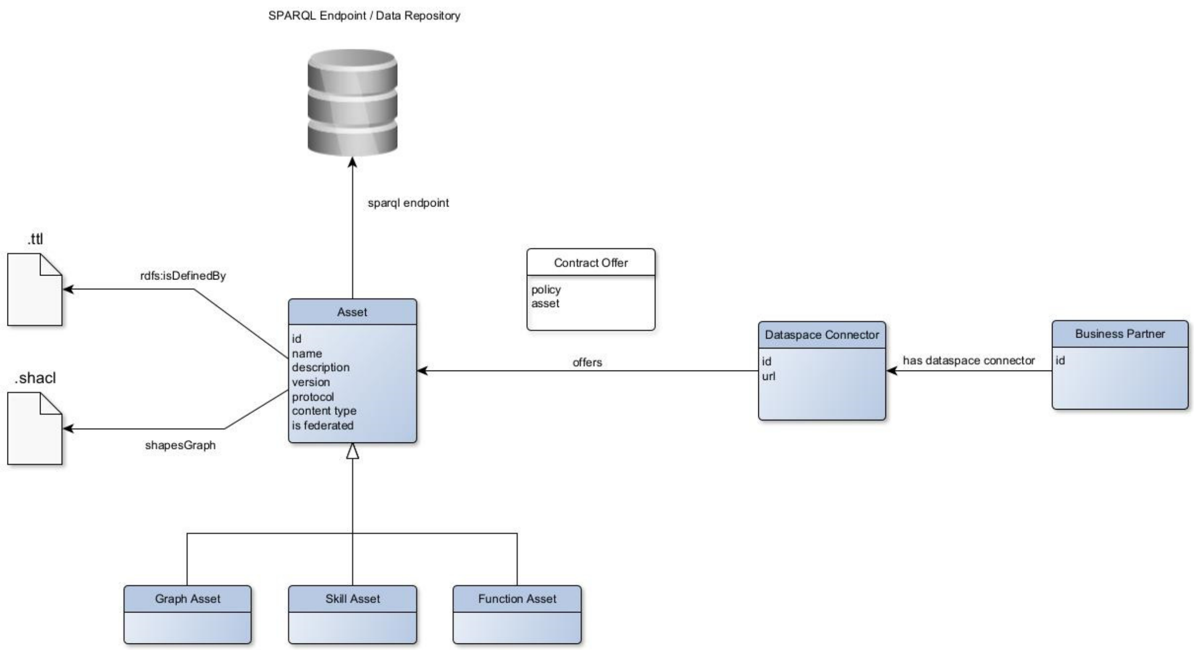


**Figure 8:** Catena-X Common Ontology Visualization (Catena-X, 2023)

## Core ontology

"The Catena-X ontologies consist of the Core Ontology and the Domain Ontologies. The Core Ontology is based on activity-oriented patterns and the Domain Ontologies build on these patterns. In parallel, a taxonomy exists in which the vocabularies created in the Catena-X project are captured in a structured way to realize Domain Ontologies. This taxonomy is not a standard and is used to realize the use cases. It can therefore be replaced or extended by other taxonomies.

Catena-X Core Ontology is a practical tool for information integration for the automotive industry. In Catena-X, product data is exchanged over the entire lifecycle from development to recycling. In each of these phases, activities on the product generate new information, e.g., manufacturing data, quality data, battery passport. This information needs to be linked semantically along the lifecycle to gain new knowledge and insights to realize traceability, sustainability, ensuring carbon footprint. For this reason, the Core Ontology is activity-centric. The activities are in the center of the modeling and all other necessary information is attached to the activities." (Catena-X, 2023)

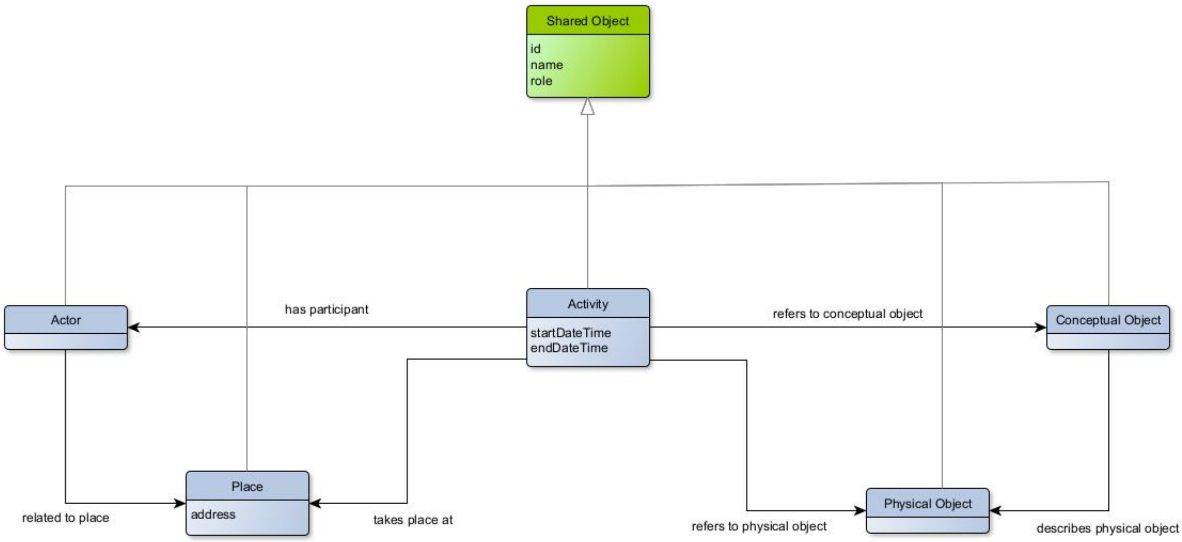


**Figure 9:** Catena-X Core Ontology Visualization (Catena-X, 2023)

The Catena-X approach on ontologies and taxonomy is complex and rather hard to understand in full without deeper knowledge about ontologies, IT and an ontology application like Protégé. As they are not specifically modelled to represent Life Cycle Assessment (LCA), they do not fit the scope of this project. The vehicle ontology could possibly be cross-checked with a material or decomposition tree in later stages of this project, as it describes the conceptual and physical objects of a vehicle.

## III.2 Nomenclature and Taxonomy

**Summary of key findings**

- Taxonomies facilitate the comprehension of relations and affiliations, forming a crucial part of an ontology´s logical structure.
- A nomenclature system can ensure an unambiguous identification of the corresponding components/materials.
- Several documents were checked to find a tailored solution: IMDS/VDA material classification, JRC CFB-EV, GBA GHG Rulebook, CATARC, and the GREET model.

The physical structure of a product can be broken down to different hierarchical levels. Starting from a complete vehicle (top level), several classes and subclasses can be derived, each representing components or ultimately materials at different levels of aggregation. In analogy to family trees, these taxonomies facilitate the comprehension of relations and affiliations, forming a crucial part of an ontology´s logical structure. Building taxonomies in a unified manner (e.g., every OEM uses the same basic structure) therefore promotes the efficient (re-)use of ontologies.

Equally as important as defining the precise position of a component/material is its designation. Once navigated to a specific place in the taxonomy, an unambiguous identification of the corresponding items needs to be ensured. Therefore, a nomenclature system must be employed which standardizes their descriptions. In return, nomenclature systems can also help to derive a meaningful taxonomy structure in the first place.

To identify a suitable approach in the TranSensus LCA project several existing decomposition trees were examined, see **Table 3**.

**Table 3:** General information on several decomposition trees

| Document | Type | Total types included | Detail of taxonomy (number of sublevels) | Reference to material or component database? | Information on material composition of components |
|---|---|---|---|---|---|
| IMDS/VDA Material Classification | Material classes | 57 | 2 | Serves as standardized nomenclature to IMDS database | N/A |
| JRC CFB-EV | Battery components | 11 | 4 | | generic |
| GBA GHG Rulebook | Battery components | 13 | 4 | Mentions IMDS database as example for primary data | generic |
| CATARC | Vehicle components | 5 | No sublevels | China Automotive Life Cycle Database (CALCD) | none |
| GREET Model | Vehicle components | 51 | 2 | Automotive System Cost Model (ASCM) | detailed |

### III.2.1 Material Classification according to IMDS and VDA

The International Material Data System (IMDS) is a web-based and industry wide database, jointly developed by automotive manufacturers. It contains data on all components and their material content present in finished vehicles. Its use is recommended by the German (VDA) and French (PFA) associations of automotive industry for instance:

*PFA: "The mass and material data of parts and components are partly derived from data collected via **IMDS.**"* (PFA, 2022)

*VDA: "The materials associated with the parts list should be derived from the International Material Data System (**IMDS**)."* (VDA, 2022)

Material entries in IMDS do not have harmonized nomenclature. For instance, "carbon steel (1020)" and "1020" refer to the same material. The hierarchical classification levels higher and lower respectively, are standardized though: material entries in IMDS are linked to broader material categories according to VDA and the basic substances, which materials ultimately consist of, have unified nomenclature according to IMDS Chemical Service. The classification in IMDS with increasing level of precision is the following (IMDS, 2023):

1. Vehicle part / component
2. Material group (**VDA**)
3. Material subgroup (**VDA**)
4. Material (nomenclature varying for the same material depending on suppliers)
5. Basic substances (**IMDS**)

The VDA identifies nine material main groups, based on a combination of content (basic substances), properties and their application (VDA, 2021):

1. steel and iron materials
2. Light alloys, cast and wrought alloys
3. Nonferrous heavy metals, cast and wrought alloys
4. Special metals
5. Polymer materials
6. Process polymers
7. Other materials and material compounds
8. Electronics / electrics
9. Fuels and auxiliary means

### III.2.2 Battery Composition according to GRB-CBF

According to the GRB-CBF, the main components of a battery are the following:

- System housing
- Module housing
- Battery housing
- Cooling system
- Electronics

- Anode
- Cathode
- Electrolyte

The Annex of GRB-CBF provides generic data collection templates to produce these components. There, some (limited) information on required subparts can be found, see Figure 10 and Figure 11. (Andreasi Bassi, et al., 2023)

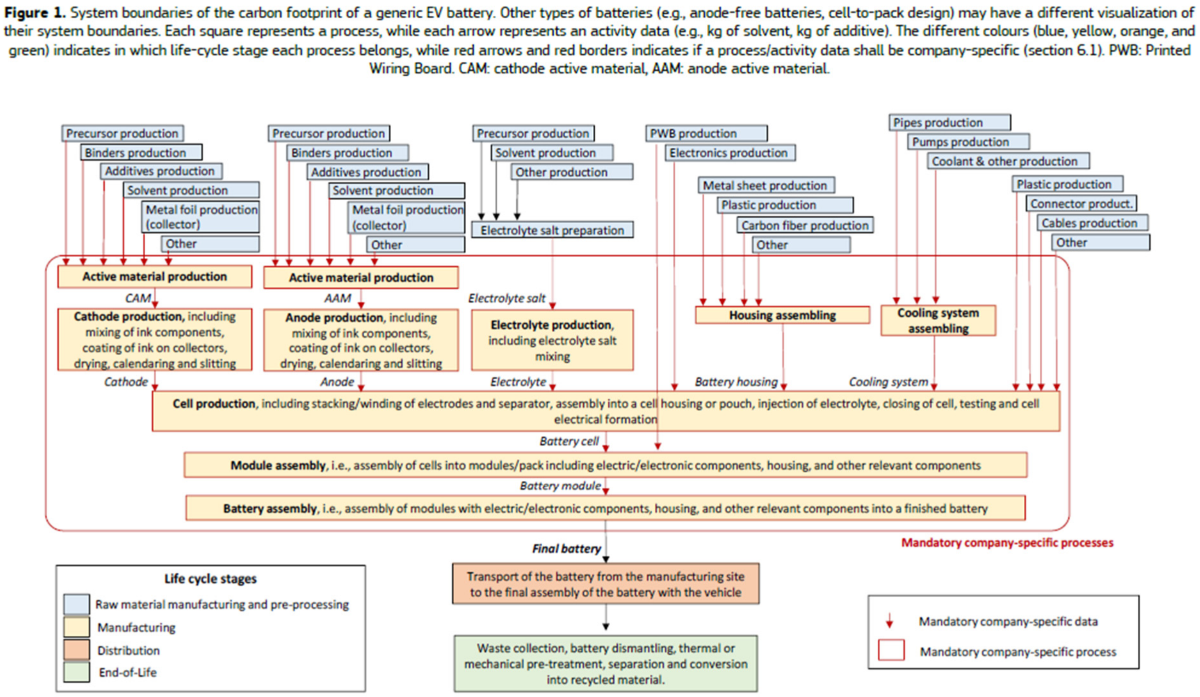


**Figure 10:** System boundaries from GRB-CBF (Andreasi Bassi, et al., 2023)

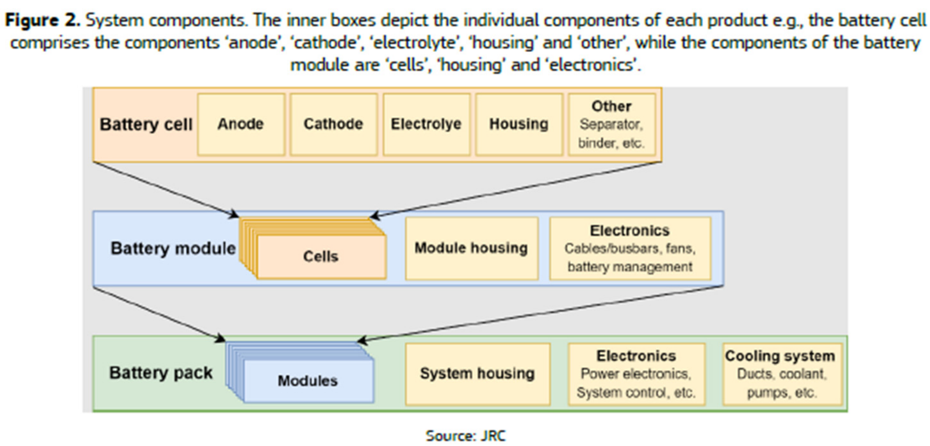


**Figure 11:** System components from GRB-CBF (Andreasi Bassi, et al., 2023)

### III.2.3 Battery Composition according to GBA

The Global Battery Alliance (GBA) Greenhouse Gas Rulebook was published in 2023. The Rulebook was developed to provide guidance on calculating comparable GHG footprints of lithium-ion batteries for electric vehicles by users of the (GBA) Battery Passport.

The GBA rulebook focuses on battery manufacture and raw materials, specifying eight hotspots along the value chain:

1. Metal sulfate (Nickel & Cobalt)
2. Lithium carbonate and hydroxide
3. Lithium metal
4. Iron phosphate
5. pCAM & CAM manufacturing
6. Electrode and cell manufacturing
7. Graphite
8. Module & battery assembly

The rulebook provides guidance and requirements for data collection and use, including generic data collection templates for each step and component / material. A process flow sheet for the battery is also provided, see Figure 12. This includes templates for cell and battery manufacture providing material categories for inclusion for inputs and outputs involved in the process.

The relationship flows for each material listed is provided in schematics, though these are not interlinked, and the names of the processes are not detailed. (Global Battery Alliance, 2023)

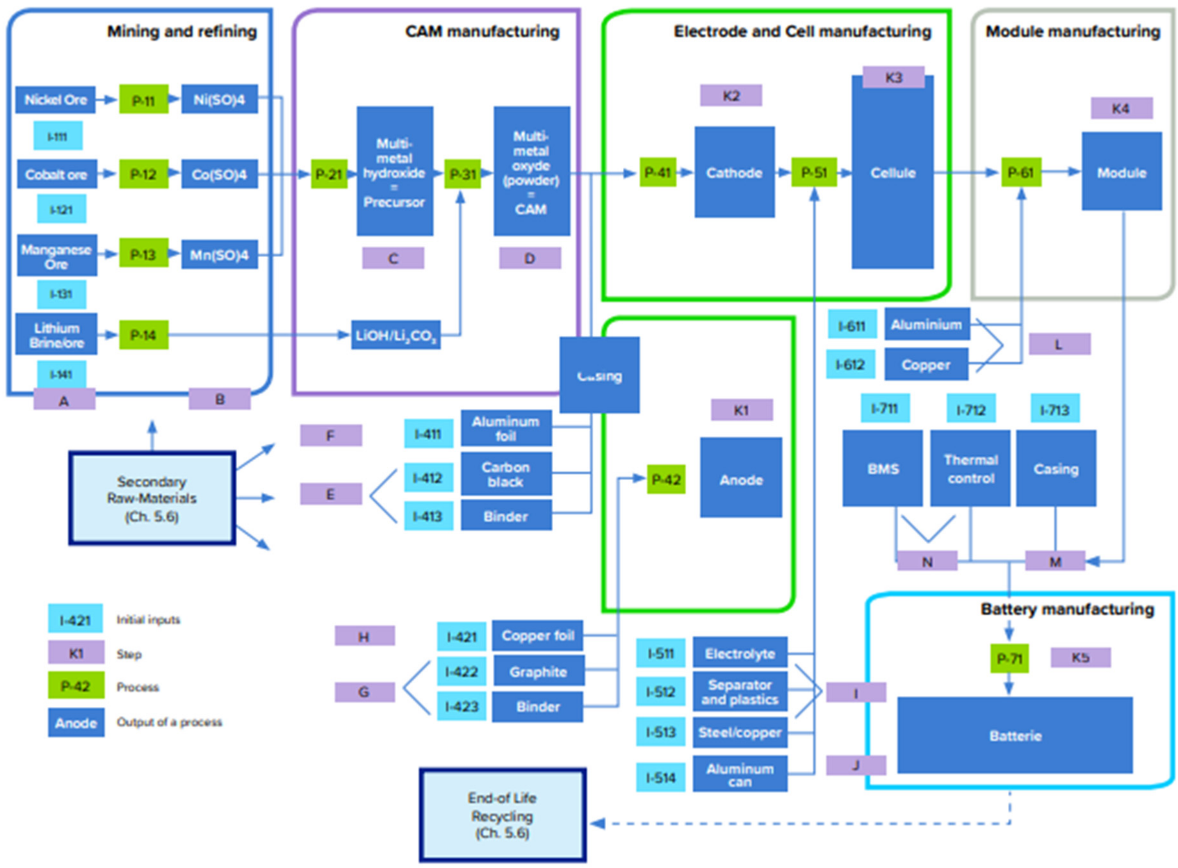


**Figure 12:** Manufacturing Process Flow Sheet of a NMC lithium-ion battery (Global Battery Alliance, 2023)

### III.2.4 Vehicle Composition according to CATARC

According to CATARC, the material decomposition of electric vehicles can be condensed to five main categories, see Figure 13. Materials are associated with one of these subsystems:

