Title:

Draft of "Scope Definition" in the LCA of electric vehicles.

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This document is an excerpt from the guidelines on the LCA of electric vehicles which are currently being developed within the eLCAr project. It addresses the Scope Definition and should be considered as "work in progress". Feedback and suggestions are therefore very welcome.

Being an excerpt, it may appear that some technical terminology and concepts are used without the required definitions. In the complete version of the guidelines the contents shown in this excerpt will come after an introductory chapter on the main principles of Life Cycle Assessment.

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Scope definition

6.1 Introduction

During the scope definition phase the object of the LCA study is defined and described in detail. This shall be done in line with the goal definition, meaning that the scope should be sufficiently well defined to ensure that breadth, depth and detail of the study are compatible and sufficient to address the stated goal. This includes to derive the requirements on methodology, quality, reporting, and review in accordance with, and based on, the reasons for the study, the decision-context, the intended applications, and the addressees of the results.

When deriving the scope of an LCA study from the goal, the following scope items shall be clearly described and/or defined (ILCD 2010)[1]:

- The system or process that is studied and its function(s), functional unit, and reference flow(s)
- LCI modelling framework and handling of multifunctional processes and products
- System boundaries, completeness requirements, and related cut-off rules
- LCIA impact categories to be covered and selection of specific LCIA methods to be applied as well as - if included - normalisation data and weighting set
- Other LCI data quality requirements regarding technological, geographical and time-related representativeness and appropriateness
- Types, quality and sources of required data and information, and here especially the required precision and maximum permitted uncertainties
- Special requirements for comparisons between systems
- Identifying critical review needs
- Planning reporting of the results

Apart from clearly identifying all relevant aspects of the object of study, defining several of the above mentioned topics also helps the practitioner planning the development of the study since particular needs, for example, in the required data, may appear during the scope definition. The following subchapters address the main challenges of the scope definition.

6.1.1 Consistency and reproducibility

The general ILCD Handbook introduces basic requirements on consistency (provision 6.2.1) and reproducibility (provision 6.2.2). These provisions aim at securing the internal consistency of LCAs in terms of modelling, methods and data (including assumptions) and at ensuring that the documentation allows another practitioner to (sufficiently) reproduce the results of LCAs.

[1] ILCD 2010: European Commission, Joint Research Centre, Institute for Environmental Sustainability, "International Reference Life Data System (ILCD) Handbook – General guide for Life Cycle Assessment – Detailed guidance", First edition March 2010.

These provisions are very valuable, on one hand to point out the importance of the issues to the practitioner and, on the other hand, to guarantee that a commissioner or reviewer of an LCA can enforce consistency and reproducibility if the terms of reference for the LCA asks for compatibility with the ILCD-Handbook. These overarching provisions must therefore be taken into account by the practitioner. Due to their general aspect, which cannot be made more specific for the case of electric vehicles, the whole text is not repeated in this Handbook.

Provision 6.1.1: Consistency and reproducibility

I. SHALL: Follow the provisions 6.2.1 "Consistency of methods, assumption and data" and 6.2.2 "Reproducibility" of the general ILCD Handbook.

6.2 Function, Functional Unit and reference flow

After having introduced the object of the study in the goal definition, it is then necessary to define as precisely as possible its key characteristics and give more detail about the exact quantitative aspects which will lead the analysis. This is important not only in order to correctly develop the study in terms of methodological and data source choices, but also with respect to comparing the results within the own analysis (if more options or technologies are evaluated) or with other studies. Only if the objects of the comparison are well defined can an interpretation based on the comparison be meaningful. A central element for comparing and interpreting the results are functions, functional units and reference flows.

Functional units name and quantify the aspects of the functions of a product. Starting from the function of a product or service, the functional unit answers the questions "what", "how much", "how well" and "for how long" the object of the study implements the function. Clearly defining these questions at the beginning of the study is a crucial element since the comparison of products or systems will only be meaningful if these fulfil exactly the same functions in all relevant terms. Otherwise the comparison occurs between two objects which do not represent a proper alternative. Hence, if some of the relevant aspects of the products to be compared are not identical, the systems have to be expanded to the point where identical functionality is achieved.

Strictly linked to the concept of functional unit is the reference flow. The reference flow is the flow to which all inputs and outputs quantitatively relate. It is the flow which realises the functional unit and, in some cases, the two will have the same definition.