- Wheels
- Fluids
- Lead-acid battery
- Lithium-ion traction battery
- Constructive automotive parts

CATARC suggest differentiating these classes and their associated processes by the origin of the corresponding materials (primary or secondary) and provides guidance on the use of primary and secondary data. Moreover, four subsequent levels regarding the production of EVs are identified: material production stage, components production stage, vehicle production stage and vehicle use stage (repair & maintenance). (China Automotive Technology and Research Center Co., Ltd, 2022)

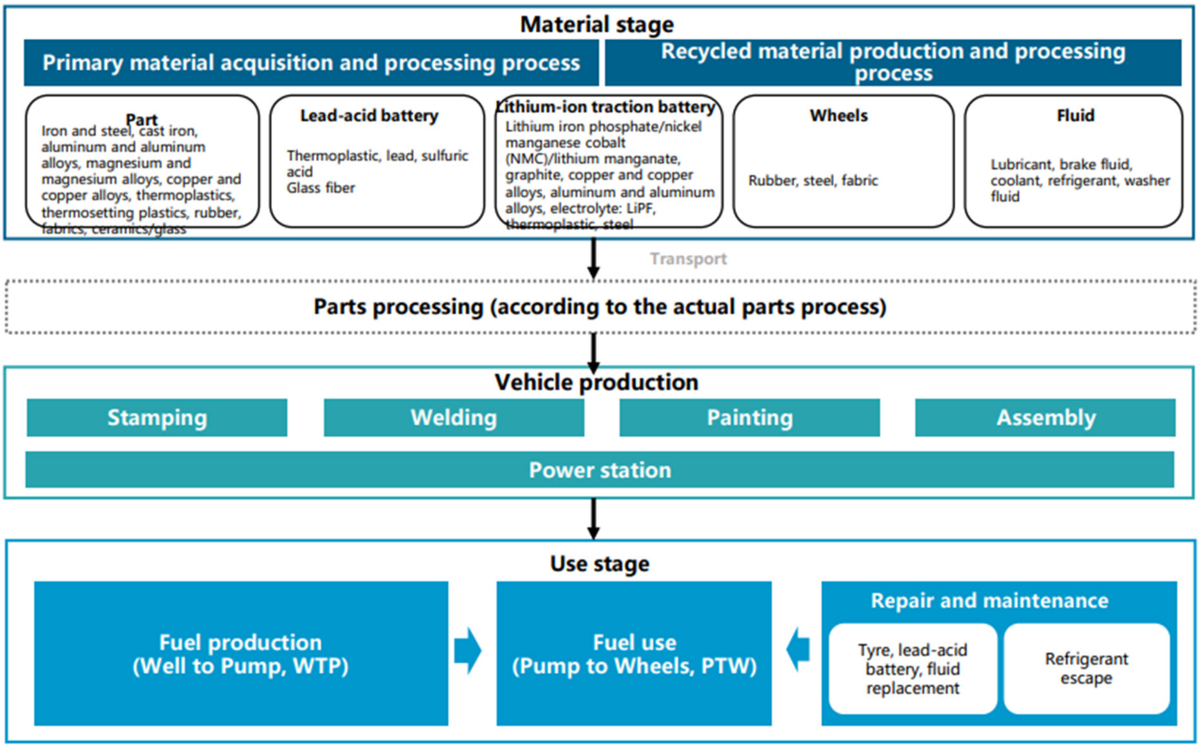


**Figure 13:** System boundary of CATARC (China Automotive Technology and Research Center Co., Ltd, 2022)

### III.2.5 Vehicle Composition according to GREET

The GREET vehicle composition was established in 2012 and is regularly updated to best represent the products that are available on the market. The GREET composition encompasses more than the EV and so they provided a decomposition, which would best fit all vehicle types. The GREET tool is widely used in the LCA community in order to model different vehicles. There is an online version but also an Excel file which are available to the public.

According to the GREET, the main vehicle components are:

- Body system
- Powertrain System
- Transmission system
- Chassis
- Traction Motor
- Generator
- Electronic controller

- Fuel Cell auxiliary system
- Batteries
- Fluids (excluding fuel)

The relevance of these components depending on the vehicle type can be seen in Figure 14.

**TABLE 2 Vehicle Systems Included in GREET2_2012**

| System | ICEV | HEV | PHEV | EV | FCV |
|---|---|---|---|---|---|
| Body system | ✓ | ✓ | ✓ | ✓ | ✓ |
| Powertrain system | ✓ | ✓ | ✓ | ✓ | ✓ |
| Transmission system | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chassis system | ✓ | ✓ | ✓ | ✓ | ✓ |
| Traction motor | | ✓ | ✓ | ✓ | ✓ |
| Generator | | ✓ | ✓ | | |
| Electronic controller | | ✓ | ✓ | ✓ | ✓ |
| Fuel cell auxiliary system | | | | | ✓ |
| Batteries | ✓ | ✓ | ✓ | ✓ | ✓ |
| Fluids (excluding fuel) | ✓ | ✓ | ✓ | ✓ | ✓ |

Figure 14: Vehicle components included in GREET depending on the vehicle type (Argonne National Laboratory, 2012)

The main components were established so as to make sure that every vehicle system can be modelled in the tool. For each main component there are sub-components described with sub-sub-components, etc. The GREET tool also provides material entries for the vehicle main components in the Excel sheet, as well as a detailed battery material composition (see Table 4 and Appendix A9. ). The list of materials is not provided for the sub-components. However, there are no entries for the processes used to build the components and the vehicle and no information about them.

Table 4: GREET – Material Composition for Vehicle Components (U.S. Department of Energy, 2022)

| Body | Powertrain System (including BOP) | Transmission System/Gearbox |
|---|---|---|
| Steel | Steel | Steel |
| Wrought Aluminum | Stainless Steel | Copper |
| Cast Aluminum | Cast iron | Cast Iron |
| Copper/Brass | Wrought Aluminum | Magnesium |
| Zinc | Cast Aluminum | Wrought Aluminum |
| Magnesium | Copper/Brass | Cast Aluminum |
| Glass Fiber-Reinforced Plastic | Magnesium | Carbon Fiber-Reinforced Plastic |

| | | |
|---|---|---|
| Glass | Glass Fiber-Reinforced Plastic | Average Plastic |
| Carbon Fiber-Reinforced Plastic | Average Plastic | Rubber |
| Average Plastic | Rubber | Others |
| Rubber | Carbon Fiber-Reinforced Plastic | **Chassis (w/o battery)** |
| Others | PFSA | Steel |
| **Traction Motor** | Carbon Paper | Cast Iron |
| Steel | PTFE | Wrought Aluminum |
| Stainless Steel | Carbon & PFSA Suspension | Cast Aluminum |
| Cast Aluminum | Platinum | Copper/Brass |
| Copper/Brass | Carbon | Zinc |
| Nd(Dy)FeB magnet | Nickel | Magnesium |
| Phenolic resin | Silicon | Glass Fiber-Reinforced Plastic |
| Enamel | Others | Average Plastic |
| Nickel | **Electric Controller** | Rubber |
| PET | Steel | Others |
| PBT | Cast Aluminum | **Fuel Cell Onboard Storage** |
| Mica | Copper/Brass | Steel |
| Fiberglass | Rubber | Stainless Steel |
| Silicone | Average Plastic | Carbon Fiber-Reinforced Plastic |
| Epoxy resin | Alumina | Glass Fiber-Reinforced Plastic |
| Nylon | Epoxy resin | Wrought Aluminum |
| Methacrylate ester resin | Fiberglass | Copper |
| Paint/Varnish | Gold | Average Plastics |
| Zinc | Nickel | Rubber |
| Others | Nylon | Nickel |

| Generator | PET | Silicon |
|---|---|---|
| Steel | Polypropylene (PP) | Others |
| Cast Aluminum | Polyurethane | |
| Copper/Brass | Zinc | |
| Others | Zinc oxide | |
| | Others | |

## III.3 Data Format and Data Exchange

**Summary of key findings**

- LCA requires standardized data exchange formats for accurate assessments.
- There are several LCA data exchange formats available, with ILCD/eILCD being the most widely used and supported by the European Commission.
- Converters, like those offered by the GLAD initiative, enable interoperability between different LCA data formats.

Life Cycle Assessment (LCA) is a crucial tool for evaluating the environmental impacts of products and processes throughout their entire life cycle. One of the fundamental aspects of conducting effective LCAs is the exchange of data among researchers, businesses, and organizations to ensure accurate assessments and meaningful comparisons. To facilitate this exchange of data, standardized LCA data exchange formats and flow list have been developed. These formats serve as structured templates for organizing and sharing LCA data, making it possible to integrate data from various sources and perform comprehensive environmental assessments. In this context, this introduction explores the importance and significance of LCA data exchange formats, shedding light on their role in enhancing transparency, consistency, and collaboration within the field of environmental assessment.

In order to facilitate the exchange of Life Cycle Assessment (LCA) and Life Cycle Inventory (LCI) data, it is essential to choose a standardized format. There are several formats available for the exchange of life cycle data, and in this report, we will introduce the most widely utilized one.

Emerging LCA databases may initially adopt a single format, which lead to multiple formats in the long run. The technical ISO standard, specifically by (ISO, 2002) offers guidance to developers of life cycle data. This standard establishes the requirements and structure for a data documentation format, which ensures transparent and unambiguous documentation and exchange of LCA and LCI data.

Currently, there is several established data exchange formats, specific to a software or not. For example, ILCD/eILCD format is supported by the European Commission. ILCD/eILCD is conform to ISO/TS 14048 and is based on the Extensible Markup Language (XML). (European Commission, 2023)

However, in order to allow the use in several software or ease the spread of the use of specific data, a converter can be used. It is the case of the GLAD initiative. Converting data between these commonly used exchange formats is facilitated by available converters, which can be found in LCA software or within the GLAD network's converter function. GLAD enables interoperability of LCA data. To enhance interoperability between formats, GLAD offers a conversion function. This allows users to convert a dataset from its native format into a format convenient for the user. (GLAD, 2023)

The next sections will only focus on ILCD and eILCD format because it is supported by the European commission, importable in most of the LCA software via the Data working groups set up by the European Commission (European Commission, 2023; ISO, 2002).

### III.3.1 The ILCD/eILCD Format

**ILCD**: the development of the International Reference Life Cycle Data System (ILCD) was driven by the need for: (i) a data format for the European Reference Life Cycle Database (ELCD), (ii) a common format to support data exchange (import and export) of the ELCD reference datasets with other databases and software tools, (iii) a common format to be used to exchange LCA datasets among all relevant LCA tools and databases (e.g. for LCA information transfer along supply chains) and for data networks, and (more recently) and (iv) the development of data under the Environmental Footprint scheme (PEF/OEF). The ILCD format is supported by most major LCA software applications, and it is used, besides in the Life Cycle Data Network (LCDN), by national LCA databases, such as SICV in Brazil, MYLCID in Malaysia and the Thai National LCI database (UN Environment programme, 2020).

Additional developments: The Product Environmental Footprint / Organizational Environmental Footprint (PEF/OEF) was developed in ILCD format with significant changes to the elementary flow nomenclature system. These changes must be considered during the development of national databases due to the need for homogeneity in nomenclature among the datasets to be created using the ILCD system. This is also fundamental for ensuring data interoperability (UN Environment programme, 2020). Several versions of the flow list were developed (2.0; 3.0 or 3.1 in the frame of the Environmental Footprint project). Currently the last elementary flow list version is the EF 3.1 available at (European Commission, 2022).

Beside ILCD format the extended ILCD (eILCD) format is also available. It allows representing entire models consisting of ILCD process data sets. In order to allow the exchange between software, some convention and modelling specifications were necessary. They are listed in in a specific report (Zampori, et al., 2020).

### III.3.2 Distribution of the LCA data

Once the dataset is produced then it needs to be set available for the final users, it can be uploaded to a specific website as ILCD file which can be downloaded, put on a node like what is done in the Environmental Footprint project (European Commission, 2023). Putting the dataset on a node allows the final user to see the documentation, the inventory in a web browser, and then download the dataset. It is important to make the data available, but it is more important to make the people know that the data is available. That is why it could be good to connect the results produced in the frame of TranSensus with GLAD.

**Global LCA Data Access (GLAD) Network**

The Global LCA Data Access Network (GLAD) is the largest directory of Life Cycle Assessment datasets, from independent LCA database providers, from around the world. GLAD does not directly host databases. Its main purpose is to help users find the LCA data they need. It then redirects the users to the data provider website, from which the datasets can be downloaded, for free or against a commercial license fee. To enhance interoperability between formats, GLAD offers a conversion function. This allows users to convert a dataset from its native format into a format convenient for the user. (UN Environment, 2020)

GLAD provides a search engine to find and access LCT datasets from different independently operated LCA databases (nodes). The interoperability of data from different nodes and in different formats is achieved through a set of metadata descriptors required for all datasets linked to GLAD. Furthermore, nodes joining the GLAD network commit to fulfilling a minimum set of requirements, including use of one of the main data exchange formats, a common flow nomenclature, that all meta-information of datasets is provided in the English language (as a minimum), and that the meta-information is freely available. (UN Environment programme, 2022; GLAD, 2023)

The GLAD node requirements are available (UN Environment programme, 2020), and a guidance on GLADs metadata descriptors is also available, see Appendix A10.  (UN Environment programme, 2023).

GLAD does not endorse or promote any specific data format. However, it is desirable that the data is made available in one of the data formats supported by the GLAD converter function (ecoSpold1, ecoSpold2, ILCD, JSON-LD) to achieve interoperability for users.

# IV. TranSensus Ontology

This chapter gives general information and detailed descriptions of certain ontology elements, which form the TranSensus LCA ontology (TLCAO). To be able to create a usable ontology that is in line with the workflows already in place on side of the OEMs, we conducted several meetings and sent a questionnaire, see appendix A2. On several occasions this led to insights and caused smaller adaptions during the creation of this report. Especially regarding the decomposition.

Starting with the intended domain and scope and a description of the concept of ontology in relation to the TranSensus LCA project. Continuing with explaining the direct implementation of ORIONT and the inclusion of a vehicle and battery decomposition. Followed by explaining the integration of S-LCA and economic factors and ending this chapter with discussing possible future implementations and use cases.

## IV.1 Intended Domain and Scope

As shown in chapter II.2 determining the domain and scope of the ontology are the first step in ontology development. This is done by giving descriptions in five categories:

**Goal:** Creation of a common ontology for an LCI database for the road transport sector and battery value chain

**Purpose**: Development of a unified, evidence based LCA approach to enable mobility providers and planners to optimize their products and solutions in a sustainable way

**Domain**: Zero emission road transport system

**People**: Mobility providers, suppliers, planners, and policy

**Utility**: Standardized and structured representation of knowledge, to facilitate data integration, interoperability, and consistency in environmental life cycle assessments for zero-emission road transport. Supporting decision-making processes, enabling comparison of different vehicles and technologies, identifying areas for improvement, and promoting sustainable practices in the development and deployment of zero-emission vehicles and associated infrastructure.

## IV.2 Description of Ontology in Relation to the Project

In the context of environmental life cycle assessment (LCA) for zero-emission road transport, an ontology can be defined as a structured and formal representation of knowledge that encompasses the environmental aspects, variables, and relationships specific to the life cycle of zero-emission vehicles and associated infrastructure. It provides a standardized framework for organizing, categorizing, and interconnecting information related to LCA in the context of zero-emission road transport, including resource consumption, emissions, waste generation, energy use, and other environmental impacts.

Properties or attributes are assigned to each class to describe their characteristics, values, and relationships with other classes. These properties can include quantitative parameters such as energy consumption, emissions, resource use, as well as qualitative attributes like technology type, and vehicle specifications.

The ontology is developed with consideration for existing standards and guidelines specific to road transport and LCA methodologies. It undergoes iterative refinement and validation through expert feedback and stakeholder engagement to ensure accuracy, consistency, and applicability.

By providing a standardized and structured representation of knowledge, the ontology facilitates data integration, interoperability, and consistency in environmental life cycle assessments for zero-emission road transport. It supports decision-making processes, enables comparison of different vehicles and technologies, identifies areas for improvement, and promotes sustainable practices in the development and deployment of zero-emission vehicles and associated infrastructure.

## IV.3 Adaption of the ORIONT ontology

As the ORIONT ontology from the ORIENTING research project formed a close match to the scope of the intended ontology in TranSensus LCA, we adopted ORIONT as our baseline to start with. The basic structure was outlined in chapter III.1.1. During several discussions within this task, we agreed to include all elements from ORIONT without deleting specific elements. The group also identified some gaps, especially regarding S-LCA and a component and material classification or decomposition. These elements are described in detail in the following two chapters. As the scope and technical implementation of ORIONT is more generic than the scope of TranSensus LCA, TLCAO can be seen as a specific use case of ORIONT by adding several elements and therefore being more detailed. There are a few benefits from using this approach: 1) It is a common method to build up on existing ontologies, 2) the workload is drastically reduced, 3) we create a linkage to another EU project, 4) the main author of ORIONT is part of TranSensus and of big help in creation of TLCAO, and 5) improved consistency in the field of ontologies for LCA in a broader context. The drawbacks are that ORIONT has not yet been officially published yet, and it would have to be checked if possible future changes in ORIONT would have to be implemented in TLCAO.

## IV.4 Inclusion of a Decomposition Tree

**Summary of key aspects**

- A standardized nomenclature system is essential to ensure unambiguous identification of items within a taxonomy.
- The decomposition tree of this report should facilitate collaboration across work packages and tasks and offers several possible applications.
- The JRC's Carbon Footprint of Electric Vehicle Batteries (CFB-EV) proposal was adapted for batteries and the US Department of Energy's GREET model for vehicles.
- The main reasons for adaptions are adaptation to ZEVs, improving clarity and detail, splitting categories, and adding process details. This is to be compatible with the OEMs needs and the scope of the TranSensus project.

**Purpose of the tree**

In the steering committee, it was decided that a decomposition tree will be established in task 2.1 and could then be used in other tasks and work packages.

In the scope of task 2.1 Ontology, the purpose of the decomposition tree is to provide a common structure to facilitate the implementation of the methodology. The nature of this decomposition tree is purely informational. Here, it is not the goal to impose a decomposition for a BOM or inventory, only to provide a support to make sure that the methodology is developed starting from a common basis. Using a common language can be very helpful in the development of a methodology. It will be up to the other tasks and work packages to propose applications using this tree and recommend or impose to use it or not.

Possible usages of this tree include (but are not limited to):

- Task 2.1 - Ontology: the decomposition tree and the "semantic ontology" are the same, they provide a common understanding of a vehicle and its components. The tree could help build the tool to visualize the ontology and modify it further.
- Task 2.2 - System boundaries: support to identify which parts, for the vehicle, must be considered or not. An example is the cable for the charge. Other examples are the maintenance parts such as tires, auxiliary battery, fluids, …
- Task 2.3 - Inventory data collection: support to define which parts should be primary or secondary data and with what level of detail. It can also help to see which parts or processes are hotspots.
- Task 2.4 - Impacts assessment: support to define groups of components in the case of recommendations for group analysis in the contribution analysis, this could help to enable comparisons.

- Task 2.5 - Sensitivity/uncertainty/scenario analysis: support to specify with precision the perimeter of one-at-a-time sensitivity analysis when components or group of components are concerned.

Note that, since the decomposition tree is a common generic structure, it will have to be adapted to the application case / project.

**Granularity**

As explained previously, in the scope of task 2.1, the goal of the decomposition tree is to provide a common structure and to facilitate communication with a clear and shared understanding of the product under study. The granularity level required for the decomposition tree must then be chosen so that:

- The decomposition tree remains as generic and simple as possible for partners and users of the TranSensus methodology.
- It also leaves as much room as possible for innovation and improvements.

In particular, the decomposition tree will be used to agree on what is included in each part of the inventory. Once this common understanding is attained, it allows comparison of LCA results not only at the level of functional unit, but also at finer level of detail. Furthermore, it also allows a clear definition of which parts of the inventory are required to use primary data. Therefore, the granularity required for the decomposition tree is set to fit LCA comparisons, and for the definition of mandatory primary data.

Consequently, in task 2.1, the decomposition tree does not provide a final detailed and complete decomposition that can be used directly to calculate an LCA. It does neither give the list of numerous possible materials (e.g., type of plastic, steel…) that could be considered in each part of the inventory. This remains the responsibility of the LCA practitioner.

**Building process of the tree**

A state-of-the-art review was done to list the different decompositions that might already exist for the vehicle, see Table 5.

Table 5: Pros and cons of existing decompositions

| Guideline | Pros | Cons |
|---|---|---|
| CFB-EV (battery) | - Detailed decomposition<br>- Takes into account the processes<br>- Clusters make it easier to associate different parts and make the tree more generic | - Takes into account the entire cooling system which is out of scope of the battery |
| GBA (battery) | - Provides a process flow sheet for the battery | - The names of the processes are not detailed on the schematics<br>- There isn't a complete visual (the information is scattered in the rulebook) |
| BVCO (battery) | - Clusters | - No processes |
| CATARC (vehicle) | - Takes into account the use phase<br>-Material/process decomposition | - Not very detailed (only 5 vehicle categories and 4 processes)<br>- The processes aren't linked to specific parts |
| GREET (vehicle) | - All types of vehicles are modelled<br>- Decomposition by parts and subparts<br>- Very detailed | - When focusing on ZEV the decomposition doesn't make a lot of sense<br>- No processes |
| EPD (passenger cars) | - In line with all the ISO regulations | - Focus on materials<br>- Mentioned processes are very generic (e.g., manufacturing process) and divided in upstream/core/downstream not by parts |

For the decomposition of the traction battery, we decided to use and adapt the one proposed by the JRC in the final draft for the Rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries (CFB-EV), Figure 1 (Andreasi Bassi, et al., 2023). This decomposition is further explained in chapter III.2.2. We chose this one because it is to our knowledge the only decomposition that includes both components and the processes associated. It is very complete while remaining generic enough so every OEM can understand it and apply it to its value chain (with minor adaptations). To be noted, we only reused and adapted the tree, not the purpose of this tree in the CFB-EV rules which is to determine where and when to use primary vs secondary data. We were only interested in the structure.

For the decomposition of the vehicle, we decided to use and adapt the one from GREET (U.S. Department of Energy, 2022). This decomposition is further explained in chapter III.2.5. It is the most complete decomposition available and very often used in the literature to model vehicles for LCAs, it is often updated to reflect best the market.

The first step of our work was to adapt these decompositions to propose a first structure of the tree. We then reached out to the OEMs to collect their inputs on this structure with a questionnaire. The first questions addressed the basis of the building process and the OEMs required having more information on the possible usages of the tree. Then a series of questions addressed the different parts of the tree to collect further data or change the structure. The OEMs gave a few remarks that were implemented in the decomposition trees.

For TranSensus, we have adapted the GREET vehicle decomposition and the JRC battery decomposition with some changes that we detail below.

**Modifications from GREET and JRC decomposition: main changes and reasons**

We have chosen to use the GREET decomposition as the base vehicle decomposition. Nevertheless, we have made a few modifications for TranSensus, for the following reasons:

- The GREET decomposition is already well detailed, but there are still some components that are not explicitly listed. That could lead to mistakes and wrong classifications by the user. Additionally, it is also interesting to provide a rather detailed list of components to be sure not to forget any. (Exhaustivity is, of course, not possible, nor even recommended). Therefore, we have added some components to make them appear clearly or completed the wording in the description categories.
- Additionally, some categories are large categories, regrouping numerous components. We have then directly split some of them into two parts (only done for the car body) or shift the level to directly have a sub-level (done for the 'Battery systems' GREET category, directly replaced with 'Auxiliary battery' and 'Traction battery' at 'n-1' level.
- Another point is that the GREET decomposition is a decomposition into parts, close to a BOM ('Bill of Materials'). It does not include processes. We have then added, for each part, a process. Each block can then be considered as including both the physical component and the process operations required to obtain this component (or system). By default, we have

considered a generic process, that we have named 'Production/assembly/control'. But, when available, we have proposed a more detailed process.

For the traction battery decomposition, we have chosen to use the JRC tree as the base. This decomposition is recent, detailed, and complete. It also includes both parts and processes. We have then only proposed very few modifications. They mainly consist of listing some sub-components in the battery pack. Like for GREET, the reason is to give a clearer view of the components (/processes) to avoid forgetting some.

In case there is an update of the GRB battery decomposition, then it may be necessary to adapt our decomposition tree.

A comment was made during the voting process, that the decomposition tree does not reflect heavy duty vehicles (HDV) sufficiently. Thus, additional elements were integrated that better reflect HDVs. Note, that while this does not change the overall concept, the additional elements still need to be verified by OEMs and the project partners.

**Limitations:**

- The first limitation of the decomposition tree is that there are plenty of possibilities to subdivide a vehicle into parts or processes. The decomposition tree, that we propose here, must therefore be considered as a proposal to help common understanding, and it will need to be adapted when needed, and will gain to be improved.
- Concerning the vehicle decomposition, we consider that the GREET decomposition has several advantages and have decided to use it as a basis. We then give priority to keep as much as possible the same structure and decomposition as GREET for the vehicle. Nevertheless, this results in some limitations.
    - One of the main examples is the 'Powertrain' category. Indeed, when we study vehicles with combustion engines, the GREET 'powertrain' category, which includes the engine, is quite easy to understand. But, when we only study ZEV, then it seems improper to still have a 'Powertrain' category. This is because the GREET 'Powertrain' category also contains some other items such as the thermal management or the fuel cell stack. Completely deleting the 'Powertrain' category would have led to move these parts (thermal management or stack) to other categories, and thus to modify the GREET structure, what we wanted to avoid. The 'Powertrain' category is also used, with an engine, for hydrogen ICEV. Note also that in many other decompositions, the electric motor can be considered as part of the powertrain. This is not the case for GREET.

- Another limitation is the 'Traction motor' category of the GREET vehicle decomposition. The sub-level is described in GREET as 'Electric motor', which is the same as 'Traction motor'. We have the same for the 'Transmission system' category, which contains the 'Transmission unit' (not deeper detailed in the GREET). Once again, to keep the GREET decomposition, we have kept the GREET categories, meaning that the 'n-1' level is more a list of categories/families, and 'n-2' is closer to a list of components, sometimes identical to their category.
- Another limitation is the consistency of the decomposition between the GREET vehicle decomposition and the JRC battery decomposition.
    - The JRC battery decomposition provides a very detailed level of decomposition. For the GREET vehicle decomposition, the level of details for the components is not as deep. Anyway, we consider it interesting, since the traction battery is a major hotspot for electric vehicle analysis. An improvement could be to also detail, with the same level as JRC, the other vehicle components that are vehicle hotspots.
    - Concerning fluids, they are all gathered in a dedicated 'fluids' category in GREET. In JRC battery decomposition, the battery coolant is included in the battery block. Our proposal is to keep it like this, so that we minimize changes from the JRC battery decomposition.

Details on the modifications are found in Appendix A13.

**Visualization**

To provide an easy visualization of the decomposition tree, the Excel file containing the decomposition, once established, can be transformed into a .html page. This .html page can then be used by anyone who wants to view the decomposition tree, see Appendix A14. Each colored block corresponds to a category of the GREET decomposition. Then the user can click and zoom on any block to access to lower levels. The view on the different blocks and zoom are interactive on the .html page, but the decomposition tree content and structure can not be modified in .html. If the decomposition tree is modified in the Excel file, then a Python code is used to regenerate the associated .html visualization.

**Future improvements**

Future improvements will be done for the decomposition tree:

- Give more specific processes for each material/component and add definitions/annotations
- Define the decomposition tree for other phases of the life cycle like the 'use and maintenance' phase, and the 'EOL' phase

- Continue to improve the contents of the decomposition tree so that it is usable not only for passenger vehicles but also for heavy duty vehicles or light vehicles.

This work is on-going.

## IV.5 Inclusion of S-LCA

**Summary of key aspects**

- Being primarily based on the UNEP Guidelines, the S-LCA ontology also integrates elements from ILCD, BONSAI and ORIONT.
- A novel feature compared to existing ontologies is the integration of the Reference Scale Approach, serving as a comprehensive method for evaluating and contrasting social impacts.

In the Social Life Cycle Assessment(S-LCA) context, ontology refers to a structured knowledge representation that defines and categorizes the various elements, relationships, and concepts within the domain of social impacts of products and services. It provides a framework for systematically understanding, assessing, and communicating the social implications throughout the life cycle of a product, from raw material extraction to disposal.

The ontology proposed in the TranSensus LCA project for the S-LCA domain is primarily based on the UNEP Guidelines (UNEP, 2020). This core structure serves as the foundational blueprint. However, to ensure a comprehensive and holistic approach, the ontology also integrates elements from other prominent ontologies, namely those presented by ILCD, BONSAI and the ORIENTING (ORIONT) project. A significant distinguishing feature of the ontology, as compared to existing ontologies, is its incorporation of the Reference Scale Approach. This approach serves as a comprehensive method for evaluating and contrasting social impacts. The ontology's foundation is rooted in TranSensus, which advocates for the utilization of the Reference Scale Approach in S-LCA for ZEV.

Although the ontology in question is primarily designed based on the Guidelines for social life cycle inventory, it is worth noting that the definitions of the incorporated classes also bear relevance to other phases of S-LCA, such as the attributes of Goal and Scope, as well as Social Life Cycle Impact Assessment (S-LCIA).

While the foundation and structure of the standard LCI database may be the same with regard to the inventory data for S-LCA, the aggregated data (as well as the intermediate and end impact categories for impact assessment) are different. The Guideline describes the types and nature of S-LCA inventory data that must be obtained (and how) and organised in the database. In real time, this can entail specific database sections or fields for S-LCA data. Data collection for S-LCA is still in its initial stages.

**Social LCA ontology proposed by the TranSensus LCA project**

The ontology is initiated from the ‘Flow’ class (at the centre of Figure 15), which serves as the central node connecting various other classes:

The ‘Flow Object’ class, for example, represents the specific entity being analysed, such as Cobalt. It is closely linked to the ‘Flow Properties’ class, which forks into two distinct sub-classes. ‘Economic Flow Properties’ encapsulate monetary dimensions, such as Currencies and their market value, exemplified by the USD. In contrast, ‘Technical Flow Properties’ delve into physical metrics, such as mass.

Another integral class branching from ‘Flow’ is the ‘Source of Collection’. This describes the genesis of the data, dividing it into ‘Primary Data’, which is data that is collected directly from stakeholders, such as through interviews, and ‘Secondary Data’, which is obtained indirectly from repositories such as databases (e.g., PSILCA, SHDB). These definitions are used for deliverable D 2.1, as by the date of submission a consensus was not yet established within WP2. These definitions can change depending on the results in other tasks. These two categories of data are further refined by their ‘Data Type’, which can be quantitative, qualitative, or semi-quantitative.

Data integrity and reliability are paramount. Hence, the ‘Data Quality’ class emerges from the ‘Flow’ class, serving as a beacon of data reliability. Inspired by the Pedigree matrix to assess the quality of data sources, this class is segmented into several criteria. These include the ‘Reliability of Source’, which might be verified by external experts, ‘Completeness Conformance’ ensuring representative data, ‘Temporal Conformance’ focusing on reference and validity years, ‘Geographical Conformance’ pinpointing data's location specifics, and ‘Technical Conformance’ which aligns with technology and sector.

Further enriching the ontology are the subclasses of Flow: ‘Product Flow’, highlighting sectors (e.g., agriculture); ‘Elementary Flow’, spotlighting elements (e.g., benzene); and ‘Social Flow’, which brings to the fore social issues (e.g., child employment risks).

The ‘Level of Resolution’ class, linked to ‘Flow and Process’, offers granularity to the data, spanning from Country Specific/Commodity insights to broader Country/Region Proxy averages.

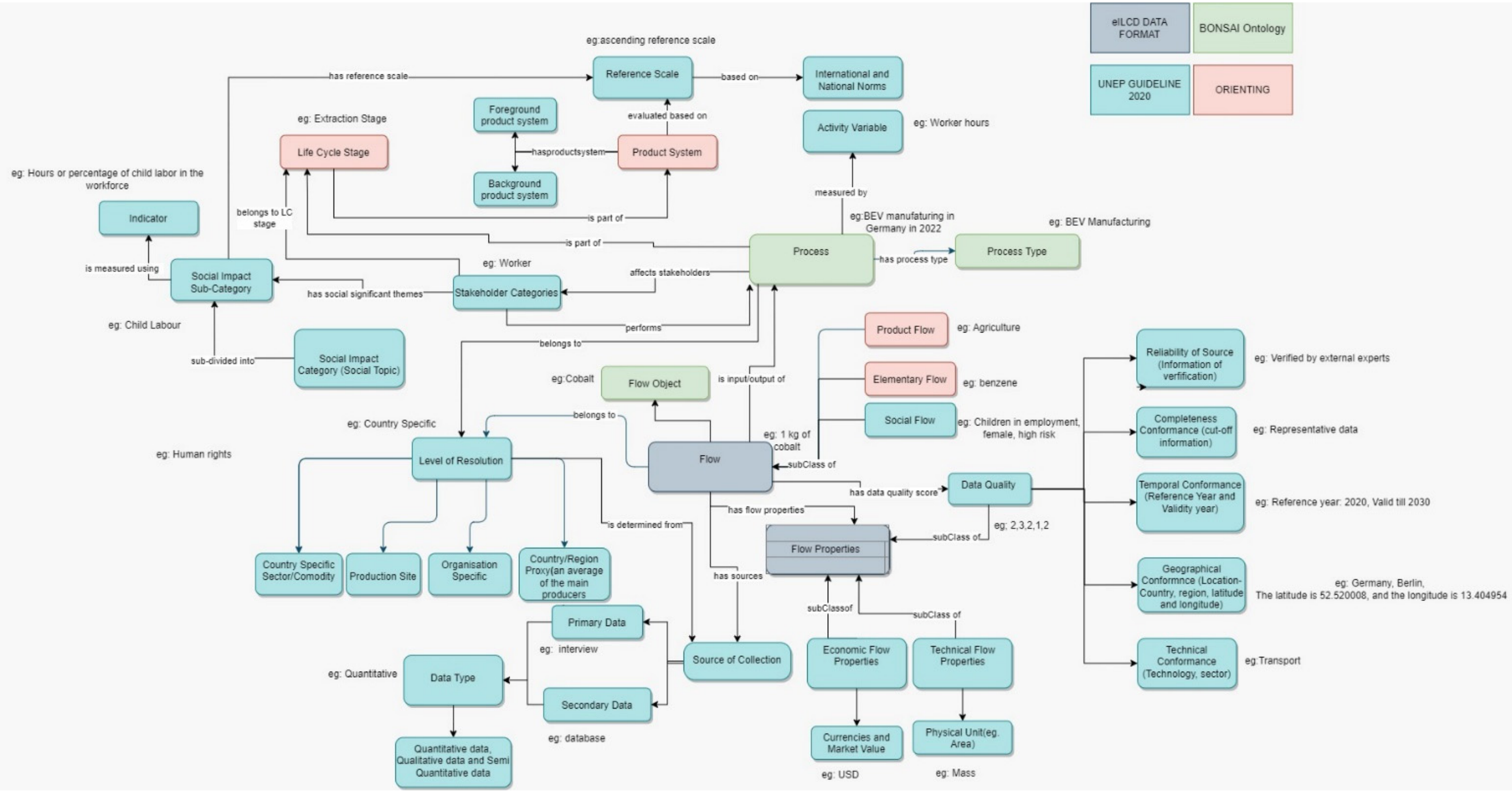


**Figure 15:** TLCAO S-LCA

The 'Flow' class, central to the ontology, interacts dynamically with the 'Process' class, serving as either an input or output. This 'Process' class is further characterized by its specific type, as defined by the 'Process Type' class. Intriguingly, the operations or actions within the 'Process' class can be influenced by various Stakeholder Categories, such as Workers. These stakeholders have social significant themes called 'Social Impact Sub-Categories', like Child Labour. The 'Social Impact Category' which is also called as social topic in other ontologies is sub-divided into impact sub-categories, which is measured using social indicators. Once these social topics are identified and selected, they undergo a rigorous evaluation process. Each Impact Sub-Category has 'Reference Scales' which are developed based on International and National Norms, ensuring that the evaluation is both standardized and contextually relevant. This evaluation leverages the 'Reference Scale Approach', which might employ methods such as an ascending reference scale. Each unit Process are part of Life Cycle Stage and finally attributes to Product System. The Product Systems are evaluated based on 'Reference Scale'. Each Process are measured by an Activity Variable (e.g.: Worker Hours). The activity variable is used to measure process activity or scale that can be related to a process output.