While more information and definitions on general functional units and reference flows can be found in the general ILCD Handbook (Paragraph 6.4), the next subchapter analyses the specific case of electric vehicles.

6.2.1 Functional Units for e-mobility applications

As described in the Goal definition, there are various components within an electric vehicle which can strongly influence its performance. A typical example is when different options of a technology will influence the overall consumption of the vehicle in the use phase. In order to correctly evaluate the impacts of the various technologies, the different options cannot be assessed as isolated components but must be considered within the vehicle they will be used for. In other words, and going back to the terminology of the previous paragraph, the various options must be compared within an equivalent functionality. Hence, consistently with the Goal definition, in an LCA of electric vehicles or of a number of key components of an electric vehicle, the functional unit and reference flow must, too, take into consideration the perspective of the entire vehicle in order to achieve equivalent functionality.

The box below illustrates this in a simplified example.

How to achieve identical functionality for comparison of non-identical products?
(Simplified example with plausible but not exact values)
Goal:
The environmental impacts caused by the cradle to grave life cycle of two different propulsion batteries for electric vehicles shall be compared.
Battery description:
Battery A
Li-ion Battery for compact car; energy density 100 Wh/kg, life time 2000 cycles → life time capacity 200 kWh/kg → mass per life time capacity 5.00 g/kWh
Battery B
Li-ion Battery for compact car; energy density 120 Wh/kg, life time 1500 cycles → life Time capacity 180 kWh/kg → mass per life time capacity 5.56 g/kWh
Functional unit, first try:
1 kg battery A and B have obviously not the same important properties (energy capacity, life time). But also 1 kWh life time capacity of battery A and B have different important properties (mass). Thus, to compare these two batteries, the "least common denominator" in terms of the batteries function needs to be identified. The batteries are to be used in electric vehicles which have the function of providing transport services. Thus one needs to compare vehicles using battery A to vehicles using battery B with the same relevant properties.
Vehicle description:
Compact class; mass w/o battery 1200 kg; range per charge (real world): 120 km; top speed 140 km/h; acceleration 0 – 100 km/h in 8 s
Battery mass depends on battery's energy density to achieve the range. However, care must be taken since the total vehicle mass influences the energy consumption.
→ Vehicle with battery A:
Battery mass to achieve 120 km real world range 350 kg; real world energy demand (at plug) 22.7 kWh/km; life time distance with 1 battery 240'000 km
→ Vehicle with battery B:
Battery mass to achieve 120 km real world range 280 kg; real world energy demand (at plug) 22.0 kWh/km; life time distance with 1 battery 180'000 km
Functional unit, vehicle perspective:
"1 km driving in a compact car of 1200 kg mass without battery, fuelled with average European electricity generated between 2012 and 2022, with battery A or B and a range of 120 km per charge in real world driving" would be a useable functional unit if it could be reasonably assumed that vehicle with battery A is disposed after 240'000 km while vehicle with battery B is disposed after 180'000 km. A better functional unit would be "240'000 km driving in compact car of 1200 kg mass

without battery, fuelled with average European electricity generated between 2012 and 2022, with battery A or B and a range of 120 km per charge in real world driving". For the vehicle with battery B one would then need to assume 1.33 batteries to achieve this mileage and for both vehicles one would need to consider the different electricity consumption. This difference is the reason why the electricity source needs to be specified.

By linking, in the latter of the above examples, the battery to the function it provides within the service delivered by the vehicle, a number of key parameters must be defined (e.g. life expectancy of, both, car and battery, driving range, exchange of battery due to ageing, consumption of the vehicle, etc.) which ultimately lead to functional equivalence. In this framework, a suitable reference flow for each of the two battery options could be: "Driving 1km in an electric compact car of 1200kg (without battery) and life expectancy of 240.000km in Europe between 2012 and 2020 with a Battery Type A (B) and corresponding driving range of 120km in real world driving".

For those components which have no influence on the vehicle performance, the practitioner can decide to limit the analysis to the isolated component. Since it is outside the scope of this Handbook to give guidance for all components in the vehicle, the practitioner shall use the general functional unit and reference flow definition given in paragraph 6.4 of the general ILCD Handbook if his analysis is limited to an isolated device.