## IV.6 Inclusion of Economic Factors

Currently, there are no standards regarding LCC and only a limited amount of literature covering LCC of ZEVs is available, as mentioned in TranSensus Deliverable D1.1. This report points out four aspects, that one has to be aware of:

1. Clear guidance on LCC type,
2. Quantification of environmental and social impacts,
3. Addressing double counting when integrating LCC with S-LCA, and
4. Harmonizing the choice of discount rate. (Eltohamy, et al., 2023)

LCC is already part of the ORIONT ontology. Specifically, LCC is an instance of the class *SustainabilityTopic*, and therefore it is part of TLCAO. In the ORIENTING report, more details can be found about their handling of the discount factor as a CF. (ORIENTING, 2022)

Once an agreement has been reached on how economic factors should be treated within TranSensus LCA, they can be further specified and integrated into the ontology. This would be similar to adding specific elements for S-LCA, as has been outlined in the previous chapter.

## IV.7 Implementation and Usage

### IV.7.1 Technical Implementation of TLCAO

To implement and visualize the technical ontology, an OWL file was created. As described in Section II.3, different tools can be used to build ontologies, with Protégé being the most common one. However, due to the iterative nature of ontology development, an automated procedure was established to streamline the ontology development, reducing the development time and manual input error (see Fig. 16).

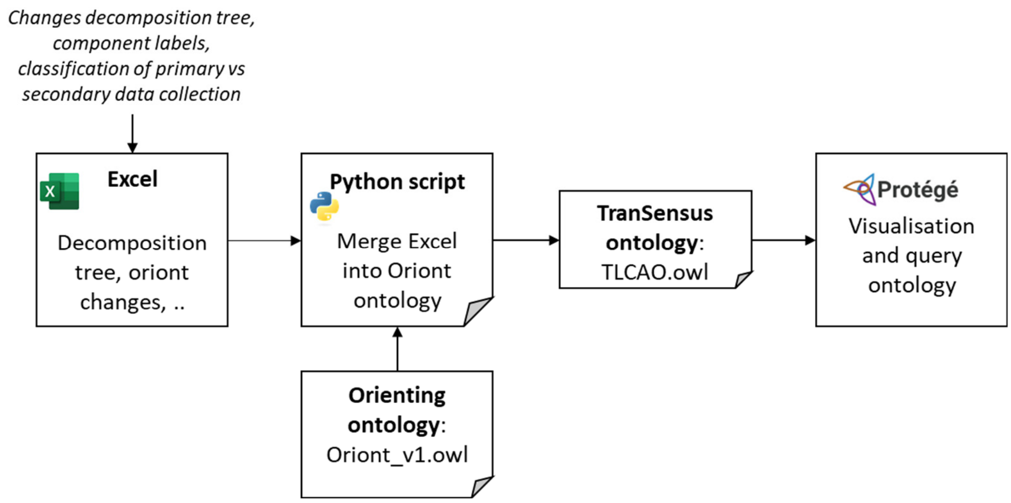


**Figure 16:** Automation logic to develop the TranSensus ontology

An Excel file was prepared listing all elements of the TLCAO. This included all vehicle components and the relation between them, annotations of components and data source types for each activity (i.e., if inventory data for each activity should be based on primary or secondary data). A Python script was created to import the ORIONT ontology and add all classes, instances and properties to the existing ontology using the Owlready2 package (Lamy, 2017). For example, anode was classified as an instance of ProductFlow (original ORIONT class), and related to cell production (an instance of the original ORIONT Activity class) through the isInputOf ORIONT property (see Fig. 17).

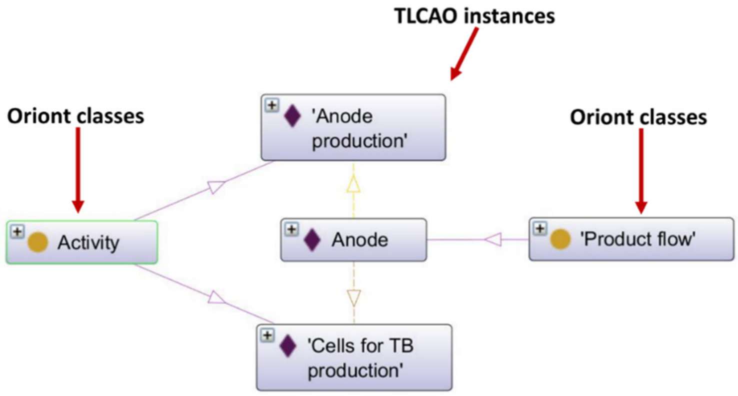


Figure 17: Example of linking TLCAO instances with Orient classes

Following the merging of the original ORIONT ontology and the TLCAO Excel file, an owl file was created, which can be imported in to Protégé to query, visualize and further develop the ontology. Browsing for components and their associated data can be facilitated by using the query function in Protégé. Queries can be conducted depending on the desired level of detail, as shown in the following, see Figure 18.

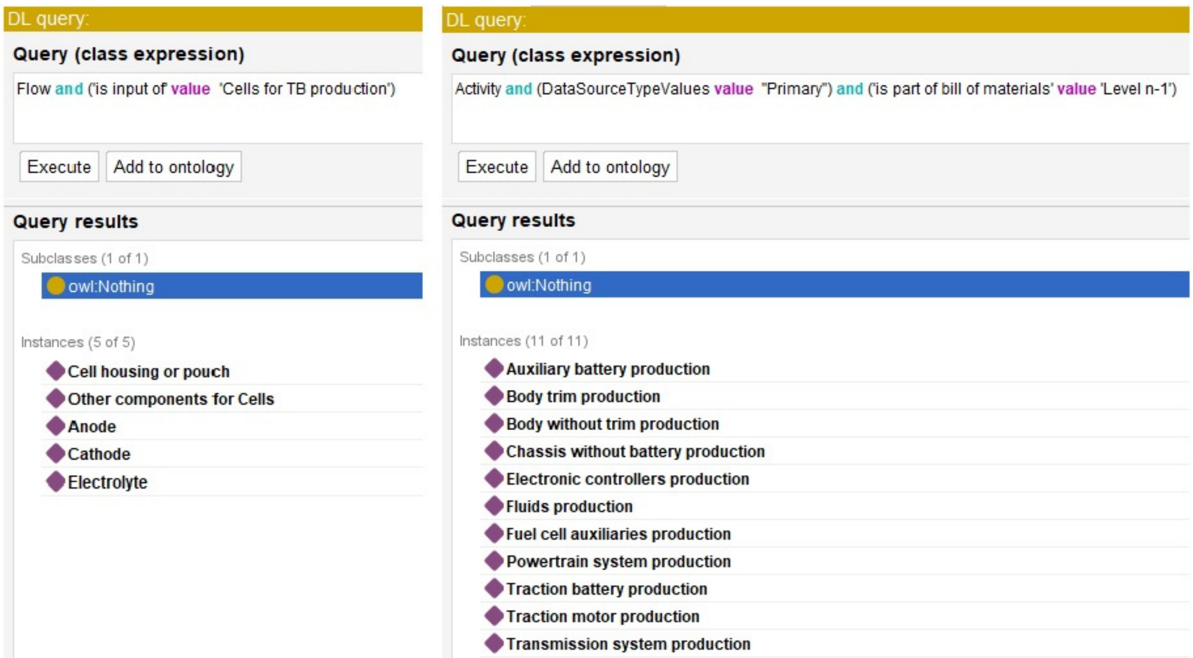


Figure 18: Examples of querying TLCAO with different degrees of specification

The visualization option in Protégé facilitates investigating the corresponding ontology. Relevant terms can be entered and displayed in an interactive knowledge graph which provides information on properties and interrelations of corresponding (sub-)components. Figure 19 demonstrates this at the example of the search term “cells for tb” which refers to the production of an automotive traction battery.

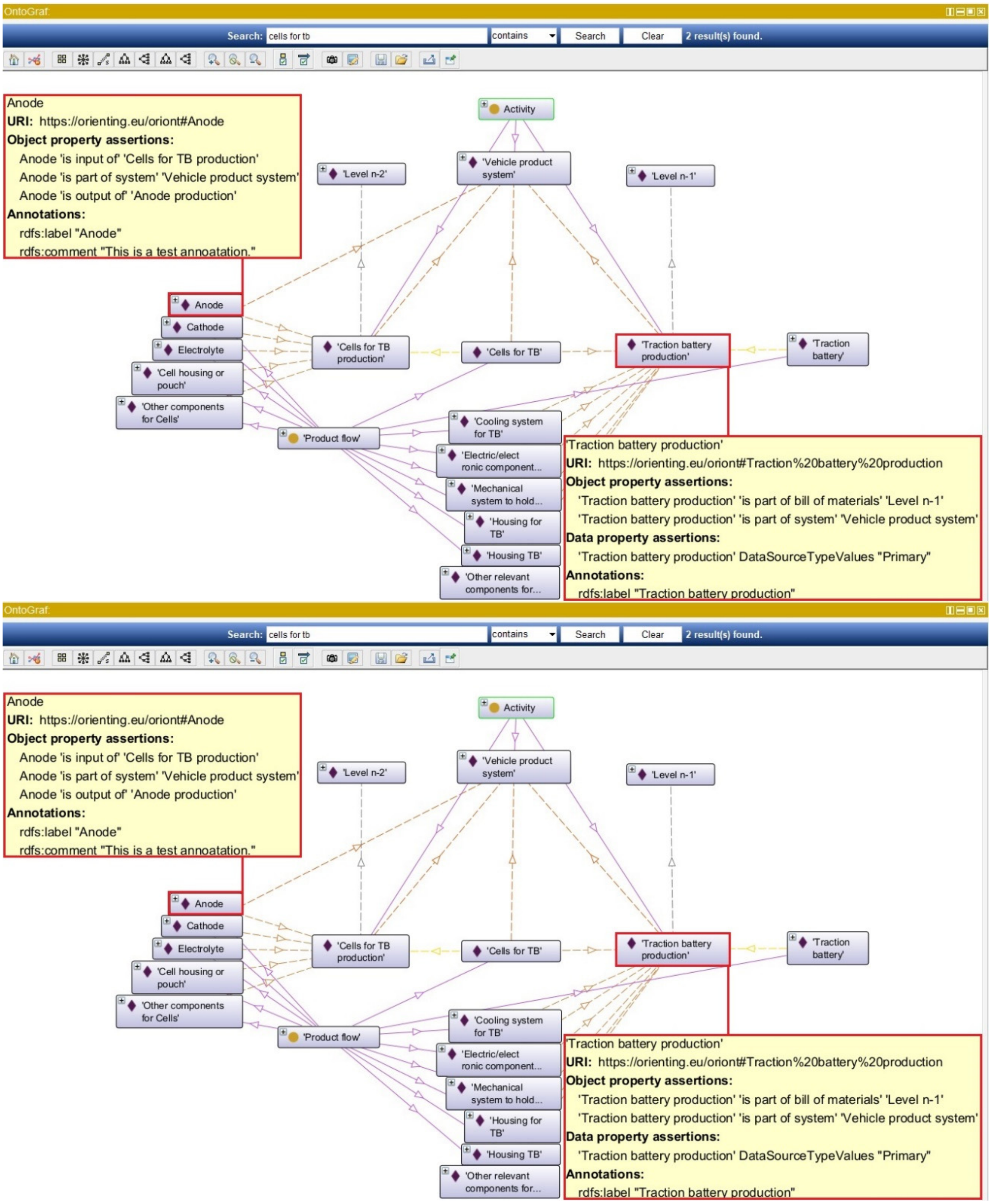


**Figure 19:** Example of visualizing relevant parts of the TLCAO

### IV.7.2 Database Maintenance and Updates

The maintenance of the data is a key point. However, one size does not fit all. A description of different aspects to be considered in data maintenance are presented below.

**Overall organization**

The general way of sharing/distributing datasets can be done in several ways. 1) An association that is collecting data, creating datasets and providing these. 2) An overarching organization that is collecting and providing received datasets and is organizing the update procedure (e.g., European Commission or data providers). 3) Each company is in charge and publishes their own datasets on their website, e. g. for Bussiness2Business data exchange of LCI data.

For example, Eucar-Concawe publishes updates of their report regularly, providing the carbon footprint of several fuels. Plastics Europe provides a website with the possibility to download ecoprofiles in several LCA software formats. Such aspects can be important because it gives consistency in data update.

Relevance in maintenance: Low to Medium

**Technical knowledge**

Knowledge on LCA methodology, the creation of LCA models, LCA software and LCA data export are important aspects to make the maintenance a success.

Making an LCA study/creating datasets either internally by a company or externally (consulting) is not the most critical question, but the workflow (for data development and maintenance) has to be clearly defined. Also, the implication of several steps (data collection, LCA model creation, QA of the model, data export, etc.) has to be well known. Even with a high knowledge of a certain company product, an LCA practitioner has to be able to model that correctly in the software. An important aspect of updating and maintenance is the possibility of being able to update the model if necessary and export datasets in the right format.

For each and every step the necessary knowledge should be available within the company or with a partner you can consult/rely on.

Relevance in maintenance: Medium

**Scope**

An important step in LCA is the definition of goal and scope. In the case of the TranSensus project, those aspects will be discussed in WP2, in particular in Task 2.2. Depending on if the company developing the data is a part supplier or a car producer the expectation regarding data maintenance/update is different. As soon as a part is changed, a new version of the corresponding dataset should be developed, either as replacement if the part is discontinued or as a new dataset if the two parts remain in the catalog of the supplier/producer. If a PCR or a PEFCR exist or a regulation (at country or regional level, e.g., like the EU) the scope is also very specific.

If the dataset corresponds to one specific company, it is easier to update than a dataset for market average. The specific company dataset is easier to update, because only one company has to collect new data. If the dataset is a market average, this average needs to be built and therefore more data needs to be collected (market share of several producers and production processes of several producers). Depending on the number of actors involved the maintenance interval shall be adapted.

Relevance in maintenance: Low

**Software capabilities in background data update**

The software shall at least make the update of background data possible. A functionality to update datasets in an automatic way is highly useful and reduces the amount of work and the number of errors.

Relevance in maintenance: Medium

**Data update**

Foreground and background data updates must be available in order to create new versions of datasets. Foreground data can be stable, but it should be cross checked that no significant changes happened in the corresponding production process. Background data shall be updated on a regular basis (interval to be defined). At the moment, only large data providers support regular updates of their data, but it is also software dependent.

Relevance in maintenance:  Low to Medium

**Data format**

Several LCA software provide several data formats. The aim of a data provider is to provide it's data to as many users/clients as possible. Several formats should be made available but usually a software can deal with only a few formats. At the moment, the ILCD/eILCD format is the LCA data exchange format that is supported by the European Commission. Therefore, it is easy to import in most software, with some compliancy needed (a software exists to test the

EF compliancy of the dataset, considering data quality indicators, documentation, version number, etc.)

Relevance in maintenance: High (especially in sharing)

A key aspect is the decision on how the database should be set up and by whom it will be managed. Three cases are presented, to show the pros and cons and a description of the aspects mentioned above, depending on the overall organization being in charge.

**Table 6:** Pros and cons for several data maintenance cases

| Case | A | B | C |
|---|---|---|---|
| **Overall organization** | Association | Consortium of organizations | Single company |
| **Technical knowledge** | Very good on all aspects because production specialists in close collaboration with LCA and software specialists | Good. Production specialists in close collaboration with LCA specialists | Company dependent |
| **Scope** | Market average | Project specific | Single product / company average |
| **Software update capabilities** | Yes | Software dependent | Software dependent |
| **Data update** | Yes | Database dependent | Database dependent |
| **Data format** | Usually several available (at least ILCD/eILCD), but depending on the software used | Software dependent | Software dependent |
| **Pros** | Experts at every level of the project, making the data very high quality and easily maintainable | High quality data | Maintenance frequency can be short, depending on company willingness and expert availability |
| **Cons** | Experts needed at every level (availability, costs), high time effort, maintenance frequency can't be short (due to time effort) | Maintenance frequency depends on too many factors | Maintenance depending on company willingness and expert availability, company experts need high knowledge on several aspects |

# V. Applicability of FAIR Principles

The application of the FAIR Principles on this report is described in Deliverable D 7.2 Data Management Plan of the TranSensus LCA project (Bein, 2023).

The following sections will provide details on the application of the FAIR principles on the ontology, divided into specific sections for data being Findable, Accessible, Interoperable, and Reusable (Wilkinson, et al., 2016).

**Findability:**

Being based on the ILCD/eILCD format allows the possibility of assigning a Universally Unique Identifier (UUID) to the datasets. This also provides the possibility to assign a large amount of metadata. In the frame of chapter III.3.2, it is suggested to make the data available via the GLAD network to allow a maximum of persons to find the LCA data developed within the frame of the project and using the ontology described in the document.

**Accessibility:**

If datasets are created according to the ontology described in this report, the data is retrievable through its UUID. The technical options of providing a database are outlined in chapter IV.7.

**Interoperability:**

The implementation of the ILCD/eILCD format implies the usage of “a formal, accessible, shared, and broadly applicable language for knowledge representation”. Once datasets are created, vocabulary that follows the FAIR Principles shall be used, and (meta)data shall include qualified references to other (meta)data.

**Reusability:**

With the proposed ontology, the (meta)data can be described with a variety of accurate and relevant attributes, and can be associated with detailed provenance. (Wilkinson, et al., 2016)

A variety of other relevant questions need to be addressed once a database is set up (see also chapter IV.7). An extensive set of questions can be found in the Data management plan of Horizon 2020. This includes for example: How will the data be made accessible (e. g. by deposition in a repository)? What methods or software tools are needed to access the data? If there are restrictions on use, how will access be provided? Is there a need for a data access committee? How will the data be licensed to permit the widest re-use possible? When will the data be made available for re-use? (European Commission)

# VI. Summary

Ontologies are formal structures that organize, classify, define, and link information. They describe concepts and their relationships, serving as data models for semantic networks and taxonomies. Ontologies enable data interoperability, knowledge reuse, and facilitate data integration. They are widely used in various fields including artificial intelligence, semantic web, software engineering, and more.

The importance of building on existing ontologies to reduce workload and increase connectivity and consistency was emphasized. Several ontologies, such as BONSAI, KIproBatt_v1, LCA methodology ontology, and ORIONT are examined for their suitability in the project's domain and scope. Additionally, various guidelines, standards, and reports were analyzed to determine their relevance to the ontology development process.

The ORIENTING research project focuses on developing a Life Cycle Sustainability Assessment (LCSA) methodology encompassing environmental, social, and economic aspects. The ORIONT ontology from ORIENTING is created for structuring crucial methodological and data elements. BONSAI ontology (BONT) forms the core of ORIONT, integrating and connecting previous sustainability assessment ontologies and public databases. Key takeaways include the importance of the development process, the acknowledgment that ORIONT is not finished yet, and that integration into the world of ontologies would require significant effort and expertise.

Life Cycle Assessment (LCA) requires standardized data exchange formats for accurate assessments. There are several LCA data exchange formats available, with ILCD/eILCD being the most widely used and supported by the European Commission. ISO standards guide the development of these formats, ensuring transparency and unambiguous documentation. Converters, like those offered by the GLAD initiative, enable interoperability between different LCA data formats.

The main development of this report is the TranSensus LCA ontology (TLCAO) for the road transport sector and battery value chain. It aims to create a standardized and structured representation of information for zero-emission road transport. The ontology facilitates data integration, interoperability, and consistency in environmental life cycle assessments, supporting decision-making processes, comparison of vehicles and technologies, identifying areas for improvement, and promoting sustainable practices.

Of high importance are hierarchical structures, or taxonomies, for understanding the relations and affiliations among components of a product. A standardized nomenclature system is vital for unambiguous identification of items within the taxonomy. The TranSensus LCA project analyzes existing decomposition trees to identify a suitable approach.

The decomposition tree in this report, aims to provide a common structure for implementing the methodology. It serves as a purely informational foundation to facilitate a shared understanding across different tasks and work packages. Applications of the tree can be found in ontology visualization, system boundary identification, inventory data collection, impact assessment, and sensitivity/uncertainty/scenario analysis. The building process of the tree started with a state-of-the-art review of existing vehicle decomposition approaches. The JRC's Carbon Footprint of Electric Vehicle Batteries (CFB-EV) proposal was adapted for batteries, and the GREET model from the U.S. Department of Energy was adapted for vehicles. After creating an initial tree structure, feedback was collected from OEMs through questionnaires and a meeting to refine the decomposition tree and make it suitably complete and accurate for all OEMs. Key reasons for these changes include adapting to zero-emission vehicles, improving clarity and detail, splitting large categories, and adding process information. The traction battery decomposition is based on the JRC tree, with minimal modifications to list sub-components in the battery pack. The decomposition tree for vehicles has several limitations: it requires adaptation and improvement due to numerous subdivision possibilities, and it largely follows the GREET structure, leading to challenges in understanding certain categories like 'Powertrain' for Zero Emission Vehicles (ZEVs). Another limitation is inconsistencies between GREET vehicle decomposition and JRC battery decomposition, particularly in terms of component detail levels and fluid classifications. These limitations need to be addressed for more accurate vehicle analysis.

The ontology elements regarding Social Life Cycle Assessment (S-LCA) are primarily based on the UNEP guidelines and is integrating elements from ILCD, BONSAI, and ORIONT. The key distinguishing feature of this ontology is its incorporation of the Reference Scale approach, aiding in evaluating and contrasting social impacts. While designed based on social life cycle inventory guidelines, the ontology's definitions are also relevant to other S-LCA phases like Goal and Scope, and Social Life Cycle Impact Assessment (S-LCIA).

The applied ontology revolves around the central "Flow" class, connecting various classes like Flow Object, Flow Properties, Source of Collection, Data Quality, and Level of Resolution. Flow Properties have economic and technical subclasses, while the Source of Collection is divided into primary and secondary data with different data types. Data Quality class ensures reliability with multiple criteria such as Reliability of Source, Completeness Conformance, Temporal Conformance, Geographical Conformance, and Technical Conformance. Subclasses of Flow include Product Flow, Elementary Flow, and Social Flow. The Level of Resolution class provides granularity to the data. The Process/Activity class interplays with Flow and involves Stakeholder Categories that bring Social Impact Sub-Categories into consideration. Evaluation employing Reference Scale Approach is based on International and National norms for contextually relevant results.

Considering economic aspects currently lacks specific guidelines and needs to address four topics: LCC type, environmental and social impact quantification, double counting issues, and discount rate harmonization. LCC is part of the ORIONT ontology as a SustainabilityTopic instance. Agreement on economic factors is needed to further specify and integrate them into the ontology. The proceedings to integrate economic elements will be similar to S-LCA elements.

A technical ontology was created using an automated procedure to streamline development and reduce errors. An Excel file listed all elements of the TLCAO, and a Python script imported the ORIONT ontology, adding classes, instances, and properties using the Owlready2 package. The merged ontology was saved as an OWL file, which can be imported into Protégé for querying, visualization, and further development. The visualization option in Protégé allows users to explore ontology components and their interrelations through an interactive knowledge graph.

The maintenance of the data is a key point, which was described according to several aspects. These are the overall organization being in charge of the database, the available technical kowledge, the scope, the software capabilities in background data update, the approach on updating the datasets, and the data format. An essential decision is how or by whom the database should be set up and managed. Three cases are presented to demonstrate the benefits and drawbacks, depending on who is in charge of the overall organization.

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# Appendix

## A1. Glossary

Note:

1) A large part of the glossary for Environmental Life Cycle Assessment was adopted from Product Environmental Footprint Guidelines (PEF) (EC-JRC, 2021). Methodological points which are PEF-specific are re-formulated for general applicability. Any new term that did not come from PEF or deviates from the definition reported in PEF will be written in *Italic*.
2) The terms for Social Life Cycle Assessment were adopted from UNEP guidelines (Benoît et al., 2013)
3) If same term was found to apply for both methodologies, the methodology intended is highlighted between parentheses next to the term
4) The list of definitions is not limited to the terms appearing in the report since the other terms were thought to be helpful to the reader as well like some basic terms.

**Acidification** – EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

**Activity data** – information which is associated with processes while modelling Life Cycle Inventories (LCI). The aggregated LCI results of the process chains, which represent the activities of a process, are each multiplied by the corresponding activity data1 and then combined to derive the environmental footprint associated with that process. Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of fuel used, output of a process (e.g. waste), number of hours equipment is operated, distance travelled, floor area of a building, etc. Synonym of ‘non-elementary flow’.

**Activity variable** – An activity variable is a measure of process activity or scale which can be related to process output. Activity variables, scaled by the output of each relevant process, are used to reflect the share of a given activity associated with each unit process. A relevant activity variable is worker-hours. Process-specific coefficients of worker-hours per unit of process output are used to estimate the share of total life cycle worker-hours associated with each unit process. The activity variable is useful to represent the product system in a way that gives an idea of the relative significance of each unit process in the whole system.

**Additional environmental information** – environmental information outside the EF impact categories that is calculated and communicated alongside LCA results.

**Additional technical information** – non-environmental information that is calculated and communicated alongside LCA results.

**Aggregated dataset** - complete or partial life cycle of a product system that – next to the elementary flows (and possibly not relevant amounts of waste flows and radioactive wastes) – itemises only the product(s) of the process as reference flow(s) in the input/output list, but no other goods or services. Aggregated datasets are also called 'LCI results' datasets. The aggregated dataset may have been aggregated horizontally and/or vertically.

**Aggregation** - The action of summing or bringing together information (e.g., data, indicator results, etc.) from a smaller scope into a larger scope, e.g., from inventory indicator to subcategory. In S-LCA, aggregation of data may be done at the life cycle inventory or impact assessment phase of the study and should not be done in a way that leads to loss of information about the location of the unit processes.

**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'.

**Area of protection** [The term "Damage category" can be used as a synonym] - A state that is desired to be sustained or protected which is of recognizable value to society, in the specific context of sustainability assessment. In the field of S-LCA, one area of protection has been defined and is referred to as human well-being (health and happiness) or simply social well-being. See also Box 17. For environmental LCA areas of protection include human health, natural resources, natural environment, and man-made environment.

**Attributes** [see "Life cycle attribute assessment"] – Properties or characteristics of a process, which are of interest to stakeholders. These are different from conventional quantitative input/output flows of processes but are of a qualitative nature, e.g. gender discrimination or safety as a whole, and thus also coincide with qualitative parameters of social issues in the context of S-LCA.

***Attributes** [regarding ontologies] – Are properties, describing each class of objects.*

**Attributional** – process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.

***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, 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).*

***Auxiliary battery** – this small (generally lead-acid) battery powers accessories and start-up. It is sometimes also called SLI (Starting, Lighting and Ignition) battery.*

**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.

**Bill of materials** – a bill of materials or product structure (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture the product. In some sectors it is equivalent to the bill of components.

***Body** – the vehicle body is the frame of the car which connects all the different vehicle parts together.*

***Body trim** – the body trim refers to all the interior and interior components added to the body (seats, instrument panel, lighting, etc.).*

**Characterization** – calculation of the magnitude of the contribution of each classified input/output to their respective EF impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterization factors for each substance and EF impact category of concern. For example, with respect to the EF impact category 'climate change', the reference substance is CO2 and the reference unit is kg CO2-equivalents.

**Characterization** (S-LCA) – In S-LCIA, the characterization models are the formalized, and - not always - "mathematical" operationalization of the social and socio-economic mechanisms. They may be a basic aggregation step, bringing text or qualitative inventory information together into a single summary, or summing quantitative social and economic inventory data within a category. Characterization models may also be more complex, involving the use of additional information such as performance reference points.

**Characterization factor** – factor derived from a characterization model which is applied to convert an assigned life cycle inventory result to the common unit of the EF impact category indicator.

**Characterization factor (S-LCA)** – Factor, derived from a characterization model, that is applied to convert an assigned Life Cycle Inventory Analysis result to the common unit of the category and/or subcategory indicator. (ISO, 2006)

***Chassis** – the chassis is the load-bearing part of the vehicle frame. It consists of the cradle, driveshaft/axle, differential, corner suspension, braking system, wheels, tires, steering system and chassis electrical system.*

***Class** – The same type of objects that exist in the data are grouped in classes.*

**Classification –** assigning the material/energy inputs and outputs tabulated in the life cycle inventory to EF impact categories, according to each substance's potential to contribute to each of the EF impact categories considered.

**Classification (S-LCA)** – The classification step is the step where the Inventory results are assigned to a specific Stakeholder Category and/or Impact (sub)Category.

**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.

**Company-specific dataset** – refers to a dataset (disaggregated or aggregated) compiled with company-specific data. In most cases the activity data is company-specific while the underlying sub-processes are datasets derived from background databases.

***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).*

**Consumer** – an individual member of the general public purchasing or using goods, property or services for private purposes.

**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.

**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.

**Critical review** – process intended to ensure consistency between an LCA study and the principles and requirements of the applied LCA method.

**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, 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.

**Data quality rating (DQR)** – semi-quantitative assessment of the quality criteria of a dataset, based on technological representativeness, geographical representativeness, time-related representativeness, and precision. The data quality shall be considered as the quality of the dataset as documented.

***Decomposition tree*** *– a decomposition tree is a detailed structure of a product starting from the materials and up to the final product assembled, it includes all the processes involved in the obtention of the parts and subparts of the product.*

**Direct elementary flows (also named elementary flows)** – all output emissions and input resource uses that arise directly in the context of a process. Examples are emissions from a chemical process, or fugitive emissions from a boiler directly onsite.

**Direct land use change (dLUC)** – the transformation from one land use type into another, which takes place in a unique land area and does not lead to a change in another system.

**Directly attributable** – refers to a process, activity or impact occurring within the defined system boundary.

**Disaggregation** – the process that breaks down an aggregated dataset into smaller unit process datasets (horizontal or vertical). The disaggregation may help make data more specific. The process of disaggregation should never compromise or threaten to compromise the quality and consistency of the original aggregated dataset.

**Downstream** – occurring along a product supply chain after the point of referral.

**Ecotoxicity, freshwater** – EF impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

**EF-compliant dataset** – dataset developed in compliance with the EF requirements, regularly updated by DG JRC2.

**E-LCA** – Environmental Life Cycle Assessment (E-LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a product, service or organization.

**Electricity tracking** – the process of assigning electricity generation attributes to electricity consumption.

***Electronic controllers*** *– Power converters that convert electrical power between the different components connected to the electrical system. It includes phase inverters connected to electrical motors, DC/DC converters that adapt DC voltage/current for the fuel cell, the traction battery, or the 12 or 24V auxiliary consumers, the on-board charger. We also include in this part the electronic controllers of the power converters and the cables.*

**Elementary flow** – Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation. (ISO, 2006)

**Elementary flows** – in the life cycle inventory, elementary flows include 'material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation'. Elementary flows include, for example, resources taken from nature or emissions into air, water, soil that are directly linked to the characterization factors of the EF impact categories.

**Endpoint impact / Endpoint (impact) indicator** – Impact at the end of the cause-effect chain for a (social) issue, which can be represented by an endpoint indicator. It captures the impact on an area of protection. For example, impact on health, represented by the DALY indicator.

**Environmental aspect (E-LCA)** – element of an organisation's activities or products or services that interacts or can interact with the environment.

**Environmental aspect (S-LCA)** – Element of an organization's activities, products, or services that can interact with the environment (ISO, 2006). The counterpart in S-LCA are social issues.

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

**Environmental mechanism** – system of physical, chemical and biological processes for a given EF impact category linking the life cycle inventory results to EF category indicators.

**Environmental mechanism / Social mechanism** – System of physical, chemical, and biological or socio-economic processes for a given impact category, linking the Life Cycle Inventory Analysis results to impact (sub)category indicators and to category endpoints.

**Eutrophication** – impact category related to nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland that accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen, resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure, expressed as the oxygen required for the degradation of dead biomass. To assess the impacts due to eutrophication, three EF impact categories are used: eutrophication, terrestrial; eutrophication, freshwater; eutrophication, marine.

***Fluid system*** *– covers all kinds of liquid used in or drained from the vehicle. This includes power steering fluid, brake fluid, transmission fluid, powertrain coolant (deionized water for a fuel cell stack), motor coolant, coolant for the power converters, refrigerant fluid/gas for HVAC, windshield fluid and adhesives. For internal combustion engines (ICE)/hybrid electric vehicles (HEV)/plug-in hybrid electric vehicles (PHEV) it also includes engine oil.*

**Focus group** – A focus group is a type of group interview organized to acquire a portrait of combined local perspective on a specific set of issues. What distinguishes the focus group technique from the wider range of group interviews is the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group. Focus groups with a range of actors can be used to identify relevant stakeholder groups and indicators. Finally, focus groups can also be used in impact assessment when defining the relative importance (weight) of each impact (sub)category.

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

**Foreground processes** – those processes in the product life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the producer or its contractors (e.g. goods transport, head-office services, etc.).

***Fuel cell auxiliaries*** *– this includes everything around the fuel cell stacks that are needed to make them function. This covers the compressed hydrogen tank system, water supply system, air supply system, cooling system for auxiliaries such as the inverter for the compressor and piping system.*

**Functional unit (E-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, 2006).

**Gate to gate** – a partial product supply chain that includes only the processes carried out on a product within a specific organisation or site.

**Gate to grave** – a partial product supply chain that includes only the distribution, storage, use, and disposal or recycling stages.

**Generic data** – Refers to data that has not been collected for the specific process concerned. If can be data collected from other manufacturers of the same kind of product or in the same country. In other words, it is data with a lower resolution than site-specific data.

***Generator*** *– it converts mechanical energy into electricity. For HEV/PHEV, it is an electric lotor used to generate electricity for the electrical power system. In EV/FCV, there is no generator. Note that the internal combustion engine vehicle (ICEV) alternator, which is run by the thermal engine and charges the auxiliary battery, is considered in the Powertrain system block according to the GREET definition.*

**Global warming potential (GWP)** – An index measuring the radiative forcing of a unit mass of a given substance accumulated over a chosen time horizon. It is expressed in terms of a reference substance (for example, CO2- equivalent units) and specified time horizon (e.g. GWP 20, GWP 100, GWP 500 – for 20, 100 and 500 years respectively). By combining information on both radiative forcing (the energy flux caused by emission of the substance) and on the time it remains in the atmosphere, GWP gives a measure of a substance's capacity to influence the global average surface-air temperature and therefore subsequently influence various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

**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 and the type of assessment (type I or type II).

**Human rights due diligence** – An ongoing risk management process in order to identify, prevent, mitigate, and account for how [a company] addresses its adverse human rights impacts. It includes four key steps:  assessing actual and potential human rights impacts; integrating and acting on the findings; tracking responses; and communicating about how impacts are addressed. (This is brought forward in the "UN Guiding Principles Reporting Framework")

**Human toxicity** – cancer – EF impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – insofar as they are related to cancer.

**Human toxicity - non cancer** – EF impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

**Impact category** – 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.

**Impact indicator / Impact (sub)category indicator** – An indicator that represents a (social) impact, linked to a particular impact category, and in that context, can be called an "impact (sub)category indicator".

**Impact pathway approach / Type II approach / Impact pathway (IP) S-LCIA approach** – Impact pathway S-LCIA assesses potential or actual social impacts by using causal or correlation/regression-based directional relationships between the product system/organizations' activities and the resulting potential social impacts – a process called "characterization". Here, the analysis focuses on identifying and tracking the consequences of activities possibly to longer-term implications along an impact pathway.

In particular in S-LCIA, aggregation is a way of combining various elements and synthesizing complex phenomena in order to achieve a better understanding and for the communication of results. As such, it may involve the construction of a single, possibly synthetic, score with two or more subcomponents. Single indices or scores are a powerful way to combine and summarize multi-dimensional information.

**Indicator** – An indicator is a measurement or value which gives you an idea of what something is like.

**Indirect land use change (iLUC)** – this occurs when a demand for a certain land use leads to changes, outside the system boundary, i.e. in other land use types. These indirect effects may be mainly assessed by means of economic modelling of the demand for land or by modelling the relocation of activities on a global scale. Input flows – product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products.

***Individuals*** *– Individuals (instances) are the basic, "ground level" components of an ontology. The individuals in an ontology may include concrete objects, as well as abstract individuals. 'Red' could be an instance of the class 'Color'. Strictly speaking, an ontology need not include any individuals, but one of the general purposes of an ontology is to provide a means of classifying individuals, even if those individuals are not explicitly part of the ontology.* (Wikipedia, 2023)

**Input** – Product, material, or energy flow that enters a unit process (ISO, 2006).

***Instances*** *– see 'Individuals'*

**Intermediate product** – output form of a unit process that in turn is input to other unit processes which require further transformation within the system. An intermediate product is a product that requires further processing before it is saleable to the final consumer.

**Inventory indicator** – An inventory indicator is a type of impact indicator that directly relates to the product life cycle, e.g. hours at risk of child labor. An inventory indicator provides the most direct evidence of the condition or result that is measured. They are specific definitions of the data sought. Inventory indicators have characteristics such as type (e.g. qualitative or quantitative) and unit of measurement.

**Ionising radiation, human health** – EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

**Land use** – EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in soil quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in soil quality multiplied by the area).

**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** – takes 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 attribute assessment** [See "attribute"] – A method that enables to express the percentage of a supply chain that possesses (or lacks) an attribute of interest (Norris, 2006).

**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.

**Life cycle impact assessment / Social life cycle impact assessment (S-LCIA)** – Phase of an S-LCA that aims at understanding and evaluating the magnitude and significance of the impacts for a product system throughout the life cycle of the product. Adapted from (ISO, 2006).