Provisions 6.2.1: Functional Units for e-mobility applications

I. SHALL: For LCA addressing the environmental impacts of an entire vehicle or of components which influence its performance, the functional unit and the reference flow must be based on the transport service provided by the vehicle and take into consideration (depending on the specific component under analysis) following parameters:
   - Life expectancy of the vehicle
   - Life expectancy of the component
   - Key links between component and vehicle performance (e.g. weight with energy consumption, etc.) and how these will quantitatively influence the service provided by the vehicle
   - The location and time horizon corresponding to the object of study.

II. SHALL: Report exactly how the parameters for the definition of the functional unit and reference flow have been chosen (e.g. life expectancies, vehicle masses, component masses, etc.). The practitioner may use the values given in the CPP[2] or use own values, more specific to the goal of the study, if documented appropriately.

III. SHOULD: For the cases described above, the reference flow should be related to 1km of the corresponding driving service.

IV. SHALL: For components which, due to lack of influence on the performance of the vehicle, may be analysed separately, the provisions given in paragraph 6.4 of the general ILCD Handbook hold.

[2] CPP: Common Parameter Platform. A framework of technical vehicle parameters which practitioners may use for defining their systems. The CPP will be part of the final version of the guidelines.

6.3 Life Cycle Inventory modelling framework

The Life Cycle Inventory modelling framework defines two key aspects of the analysis: Firstly, what perspective is used in the description of the general life cycle model, meaning the supply-chain processes involved in the production, use and end-of-life of the product or service under study. Then, the methodology adopted for solving multifunctionality problems, where "multifunctionality problems" are all these situations in which a process returns several products and it is necessary to understand how much of its inputs and outputs can be associated to a specific product out of the ensemble. In the following sub-chapters, the basic principles for modelling the Life Cycle Inventory are summarized since clearing the above mentioned aspects is key for planning the implementation of the study. More guidance will also be given in Chapter 7.

6.3.1 General Life Cycle Model

As stated previously, this Handbook focuses on Situation A and Situation B of the ILCD framework, the two cases in which the results of the LCA aim at supporting a decision process(ILCD 2010). While both cases address the consequences of the decision at the base of the analysis, the extent and nature of the consequences is so different, that a different perspective in the description of the Life Cycle under study, and particularly in the involved supply-chains, can be used.

In Situation A, the decisions which may derive from the results of the LCA will not influence the infrastructure corresponding to the supply-chains supporting the life cycle. Coming back to a previous example, the results of an LCA comparing two brands of electric vehicles and published in a local car magazine may influence a buyer, but ultimately this will not cause a shift in the amount of steel absorbed by the automotive industry for the production of vehicles or in the production of electricity. Overall, in an LCA addressing such a situation, the life cycle can be modelled depicting the average supply-chain (if the life cycle requires common resources from a general market such as, for example, "steel" without particular characteristics which would require to depend on more specific products) or the specific supply-chain (if, due to particular requirements, products are needed which can be obtained only from specific manufacturers), without worrying about potential changes deriving from demand-supply mechanisms of the market. In short, the Life Cycle can be modelled "as it is" (be it in reference to today or forecasted for a particular time period) or, in other words, as if it was static(ILCD 2010).

In Situation B, instead, the nature and extent of the decisions is such that major transformations in the supply-chains involved in the Life Cycle under study may be caused. An example could be an LCA aimed at identifying the impacts of an increase of 30% in the share of electric medium sized passenger cars in a specific European country. Clearly, such a large increase in electric mobility would have major influences on the electricity production required to sustain the vehicles in the use phase, possibly requiring the installation of new electricity plants. Other implications may derive from the end-of-life of these vehicles. Batteries for electric vehicles, for example, typically require large quantities of copper which can be recovered through recycling processes. In such a scenario, these large quantities of recycled (or secondary) copper would now be available for the market. Could that lead to changes in the overall supply-chain of copper in the production system? These transformations must not only be taken into account, they represent a key part of the analysis.

Hence, the Life Cycle should be modelled depicting the supply-chains as these are theoretically expected to be in consequence of the analysed decision(ILCD 2010).