**Life cycle inventory (LCI)** – the combined set of exchanges of elementary, waste and product flows in a LCI dataset.

**Life cycle inventory (LCI) dataset** – a document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. A LCI dataset could be a unit process dataset, partially aggregated, or an aggregated dataset.

**Life cycle inventory / Social life cycle inventory (S-LCI)** – Phase of an S-LCA where data are collected, the systems are modelled, and the LCI results are obtained.

**Life cycle thinking** – Going beyond the traditional focus on production site and manufacturing processes so to include the environmental, social, and economic impact of a product over its entire life cycle. UNEP-DTIE-Life Cycle Management, a Business Guide to Sustainability.

**Loading rate** – ratio of actual load to the full load or capacity (e.g. mass or volume) that a vehicle carries per trip.

**Materiality assessment** – Materiality assessment is a process to select topics that are more important because of their impact on stakeholders and/or on the business. The Global Reporting Initiative consider material issues to be the ones that reflect the organization's significant social impacts; or that substantively influence the assessments and decisions of stakeholders. This is also recommended by ISO 26000.

***Material composition** – provides the materials used for each part and subpart of a product.*

**Materiality principle** – Materiality (principle) constitutes social matter (information, data, performance, impact, stakeholder) that is of such relevance and importance that it could substantially influence the conclusions of the study, and the decisions and actions based on those conclusions. In the Interpretation section, we follow this definition.

**Material-specific** – a generic aspect of a material. For example, the recycling rate of polyethylene terephthalate (PET).

**Method** – Specific procedure within a technique.

**Methodology** – Coherent set of methods.

**Midpoint impact / Midpoint (impact) indicator** – Impact midway the cause-effect chain of a social issue, which can be represented by a midpoint indicator. It does not imply a fixed point halfway through the cause-effect chain.

***Models**: mathematical description/formula*

**Multi-functionality** – 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.

**Non-elementary (or complex) flows** – in the life cycle inventory, non-elementary flows include all the inputs (e.g. electricity, materials, transport processes) and outputs (e.g. waste, by-products) in a system that need further modelling efforts to be transformed into elementary flows. Synonym of 'activity data'.

**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.

***Ontology*** – *In information science, ontologies provide a formal structure where information/knowledge/data are organized, classified, defined, named, and linked to each other. It is "a way of showing the properties of a subject area and how they are related, by defining a set of concepts and categories that represent the subject"* (Wikipedia, 2023). *In other words, these general semantic data models define and classify the type of information/data that exist and the properties that describe them* (Schrader, 2020). *They are closely linked to semantic network and taxonomies.*

**Organization** – Company, corporation, firm, enterprise, authority, or institution, or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration (ISO, 2004).

**Output** – Product, material, or energy flow that leaves a unit process (ISO, 2006).

**Output flows** – product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases. Output flows are also considered to cover elementary flows.

**Ozone depletion** – EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons).

**Partially disaggregated dataset** – a dataset with an LCI that contains elementary flows and activity data, and that yields a complete aggregated LCI data set when combined with its complementing underlying datasets.

**Particulate matter** – EF impact category that accounts for the adverse effects on human health caused by emissions of particulate matter (PM) and its precursors (NOx, SOx, NH3).

**Performance reference point (PRP)** – Performance reference points (PRPs) are thresholds, targets, or objectives that set different levels of social performance or social risk. PRPs allow to estimate the magnitude and significance of the potential social impacts associated with organizations in the product system. The PRPs are context-dependent and are often based on international standards, local legislation, or industry best practices – Comparing inventory indicator data with PRPs allows to qualify performance on a scale.

**Photochemical ozone formation** – EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials, by reacting with organic materials.

***Powertrain system** – a powertrain system is designed to propel the vehicle forward. Depending on the technology, it comprises the engine unit, engine fuel storage system, exhaust system, powertrain control devices and emission control electronics, powertrain thermal system, and fuel cell stack for a fuel cell vehicle. In the GREET definition, the electric motor is separated from the powertrain system.*

**Primary data (E-LCA)** – data from specific processes within the supply chain. Such data may take the form of activity data, or foreground elementary flows (life cycle inventory). Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain. In this report, primary data is a synonym of 'company-specific data' or 'supply chain specific data'.

**Primary data (S-LCA)** – Refers to data that has been directly collected by the practitioner, via interview, survey, or participant observation for instance.

***Process tree/flow chart** – provides the processes needed to obtain each part and subpart of a product.*

**Product (S-LCA)** – Any good or service offered to members of the public either by sales or otherwise. ISO 26000 WD4.2 (2008)

**Product (E-LCA)** – any good or service.

**Product category** – group of products (or services) that can fulfil equivalent functions.

**Product category rules (PCRs)** – set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

**Product flow** – products entering from or leaving to another product system.

**Product system** – collection of unit processes with elementary and product flows, performing one or more defined functions, which model the life cycle of a product.

***Prospective LCA****: A prospective LCA is conducted in the development stage and aims to estimate environmental impacts before the start of production (several years). The TRL is low (TRL<6) and the BOM is not completely defined.*

**Qualitative indicator** – Qualitative indicators are nominative; they provide information on a particular issue using words. For instance, text describing the measures taken by an enterprise to manage stress.

**Quantitative indicator** – A quantitative indicator is a description of the issue assessed using numbers, e.g. number of accidents by unit process.

**Raw material** – primary or secondary material used to produce a product.

**Reference flow (S-LCA)** – A reference flow is a quantified amount of product(s), including product parts, necessary for a specific product system to deliver the performance described by the functional unit.

**Reference flow (E-LCA)** – measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.

**Reference scale** – Reference scales are ordinal scales, typically comprised of 1 to 5 levels, each of which corresponds to a performance reference point (PRP).

**Reference scale approach / Type I approach / Reference scale (RS) S-LCIA** – Reference scale S-LCIA assesses the social performance in the product system. More specifically, it assesses the social performance of activities of organizations in the product system (e.g. the practices implemented to manage social impacts) based on specific reference points of expected activity (called performance reference points - PRPs).

***Relationships*** *– Relationships (relations) between objects in an ontology specify how objects are related to other objects. Typically, a relation is of a particular type (or class) that specifies in what sense the object is related to the other object in the ontology.* (Wikipedia, 2023)

**Representative product (model)** – this may be a real or virtual (non-existing) product. The virtual product should be calculated based on average European market sales-weighted characteristics for all existing technologies/materials covered by the product category or sub-category.

Other weighting sets may be used, if justified – for example weighted average based on mass (ton of material) or weighted average based on product units (pieces).

**Representative sample** – a representative sample with respect to one or more variables is a sample in which the distribution of these variables is exactly the same (or similar) as in the population of which the sample is a subset.

**Resource use, fossil** – EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

**Resource use, minerals and metals** – EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).

***Retrospective LCA****: A retrospective LCA aims to evaluate environmental impacts slightly before or after the start of production. A nearly finalised bill of materials of all parts is available to the OEM.*

**Review** – procedure intended to ensure that the process of developing or revising a PEFCR has been carried out in accordance with the requirements provided in the PEF method and part A of Annex II.

**Review report** – a documentation of the review process that includes the review statement, all relevant information about the review process, the detailed comments from the reviewer(s) and the corresponding responses, and the outcome. The document shall carry the electronic or handwritten signature of the reviewer (or the lead reviewer, if a reviewer panel is involved).

**Reviewer** – independent external expert conducting the review of the PEFCR and possibly taking part in a reviewer panel.

**Salient social risks / impacts** – Social impact subcategories that account for a greater share of the overall risk/impact. The UN Guiding Principles consider salient risks/impacts to be the ones that affect the most vulnerable stakeholders and that cause irreparable damages.

**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 (E-LCA)** – 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 and other generic data. Primary data that go through a horizontal aggregation step are considered to be secondary data.

**Secondary data (S-LCA)** – Refers to data that has been initially collected and manipulated by another person/institution than the practitioner or collected for another purpose than the one being currently considered or, often a mix of the two. For example, a publication, third party audit, or a database.

**Semi-quantitative indicator** – Semi-quantitative indicators are indicators that have results expressed into a yes/no form or a scale (scoring system): for example, presence of a stress management program (yes-no). Qualitative and quantitative indicator results may be translated into a semi-quantitative form.

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

**Sensitivity analysis (S-LCA)** – Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study.

**Single overall score** – sum of the weighted EF results of all environmental impact categories.

**Site-specific data** – directly measured or collected data from one facility (production site). A synonym of ‘primary data’.

**S-LCA** – A social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (actual and potential impacts) assessment technique that aims to assess the social and socio-economic aspects of products and their positive and negative impacts along their life cycle encompassing extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling, and final disposal.

**Social capital** – The social conditions, such as institutions, rule of law, trust, and human networks, that are prerequisites or catalysts for production, but do not enter into the production themselves.

**Social endpoint / Social category endpoint** – A social attribute or aspect identifying an issue giving cause for concern Adapted from (ISO, 2006). It is thus an aspect of an area of protection, e.g. the payment for workers relating to their well-being. They are closely related to endpoint impact categories.

**Social footprint** – A social footprint refers to the end result of an S-LCA study, in term of adverse effects, overall or by impact category/subcategory (e.g. The total medium risk hours equivalent for labor rights and decent work by purchase category supply chain).

**Social handprint** – Social handprints are the results of changes to business as usual that create positive outcome or impacts. They can be changes reducing the social footprint, or changes that create additional/unrelated positive social impacts. Those changes can apply to the product or organization value chain, or they may be beyond its scope.

**Social hotspots** [The term "Bottleneck" can be used as a synonym for negative hotspots] – A social hotspot is a location and/or activity in the life cycle where a social issue (as impact) and/or social risk is likely to occur. It is usually linked to life cycle stages or processes. It needs to contribute significantly to the impact (overall, by impact category or subcategory). In other words, social hotspots are unit processes located in a region where a problem, a risk, or an opportunity may occur in relation to a social issue that is considered to be threatening social well-being or that may contribute to its further development.

**Social impact assessment (SIA)** – Social Impact Assessment (SIA) is the process of identifying the social consequences or impacts that are likely to follow specific policy actions or project development, to assess the significance of these impacts and to identify measures that may help to avoid or minimize adverse effects.

**Social impact pathway** [The term "Social mechanism" can be used as a synonym] – An impact pathway that covers the propagation of the cause-effect chain from social LCI results to impact, and is specified per social impact (sub)category.

**Social impacts** – Social impacts are consequences of positive or negative pressures on social endpoints of area of protection (i.e., well-being of stakeholders).

**Social indicators** – Social indicators are evidence, subjective or objective, qualitative, quantitative, or semi-quantitative being collected in order to facilitate concise, comprehensive and balanced judgements about the condition of specific social aspects with respect to a set of values and goals. In LCA social indicators are indicators of a social LCI result (inventory indicators) or represent impact per social impact (sub)category.

**Social performance** – Social performance refers to the principles, practices, and outcomes of businesses' relationships with people, organizations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard (Wood, 2016). Commonly, social performance is measured at the inventory indicator level.

**Social significance / significant** – Social significance is a judgment on the degree to which a situation or impacts are important. It is highly dependent on context, based on criteria, normative, contingent on values, and entails considering trade-offs.

**Social themes / Social issues** – Social themes or issues are considered as threatening social well-being or that may contribute to its further development. Social themes of interest include but are not restricted to: human rights, work conditions, cultural heritage, poverty, disease, political conflict, indigenous rights, etc.

**Socio-economic** – Which involves a combination of social and economic factors or conditions.

**Specific data** – directly measured or collected data representative of activities at a specific facility or set of facilities. A synonym of ‘primary data’.

**Stakeholder category / Stakeholder group** – Cluster of stakeholders that are expected to have similar interests due to their similar relationship to the investigated product system.

**Stakeholder** – Individual or group that has an interest in any activities or decisions of an organization (ISO, 2010).

**Subcategory / Impact subcategory** – It is a constituent of an impact category that is assigned to a stakeholder group, for example “Health and Safety” for the stakeholder group “Workers”. Multiple subcategories, possibly across various stakeholder groups, may be part of an overarching impact category.

**Subdivision** – subdividing involves disaggregating multifunctional processes or facilities to isolate the input flows directly associated with each process or facility output. The process is investigated to see whether it may be subdivided. Where subdivision is possible, inventory data should be collected only for those unit processes directly attributable to the products/services of concern.

**Sub-processes** – processes used to represent the activities of the level 1 processes (=building blocks). Sub-processes may be presented in their (partially) aggregated form.

**Supply chain** – A supply chain, or logistics network, is the system of organizations, people, technology, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer. In sophisticated supply chain systems used products may re-enter the supply chain at any point where residual value is recyclable.  Supply chains link value chains.

**Supply chain-specific** – refers to a specific aspect of a company’s specific supply chain. For example, the recycled content of aluminium produced by a specific company.

**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.

**System boundary diagram** – graphic representation of the system boundary defined for the LCA study.

**System scope / System boundary** – System scope = system boundary: set of criteria specifying which unit processes are part of a product system (ISO, 2006).

**Tool (S-LCA)** – Instrument used to perform a procedure.

***Tools (E-LCA)*** *– software or applications supporting the analysis (e.g. LCA software or excel based tool)*

***Traction battery*** *– a rechargeable energy storage system that powers the electric motor. This is a large (generally lithium-ion) battery.*

***Traction motor*** *– a traction motor is an electric motor used for the propulsion of a vehicle.*

***Transmission system*** *– it is a medium that conveys the power generated by the engine to the wheels via a mechanical system. The transmission unit is composed of a gearbox, torque converter and controls. This system differs according to the vehicle type. For ICEV there is an automatic transmission and therefore a torque converter. For HEV/PHEV there is a continuously variable transmission with a planetary gear set and no torque converter. For EV/FCV there is a single-ratio gearbox and no torque converter.*

**Uncertainty** – 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.

**Uncertainty analysis** – procedure for assessing uncertainty in the results of a PEF study due to data variability and choice-related uncertainty.

**Unit process (E-LCA)** – smallest element considered in the LCI for which input and output data are quantified.

**Unit process (S-LCA)** – Smallest portion of a product system for which data are collected when performing a life cycle assessment (ISO, 2006).

**Unit process, black box** – process chain or plant-level unit process. This covers horizontally averaged unit processes across different sites. Also covers multi-functional unit processes where the different co-products undergo different processing steps within the black box, hence causing allocation problems for this dataset.

**Unit process, single operation** – unit operation type unit process that cannot be further subdivided. Covers multi-functional processes of the unit operation type.

**Upstream** – occurring along the supply chain of purchased goods/ services prior to entering the system boundary. User of the PEFCR – stakeholder producing a PEF study based on a PEFCR.

**Validation** – confirmation – by the environmental footprint verifier – that the information and data in the PEF study, PEF report and communication vehicles are reliable, credible and correct.

**Validation statement** – conclusive document aggregating the conclusions from the verifiers or the verification team regarding the EF study. This document is mandatory and shall carry the electronic or handwritten signature of the verifier or (where a verification panel is involved) the lead verifier.

***Value chain*** *– a synonym of 'supply chain'*

**Verification** – conformity assessment process carried out by an environmental footprint verifier to demonstrate whether the PEF study has been carried out in compliance with Annex I

**Verification report** – documentation of the verification process and findings, including detailed comments from the verifier(s), as well as the corresponding responses. This document is mandatory, but it may be confidential. The document shall carry the electronic or handwritten signature of the verifier or (where a verification panel is involved) the lead verifier.

**Verification team** – team of verifiers who will verify the EF study, EF report and EF communication vehicles.

**Verifier** – independent external expert performing a verification of the EF study and possibly taking part in a verification team.

**Waste** – substances or objects which the holder intends (or is required) to dispose of.

**Water use** – EF impact category that represents the relative available water remaining per area in a watershed, after demand from humans and aquatic ecosystems has been met. It assesses the potential for water deprivation, to either humans or ecosystems, based on the assumption that the less water remaining available per area, the more likely it is that another user will be deprived.

**Weighting (E-LCA)** – 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.

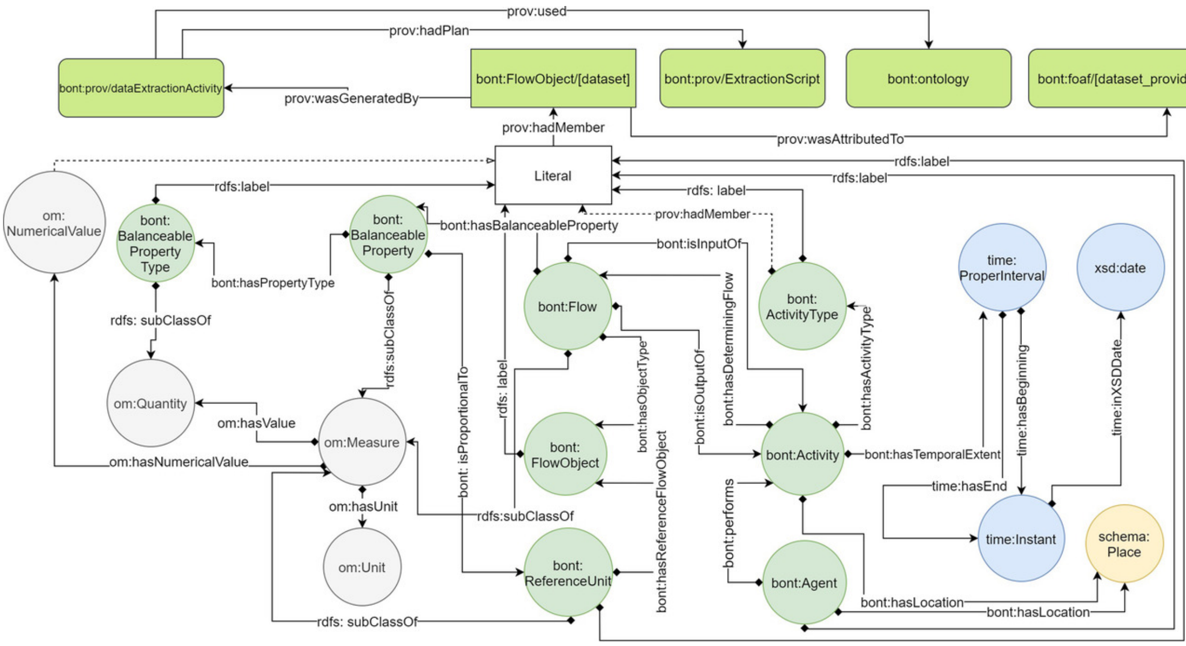
**Weighting (S-LCA)** – Converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available (ISO, 2006).