6.3.2 Multifunctionality

In the analysis of the life cycle of a product, situations may occur in which a specific step or process under study will have several products as outputs. Such a process is called a multifunctional process. Multifunctional processes pose a challenge in the analysis as typically one is only interested in one particular product out of the ensemble. The question therefore rises as to how much of the total inputs and outputs of the process can be associated to the specific product of interest. A schematic of such a situation is shown in Figure 1, in which, for example, one might be interested only in the resources, emissions and wastes flows of Product A, but only knows the values for the combined production of A and B. In order to isolate the specific exchanges for the product of interest, the multifunctionality must be solved. Multifunctionality can occur in production, where a production step may return several products, as well as during end-of-life where recycling, reuse and recovery can lead to equivalent situations.

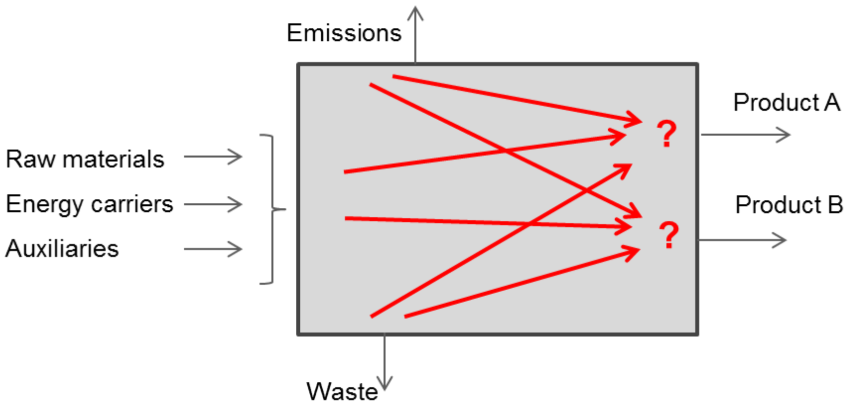

Figure 1: Multifunctional process

A typical example can be taken from the production of a vehicle door. A certain amount of steel will be required for its production. However, during manufacturing, part of this steel will, for example through cutting, not flow into the door but become production scrap. This scrap will then be collected and sent to the production of recycled steel and is, therefore, a co-product of the production process of the door. Hence, not all of the inputs and outputs who entered the door production process actually flowed into the door; some of these went into the production scrap.

To solve multifunctionality cases, in ISO and the general ILCD Handbook(ILCD 2010), the following hierarchy is defined (Figure 2):

- The first option is *subdivision* (including *virtual subdivision*), (a)
- The second option is system expansion and substitution, (b)
- The third one is allocation, (c).

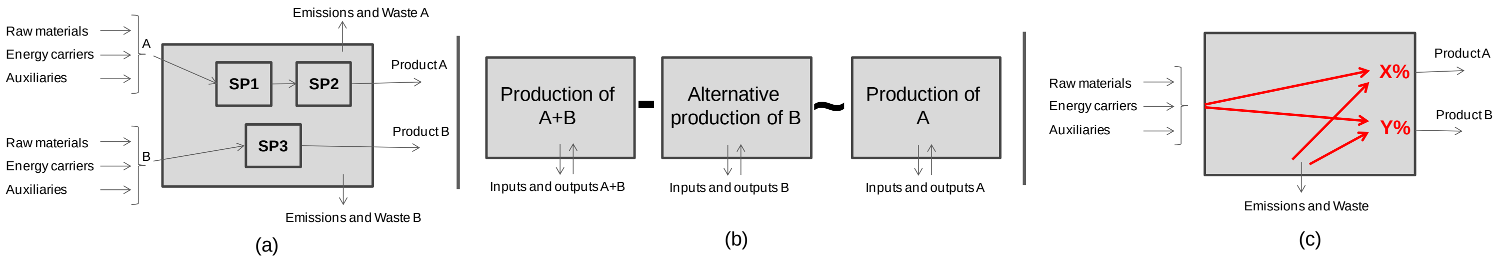

Figure 2: Various methods for solving multifunctionality: (a) Subdivision (including virtual subdivision), (b) System expansion and substitution, (c) allocation. (Based on ILCD 2010)

In *subdivision*, the multifunctional process is further analysed with the aim of finding separate sub-processes for Product A and B so as to be able to quantify exactly how the inputs and outputs distribute over A and B. In some cases, an ensemble of sub-processes cannot be found, but it is nevertheless possible to derive a quantitative distribution of the inputs and outputs based on technological knowledge about the production process. In this case, the solution is obtained through *virtual subdivision*. Subdivision is the preferred option since it is based on technical relationships within the system and, ultimately, leads to a better understanding of the system.