## A2. Synthesis of OEM Interviews and the respective Questionnaire

| Topic/Question | Synthesis of the answers |
|---|---|
| What is the granularity of the materials? | - Mostly based on IMDS and a company specific mapping list. |
| Which background data sources are used? | - LCA FE/MLC (former GaBi SW/databases)<br>- Supplier data rarely used today, but desired in the future. |
| How is the Bill of Materials (BOM) obtained? | - Different approaches exist on how to receive data from several internal areas. |
| How are delivered parts considered? | - Mostly based on IMDS<br>- Most of the time 100 % of the BOM is mapped<br>- Not every single material can be mapped precisely, due to unclear naming in IMDS or a missing match in databases |
| Is IMDS used? | - This is an integral part for most OEMs.<br>- Vehicles are mapped to a few hundred datasets. |
| Is there a standardized approach on how to conduct an LCA? | - Internal workflows are more or less standardized (but differ between the companies).<br>- For vehicle LCA no published standard is in use for all aspects of a certain LCA. |
| How is the inhouse production considered? | - Companies use different approaches regarding multi-output allocation, included emissions or use of aggregated secondary data/own modelling. |
| Which production processes (suppliers and inhouse) are included in the LCA? | - All relevant inhouse processes are included.<br>- Often no specific information is available from the suppliers. |
| Which emissions are asked for at plant level/production and for the use phase? Which of these data is actually reported and then used for LCA? | - Different approach on how and which emissions are reported and how these are grouped to workshops/production plants. |
| What are the assumptions for the different life cycle steps (production, use, end-of-life)? | - Different assumptions regarding mileage and maintenance.<br>- At end-of-life mostly Cut-Off is used. |
| What are the logistic distance assumptions? | - Different assumptions for the distance value and differs in split between inbound and outbound transport. |
| What type of fuel/energy is considered for the different drive types? | - Mostly EU-mixes used. |

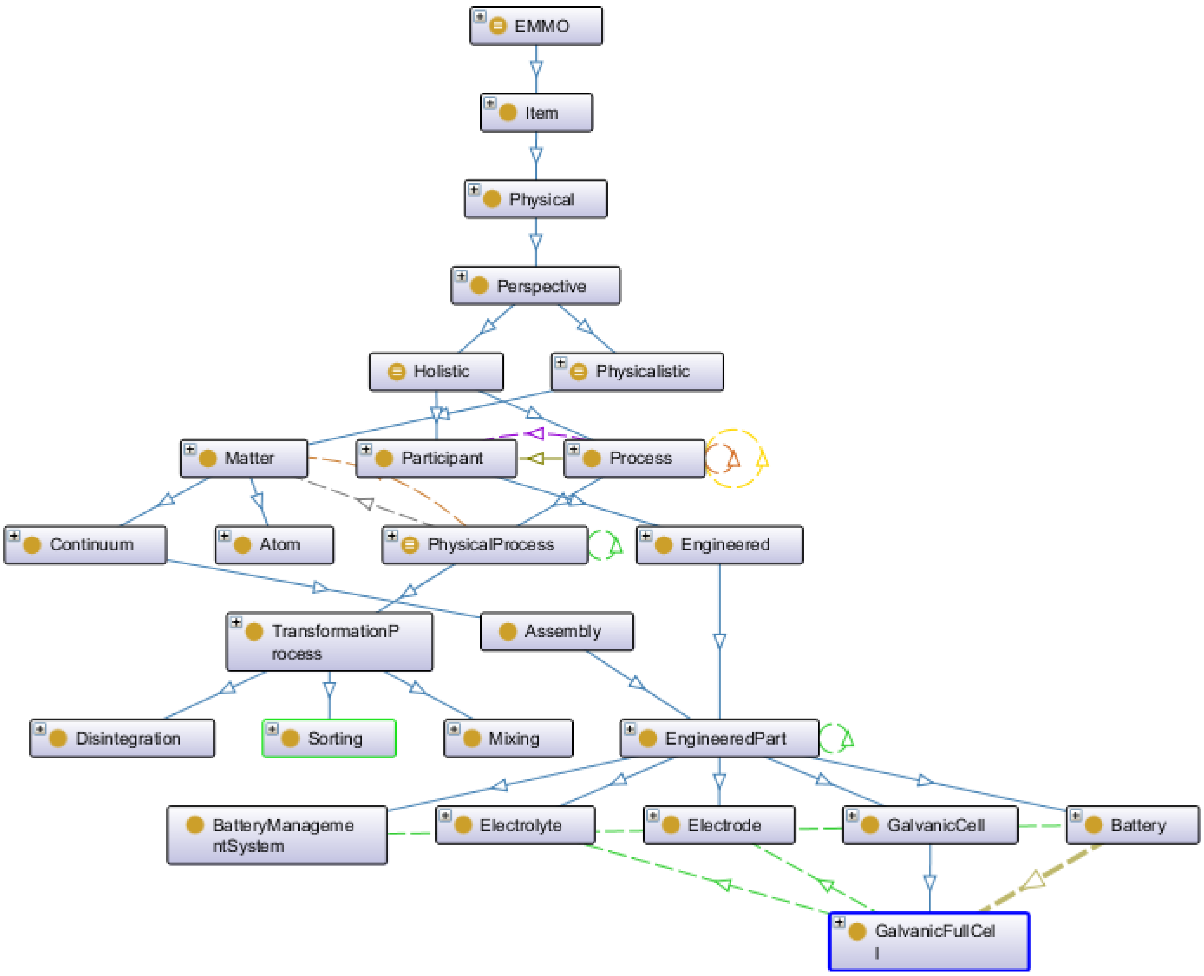
| | |
|---|---|
| | - Sometimes country specific or future mixes for scenario analysis. |
| What is the update cycle? | - Most LCAs are done before or at start of production (SOP).<br>- Some companies rarely do updates, some when major changes occur, some on a yearly basis. |
| How many LCAs were done already? | - The experience, especially regarding BEVs highly differs between the companies. |

## A3. Visualization of the BONSAI Ontology BONT




From: (Ghose, et al., 2021)

## A4. Visualization of the Battery Value Chain Ontology (BVCO)




From: (Stier, et al., 2023)

## A5. ORIONT classes

Within task 2.1 and in consultation with WP 2 leaders, it was agreed to copy/paste information tables from the ORIENTING deliverable D3.1. The main reason is to collect all necessary information in one place, rather than having the necessity to open several documents.

| Class | Description |
|---|---|
| Activity | Activity is the act of making or doing something which is defined both spatially and temporally. This is one of the identifying dimensions of a datapoint. This class defines multiple properties on the type and direction of flows. 'Process' is a commonly used synonym in other LCA databases (Ghose et al. 2021). |
| ActivityType | The type of an activity, e.g., stock accumulation, steel production, etc. This class includes the labels of activities. Includes both human activities and environmental mechanisms (Ghose et al. 2021). |
| Agent | An entity (person or thing) that performs an activity, usually it has a specific location (Ghose et al. 2021). |
| BalanceableProperty | A quantity for which the sum for all input flows must equal the sum for all output flows. A quantity that follows a conservation law. Balanceable properties are particularly relevant for validating the completeness and consistency of an Activity description or a database of such activities (Ghose et al. 2021). |
| BalanceablePropertyType | Contains the labels of BalanceableProperty such as dry mass, wet mass, elemental mass, person-time, monetary value (Ghose et al. 2021). |
| BillOfMaterials | A bill of materials or product structure (sometimes bill of material, BoM, or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product (European Commission, 2018). |
| CF | Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator (ISO 14040). |
| CFUnit | Units of characterisation factors are given in the unit of the indicator quantified divided by the unit of the reference flow or property (if any); otherwise it is equivalent to the indicator unit (ORIONT). |
| CharacterisationModel | A model underlying an LCIA method used to calculate characterization factors (ORIENTING) |
| EFCategories | Categories used in the elementary flow categorisation system (ORIONT). |
| EFCategorisation | Identifying category/compartment information exclusively used for elementary flows. E.g. "Emission to air", "Renewable resource", etc. (European Commission, 2022). |
| ElementaryFlow | (a) material or energy flow that has been drawn from the environment without previous human transformation and that enters the system being studied; or (b) material or energy |

| | |
|---|---|
| | flow that leaves the system being studied and is released into the environment without subsequent human transformation (ISO, 2006). |
| Flow | An input or output of an entity to or from an instance of an Activity or a directional exchange of an entity between two instances of Activity. This class contains the quantity of the entity (Flow Object) that is consumed as input or produced as output of an Activity (Ghose et al. 2021). |
| FlowClasses | Classes used in the flow classification system (ORIONT). |
| FlowClassification | Optional statistical or other classification of the data set. Typically, also used for structuring LCA databases (European Commission, 2022). |
| FlowDirection | Direction of Input or Output flow (European Commission, 2022). |
| FlowObject | This class includes the labels of entities that are produced or consumed by an activity or added to or removed from a stock accumulation (Ghose et al. 2021). |
| ImpactCategory | Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned; for example, climate change or acidification (ISO, 2006). |
| ImpactCategoryIndicator | Quantifiable representation of an impact category (ISO, 2006). |
| ImpactCategoryName | Name of the impact category (ORIONT). |
| IndicatorName | Description of the meaning of the impact indicator (based on European Commission, 2022). |
| IndicatorUnit | Special units used for impact category indicators such as "kg CO2 equivalent" or "mol N equivalent" (ORIONT). |
| LCIAResult | LCIA results provided for an activity (ORIONT). |
| LCSAMethodology | LCSA methodology is understood as a set of different methods to perform a life cycle sustainability assessment (ORIONT). |
| LCSAMethodologyName | Name of the LCSA methodology (ORIONT). |
| LCStage | Life Cycle Stage of a product system; the stages defined in ORIENTING are “Design - R&D”, “Raw material acquisition”, “Manufacturing”, “Installation/distribution/retail”, “Use”, “Maintenance, repair, refurbishment”, and “End-of-life”; “Design - R&D” and “Maintenance, repair, refurbishment” are additional to the minimum stages defined in the PEFCR guidance (ORIENTING). |
| Location | Location, country or region the data set represents (European Commission, 2022). |
| Method | Method refers to a procedure, e.g. evaluating the sustainability performance of products regarding an individual aspect (e.g. climate change, child labour, investment costs) under a life cycle perspective (ORIENTING). |

| | |
|---|---|
| MethodName | Name of the method. Composed as follows "LCIA methodology short name; Impact category/ies; midpoint/endpoint; Impact indicator; Source short name". Not applicable components are left out. Examples: "Impacts2007+; Climate change; midpoint; Global Warming Potential; IPCC 2001"; "ABC 2006; Acidification; endpoint; Species diversity loss; John Doe 2006"; "My-indicator2009; combined; endpoint; Ecopoints; various" (based on European Commission, 2022). |
| Methodology | Methodology is understood as a set of different methods (ORIENTING). |
| Methodology-Name | Name of the LCIA methodology/ies the method belongs to, if any (based on European Commission, 2022). |
| OtherFlow | Exchange of a type other than elementary/product/waste, e.g. dummy or modelling support flows (based on European Commission, 2022). |
| OtherProperty | A quantity for which the sum for all input flows does not balance with the sum for all output flows (ORIONT). |
| OtherProperty-Type | Contains the labels of UnbalanceableProperty such as product lifetime or recycled content (ORIONT). |
| ProductFlow | Products entering from or leaving to another product system (ISO, 2006). |
| ProductSystem | Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (ISO, 2006). |
| ReferenceUnit | Quantified performance of a product system to which LCSA data and impacts are referred (ORIENTING). |
| ReferenceYear | Start year of the time period for which the data set is valid (until ValidityYear). For data sets that combine data from different years, the most representative year is given regarding the overall environmental impact. In that case, the reference year is derived by expert judgement (European Commission, 2022). |
| Sector | Sector refers to economic/industry sectors as used in input-output models to consider transactions between these different sectors of a national economy or different regional economies (ORIENTING). |
| SocialTopic | A generic terminology used to describe more generically social issues of concern, both positive and negative. They can include social risks, or can be measured with reference to performances, or give rise to social impacts (ORIENTING). |
| SocialTop-icName | Description of the meaning of the social topic (ORIONT). |
| Stakeholder | Person or organisation that can affect, be affected by, or perceive itself to be affected by a decision or activity” (ISO, 2020). |

| | |
|---|---|
| Sustainabil-ityTopic | Sustainability topics in ORIENTING include the three classic sustainability domains or pillars (LCA, social LCA and Life Cycle Costing) as well as (material) Criticality and (material) Circularity (ORIENTING). |
| ValidityYear | End year of the time period for which the data set is still valid / sufficiently representative. This date also determines when a data set revision / remodelling is required or recommended due to expected relevant changes in environmentally or technically relevant inventory values, including in the background system (European Commission, 2022). |
| WasteFlow | Substances or objects which the holder intends or is required to dispose of (ISO 14040). |
| om:Measure | A measure combines a number to a unit of measure. For example, "3 m" is a measure (Wageningen University, 2015). |
| om:Quantity | A quantity is a representation of a quantifiable (standardised) aspect (such as length, mass, and time) of a phenomenon (e.g., a star, a molecule, or a food product). Quantities are classified according to similarity in their (implicit) metrological aspect, e.g. the length of my table and the length of my chair are both classified as length (Wageningen University, 2015). |
| om:Unit | A unit of measure is a definite magnitude of a quantity, defined and adopted by convention or by law. It is used as a standard for measurement of the same quantity, where any other value of the quantity can be expressed as a simple multiple of the unit. For example, length is a quantity; the metre is a unit of length that represents a definite predetermined length. When we say 10 metre (or 10 m), we actually mean 10 times the definite predetermined length called "metre" (Wageningen University, 2015). |

From: (ORIENTING, 2022)

## A6. ORIONT Instances of classes

| Class | Individual |
|---|---|
| FlowDirection | Input |
| FlowDirection | Output |
| ImpactCategoryName | Acidification |
| ImpactCategoryName | Climate change |
| ImpactCategoryName | Climate change: Biogenic |
| ImpactCategoryName | Climate change: Fossil |
| ImpactCategoryName | Climate change: Land use and land use change |
| ImpactCategoryName | Ecotoxicity, freshwater |
| ImpactCategoryName | Eutrophication, freshwater |
| ImpactCategoryName | Eutrophication, marine |
| ImpactCategoryName | Eutrophication, terrestrial |
| ImpactCategoryName | Human toxicity, cancer |
| ImpactCategoryName | Human toxicity, non-cancer |
| ImpactCategoryName | Ionising radiation, human health |
| ImpactCategoryName | Land use Biodiversity |
| ImpactCategoryName | Land use, Biotic resources |
| ImpactCategoryName | Land use, Soil Quality |
| ImpactCategoryName | Land use, total |
| ImpactCategoryName | Ozone depletion |
| ImpactCategoryName | Particulate Matter |
| ImpactCategoryName | Photochemical ozone formation - human health |
| ImpactCategoryName | Resource use, fossils |
| ImpactCategoryName | Resource use, minerals and metals |

| | |
|---|---|
| ImpactCategoryName | Water use |
| ImpactCategoryName | Supply risk |
| ImpactCategoryName | Economic Importance |
| ImpactCategoryName | Material criticality |
| ImpactCategoryName | Material circularity |
| ImpactCategoryName | Net Present Value |
| ImpactCategoryName | Present Costs |
| ImpactCategoryName | Total Undiscounted Costs |
| ImpactCategoryName | Total Undiscounted Value |
| IndicatorName | % Circularity |
| IndicatorName | EUCRM |
| IndicatorName | EUCRM EI |
| IndicatorName | EUCRM SR |
| IndicatorName | GeoPolRisk |
| IndicatorName | Material Circularity Indicator |
| IndicatorName | Net Present Value |
| IndicatorName | Present Costs |
| IndicatorName | Total Undiscounted Costs |
| IndicatorName | Total Undiscounted Value |
| IndicatorUnit | CTUe |
| IndicatorUnit | CTUh |
| IndicatorUnit | CTUh |
| IndicatorUnit | % |
| IndicatorUnit | kg CFC-11 eq |
| IndicatorUnit | kg CO2 eq |
| IndicatorUnit | kg CO2 eq |

| | |
|---|---|
| IndicatorUnit | kg CO2 eq |
| IndicatorUnit | kg CO2 eq |
| IndicatorUnit | kg NMVOC eq |
| IndicatorUnit | kg P eq |
| IndicatorUnit | kg P eq |
| IndicatorUnit | kg PM2.5 eq |
| IndicatorUnit | kg Sb eq |
| IndicatorUnit | kg Sb eq |
| IndicatorUnit | kg U235 eq |
| IndicatorUnit | m3 |
| IndicatorUnit | mol H+ eq |
| IndicatorUnit | mol N eq |
| IndicatorUnit | Pt |
| IndicatorUnit | Pt |
| IndicatorUnit | Pt |
| IndicatorUnit | Pt |
| LCStage | Design - R&D |
| LCStage | End-of-life |
| LCStage | Installation/distribution/retail |
| LCStage | Maintenance, repair, refurbishment |
| LCStage | Manufacturing |
| LCStage | Raw material acquisition |
| LCStage | Use |
| SocialTopic | Access to material, immaterial resources and cultural heritage |
| SocialTopic | Accessibility |
| SocialTopic | Affordability |

| | |
|---|---|
| SocialTopic | Child labour |
| SocialTopic | Community engagement |
| SocialTopic | Contribution to economic development (including local employment) |
| SocialTopic | Corruption |
| SocialTopic | Delocalization and migration |
| SocialTopic | Discrimination and equal opportunities |
| SocialTopic | Effectiveness and comfort |
| SocialTopic | End-of-life responsibility |
| SocialTopic | Ethical treatment of animals |
| SocialTopic | Fair competition |
| SocialTopic | Forced labour |
| SocialTopic | Freedom of association and collective bargaining |
| SocialTopic | Health and safety |
| SocialTopic | Prevention and mitigation of armed conflicts |
| SocialTopic | Privacy |
| SocialTopic | Promoting social responsibility and public commitments to sustainability issues |
| SocialTopic | Remuneration and social benefits |
| SocialTopic | Respect of indigenous rights and land rights |
| SocialTopic | Respect of intellectual property rights |
| SocialTopic | Responsible communication and feedback mechanisms |
| SocialTopic | Skill development and technology development |
| SocialTopic | Supplier relationships and fair trading |
| SocialTopic | Women's empowerment |
| SocialTopic | Work life balance and working hours |
| Stakeholder | children |

| | |
|---|---|
| Stakeholder | Local community |
| Stakeholder | small scale entrepreneur |
| Stakeholder | society |
| Stakeholder | User/consumer |
| Stakeholder | value chain actor |
| Stakeholder | Worker |
| SustainabilityTopic | Material circularity |
| SustainabilityTopic | Material criticality |
| SustainabilityTopic | LCA |
| SustainabilityTopic | LCC |
| SustainabilityTopic | S-LCA |