If subdivision is not possible, the second option is system expansion and substitution (b). Here, multifunctionality is solved creating a new process which approximates one only returning Product A by subtracting or *substituting* from the combined production of A and B an alternative production of B. Often, other processes need to be added to the system in order to bring product B which comes out of the multifunctional product to a state in which the subtraction can take place.

A key factor is with what to substitute the not required co-product and the various ILCD Situations are treated differently in this context. In general, for Situation A, in which the study is compatible with a static supply chain, the not required co-function can be substituted with the average market consumption mix of functionally equivalent alternative processes, eliminating from this mix the to-be-substituted product. Instead, for Situation B, those processes, for which in the context of multifunctionality, the consequences are very large, must be substituted by the long-term mix which is expected due to the taken decision (ILCD 2010).

In this context, it is also important to note that the treatment of waste and end-of-life cases usually leads to multifunctionality situations. While conceptually system expansion and substitution is applied according to the same principles in these cases, some specific indication is provided within the ILCD framework. In general[3], the avoided primary production of the reused part, recycled good or recovered energy shall be substituted with the simplification of substituting the average primary route market consumption mix of the market where the secondary good is produced.

It is important to notice that, since this method uses the subtraction of LCI data, negative exchanges and results can occur. This means there is a net benefit of producing the analysed system as the overall impact is more than compensated by the avoided impact the co-products have elsewhere. This is the correct interpretation within the assumption of the study, even though it can lead to communication problems(ILCD 2010). It therefore requires particular attention during the reporting of the results.

[3] In the general ILCD Handbook, special cases are also discussed (see Provisions 6.5.4)

The last option is allocation, which solves the multifunctionality by splitting up the amounts of the inputs and outputs between the various co-products according to some allocation criterion based on their properties. Typical allocation criteria can be: element content, energy content, mass, market price, etc.). Say, for example, that mass is used as the allocation criterion. Having two processes A and B with mass X and Y, product A would receive X/(X+Y), while product B would receive Y/(X+Y) parts of the multifunctional process' inputs and outputs.

If possible, allocation should be performed in accordance with the underlying causal physical – and implicitly also covered: chemical and biological – relationship between the different products.

6.3.3 Comparative studies

For comparative studies of Situation A the main model for each of the compared alternatives shall be complemented with assumption scenarios of reasonably best and reasonably worst cases and (optionally) further assumption scenarios within the reasonably best and worst cases. Uncertainty calculation shall be performed, unless it has already been used to derive the reasonably best and worst case scenarios. The interested parties shall be involved towards a best attainable consensus on the definition of the reasonably best and reasonably worst assumption scenarios that can in principle vary all data and method provisions and assumptions for Situation A, except for the "shall" provisions and assumptions. In Situation B, the assumption scenarios and uncertainty calculation can in principle vary all data and method provisions and assumptions including the "shall" provisions and assumptions / conventions of the ILCD Handbook, while not those of ISO 14040 and 14044(ILCD 2010).

Provisions 6.3: Life Cycle Inventory modelling framework (Summary of Provisions 6.5.4 of the general ILCD Handbook)

I. SHALL: For Situation A, model the Life Cycle depicting the existing (or forecasted) supply-chains.
II. SHALL: For Situation B, model the Life Cycle depicting the supply-chains as these are expected to be in response to the decision taken.
III. SHALL: Use subdivision as the first choice for solving multifunctionality problems.
IV. SHALL: Use system expansion and substitution if subdivision is not possible.
V. SHALL: When using system expansion and substitution the practitioner shall refer to the specific provisions given under "Provisions 6.5.4 – I.a.iv) Cases of multifunctionality – general" and "Provisions 6.5.4 – I.a.v) Cases of multifunctionality – waste and end-of-life treatment" of the general ILCD Handbook. In many cases, this will require, for the general case, to substitute the not required co-function, as far as possible, with the average market consumption mix of the processes or systems it supersedes, excluding the to be substituted function from the mix. If the to be substituted function has a small share in the overall environmental impact of the market mix, the market mix can