From: (ORIENTING, 2022)

## A7. ORIONT object properties

| Object Property | Description |
|---|---|
| affectsStakeholder | Specifies the stakeholder that is affected by an impact category/social topic |
| assessesImpactCategory | Specifies the impact category that is assessed by an impact category indicator |
| assessesTopic | Specifies the sustainability topic that is assessed by a method or methodology |
| behavesTowards | Specifies the social topic/impact category towards which an agent behaves |
| belongsToSector | Specifies the sector to which an activity of flow belongs |
| calculates | Specifies the characterisation factor that is calculated by a characterisation model |
| containsMethod | Specifies the methods contained in a methodology |
| containsMethodology | Specifies the methodologies contained in an LCSA methodology |
| hasActivityType | Specifies the type of the Activity |
| hasBalanceableProperty | Specifies the Measure of a Flow when this Measure is a BalanceableProperty, that is, when it follows a conservation law |
| hasCFUnit | Specifies the unit of a characterisation factor |
| hasDeterminingFlow | Specifies a flow object produced or consumed by an activity for which a change in demand or supply will affect the activity level (such as its production volume or extent) |
| hasEFCategories | Specifies the categories of an elementary flow categorisation system |
| hasEFCategorisation | Specifies the categorisation of an elementary flow |
| hasFlowClasses | Specifies the classes of a flow classification |
| hasFlowClassification | Specifies the classification of a product, waste, or other flow |
| hasFlowDirection | Specifies the direction of a flow (input or output) |
| hasImpactCategoryName | Specifies the name of an impact category |
| hasIndicatorName | Specifies the name of an impact category indicator |

| | |
|---|---|
| hasIndicatorUnit | Specifies the unit of an impact category indicator |
| hasLCIAResult | Specifies the life cycle impact assessment results of an activity |
| hasLCSAMethodologyName | Specifies the name of an LCSA methodology |
| hasLCStage | Specifies the life cycle stage to which an activity belongs |
| hasLocation | Specifies the location of an Activity, Agent, Flow or Characterization Factor (CF) |
| hasMethodName | Specifies the name of a method |
| hasMethodologyName | Specifies the name of a methodology |
| hasObjectType | Specifies the Flow Object consumed or produced |
| hasOtherProperty | Specifies the Measure of a Flow when this Measure is a UnBalanceableProperty, that is, when it follows a conservation law |
| hasOtherPropertyType | Specifies the dimension (Quantity) of a Measure that is classified as a UnBalanceableProperty |
| hasPropertyType | Specifies the dimension (Quantity) of a Measure that is classified as a BalanceableProperty |
| hasReferenceFlow | Specifies the reference flow of a characterisation factor |
| hasReferenceFlowObject | Specifies a FlowObject that functions as the ReferenceUnit for a BalanceableProperty measure |
| hasReferenceProperty | Specifies the property that is assessed by a CF |
| isAssessedByIndicator | Specifies the impact category assessed by an impact category indicator |
| isAssessedByMethod | Specifies the sustainability topic assessed by a method |
| isAssessedByMethodology | Specifies the sustainability topic assessed by a methodology |
| isInputOf | Specifies the Activity that a Flow is an input to |
| isOutputOf | Specifies the Activity that a Flow is an output of |
| isPartOfBOM | Specifies the properties (elemental masses) that constitute the bill of materials |
| isPartOfSystem | Specifies the ProductSystem that an activity or flow belongs to |
| isProportionalTo | Specifies the reference unit that the amount of a BalanceableProperty of a Flow is proportional to |

| | |
|---|---|
| isUsedByLCSAMethodology | Specifies the methods and methodologies used by an LCSA methodology |
| isUsedByMethodology | Specifies the methods used by a methodology |
| performs | Specifies the Activity that an Agent performs |
| quantifiesImpactIndicator | Specifies the impact category indicator which is quantified by a CF |
| usesModel | Specifies the characterisation model used by a method to calculate characterisation factors |
| om:hasUnit | Specifies the unit of an om:Measure |
| om:hasValue | Specifies the value of an om:Quantity, which is a measure having a numerical value and a unit |

From: (ORIENTING, 2022)

## A8. ORIONT data properties

| Data Property | Description |
|---|---|
| hasReferenceYear | Specifies the reference year (start year) for which and activity dataset is valid |
| hasValidityYear | Specifies the last year for which and activity dataset is valid |
| om:hasNumericalValue | Specifies the numerical value of an om:Measure |

From: (ORIENTING, 2022)

## A9. GREET – Material Composition for Battery Components

| Li-Ion | Lead-Acid |
|---|---|
| Active Material | Plastic: Polypropylene |
| Graphite/Carbon | Lead |
| Silicon | Sulfuric Acid |
| Binder | Fiberglass |
| Copper | Water |
| Wrought Aluminum | **Ni-MH** |
| Cast Aluminum | Iron |
| Electrolyte: $LiPF_6$ | Steel |
| Electrolyte: Ethylene Carbonate | Aluminum |
| Electrolyte: Dimethyl Carbonate | Copper |
| Plastic: Polypropylene | Magnesium |
| Plastic: Polyethylene | Cobalt |
| Plastic: Polymer | Nickel |
| Plastic: Polyethylene Terephthalate | Rare Earth Metals |
| Steel | Average Plastic |
| Stainless Steel | Rubber |
| Ceramic | |
| Thermal Insulation | |
| Coolant: Glycol | |
| Electronic Parts | |

From: (U.S. Department of Energy, 2022)

## A10. GLAD template

| Metadata descriptor name (required) | Description | Default | Data type |
|---|---|---|---|
| Unique identifier of dataset (usually a UUID) | The unique identifier of the data set, usually a UUID | | String |
| Process name | The name of the data set | | String |
| Categories: top category (level 1) | The top category | | String |
| Categories: sub category (level 2) | The first level subcategory | | String |
| Categories: second sub category (level 3) | The second level subcategory | | String |
| Process type | The type of process (unit, system, etc.) | UNKNOWN | Enum |
| Description | The description of the data set | | String |
| valid from | The year of the start of the validity of the data set | | Integer |
| valid until | The year of the end of the validity of the data set | | Integer |
| Regional code | The location of the data set | | String (ISO code) |
| Technology | A description of the technology used in the data set | | String |
| Data format | The data format the data set is available in (e.g. ECOSPOLD1, ECOSPOLD2, ILCD etc.) | | Enum |
| Supported LCA nomenclature system(s) | The nomenclatures the data set is compliant to | | String |
| Representativeness type | The representativeness type | EXPERT_BASED | Enum |
| Completeness | The percentage of flows covered according to nomenclature | 100 | Number (double) |

| | | | |
|---|---|---|---|
| LCI modeling approach | The LCI modeling type (attributional, consequential, before modeling) | UNKNOWN | Enum |
| Method used to deal with multifunctional processes | | NOT_APPLICABLE | Enum |
| Biogenic carbon | | NOT_APPLICABLE | Enum |
| End of life modeling | | NOT_APPLICABLE | Enum |
| Water modeling | | NOT_APPLICABLE | Enum |
| Infrastructure modeling | | NOT_APPLICABLE | Enum |
| Emission modeling | | NOT_APPLICABLE | Enum |
| Carbon storage modeling | | NOT_APPLICABLE | Enum |
| Source reliability | | ESTIMATED_ UNQUALIFIED | Enum |
| Aggregation type if any | | NOT_APPLICABLE | Enum |
| Dataset review performed | | NONE | Enum |
| Review system | | NOT_APPLICABLE | Enum |
| Reviewing persons | A list of the names of the reviewers of the data set | | List of String |
| CO2PE product code | A CO2PE product code identifying the product of the data set | | String |
| UNSPSC process code | A UNSPSC process code categorizing the data set | | String |
| supported LCIA methods | A list of supported LCIA methods | | List of String |
| Representativeness | The percentage of variation coefficient, s/(arithm. mean) | | Double |
| Deviation in mass and energy balance | The deviation in mass and energy balance | | Double |

| | | | |
|---|---|---|---|
| Copyright protected dataset? | Indicates if the data set is copyright protected | | Boolean |
| Copyright holder | The owner of the copyright of the data set if applicable | | String |
| Dataset publicly accessible? | Indicates if the data set can be downloaded from the given dataSetUrl without further login | | Boolean |
| Available for free? (vs. for purchase) | Indicates if the data set is available for free | | Boolean |
| Dataset license | The license the data set is released under | | String |
| Dataset contact | A contact person for information on the data set | | String |
| URL to dataset or database | A URL to download the complete data set, or alternatively, the website of the data provider | | String |

From: (GLAD, 2023)

## A11. Questionnaire to the OEMs for the decomposition tree

As mentioned in the document, a questionnaire was sent to the OEMs in order to gather their inputs and thoughts about the decomposition tree. Several questions were asked and some of them are represented in the picture below.

First, we asked some general questions about the method we used to build the tree and their view and opinion on the existing decompositions we used as a basis for the TranSensus tree. We also wanted to know if they saw other usages of this tree.

- Do you agree with the rules to establish the tree?
- Do you see any supplementary use for this tree in TranSensus?
- Do you agree with the battery decomposition by the JRC? If no, please comment.
- Do you agree with the GREET decomposition of level n-1 parts? If no, please comment.

Then, for each part and subpart we asked questions to collect more information, change the organisation if needed, add missing components, etc.

- Do you agree with the decomposition of the level n-2? If no, please comment.
- Do you agree with the exclusions? If no, please comment.
- Would you add sub levels concerning the *powertrain parts*?
- What are the processes linked to the *powertrain system* and subparts?

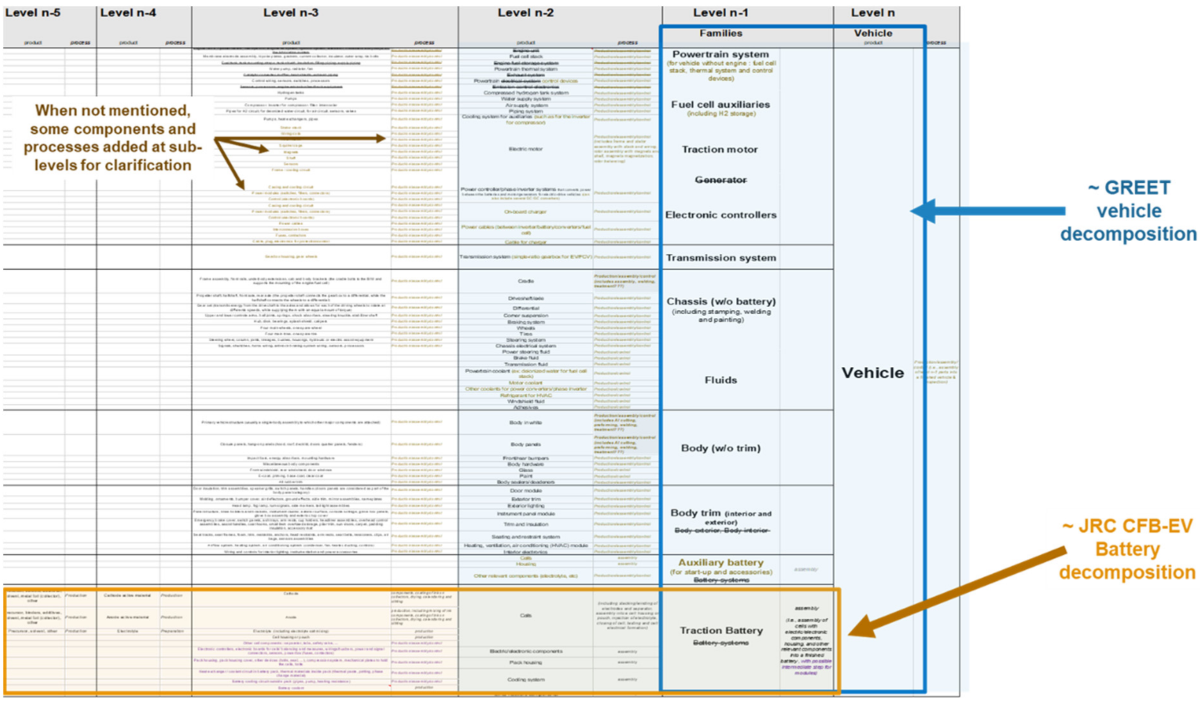
Finally, we left room for more remarks about the tree and its use in the project.

## A12. Decomposition tree

A proposal for the decomposition tree is available under an Excel format online. The picture below shows the first version of the decomposition tree.

The blue part shows the decomposition according to the GREET vehicle decomposition, some adjustments were made to best fit the products studied under TranSensus LCA. The orange part highlights the JRC CFB-EV battery decomposition which was also slightly modified to fit in the TranSensus LCA methodology. For now, it is still possible to see the components that have been removed (crossed) and those that have been added (in brown).

The tree is organized in various levels, the highest level is the level n and corresponds to the vehicle assembled. Then moving to the left the levels decrease representing the sub-parts of each component up until the material part, see Figure 19.



## A13. List of modifications to the vehicle and battery decomposition

**List of detailed modifications made from GREET vehicle decomposition:**

Deleted because not used in TranSensus vehicles technologies:

- 'Engine fuel storage system'

Renamed or completed for clarification:

- 'Powertrain system' completed with '(for vehicle without engine: fuel cell stack, thermal system and control devices)'
- 'Powertrain electrical system' renamed into 'Powertrain control devices'
- 'Fuel cell auxiliaries' renamed into 'Fuel cell and H2 auxiliaries', because it includes hydrogen tanks that are also used for hydrogen ICEV
- 'Cooling system' (in 'Fuel cell auxiliaries') renamed into 'Cooling system for auxiliaries (such as the inverter for compressor)'. Remark: the heat exchanger and radiator for stack are considered in 'Powertrain thermal system'
- 'Power controller/phase inverter systems that converts power between the batteries and motor/generators for electric-drive vehicles' completed with ' (can also include several DC/DC converters)'
- 'Pb-Ac battery to handle the startup and accessory load and either an Ni-MH or Li-ion battery for use in the electric-drive system' renamed into 'Auxiliary battery (for start-up and accessories)' and 'Traction Battery'
- 'Transmission system' completed with ' (single ratio gearbox for passenger EV/FCV)'
- 'Powertrain coolant' completed with ' (ex: deionized water for fuel cell stack)'

Added:

- 'Power cables (between inverter/battery/converters/fuel cell)', and list of sub-components added as sub-system of 'Electronic controllers'
- 'On-board charger', and a list of sub-components, added as sub-system of 'Electronic controllers'. Note: 's' added at the end of 'Electronic controllers'
- 'Charger cable', and a list of sub-components, added as sub-system of 'Electronic controllers'
- 'Motor coolant'
- 'Other coolants for power converters/phase inverter'
- 'Refrigerant for HVAC'
- sub-components of the 'Auxiliary battery (for start-up and accessories)'

Remark: the coolant for the traction battery is in the battery block, like in the JRC decomposition.

Level adjustment:

- 'Body' directly split at first level into 'Body (w/o trim)' and 'Body trim (interior and exterior)'
- 'Battery system' directly separated and replaced at ‘n-1’ level into 'Traction battery' and 'Auxiliary battery (for start-up and accessories)'

**List of detailed modifications made for battery compared to JRC in CFB decomposition**

Level adjustment:

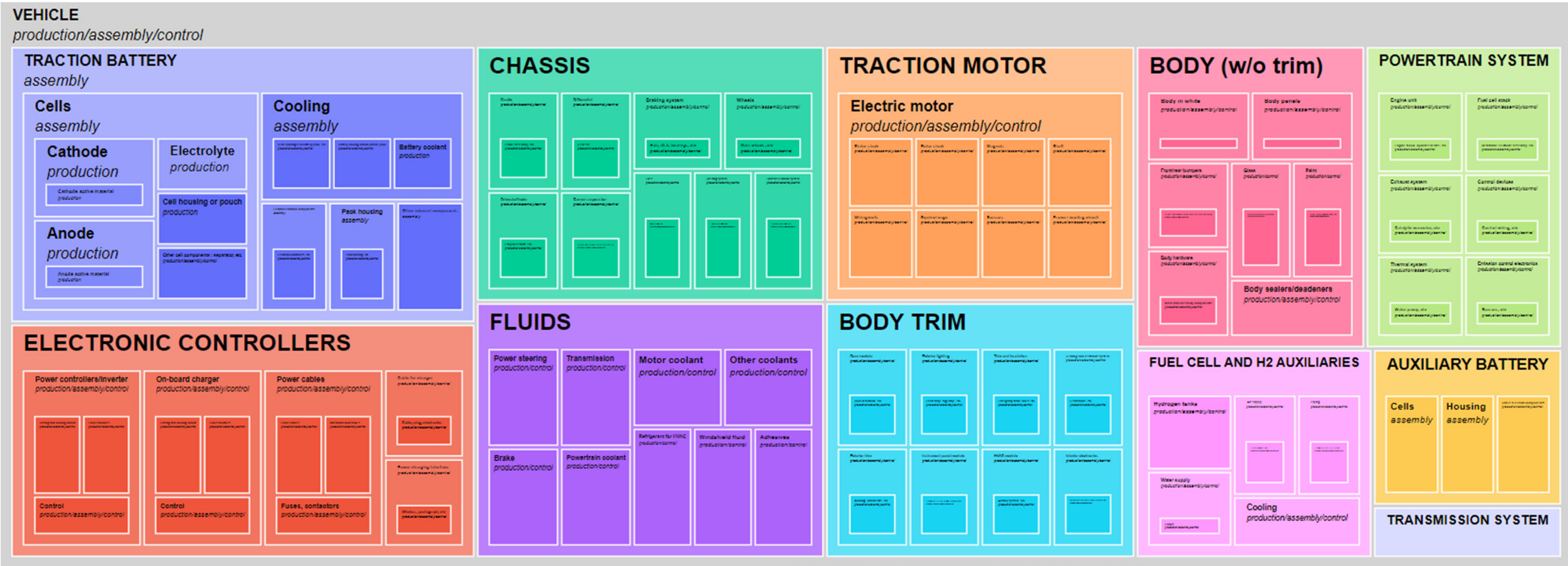
- Module level is deleted. 'Traction Battery assembly' renamed adding ' (with possible intermediate step for modules')

Added:

- 'Other components: separator, tabs, safety valve, …' as sub-components of 'Cell'
- Sub-components of 'Cooling system'
- Sub-systems of 'Electric/electronic components'
- Sub-components of 'Housing'
- 'Mechanical system to hold cells' and sub-components

## A14. Visualization of the decomposition tree

Decomposition tree on vehicle level:



Decomposition tree on battery level: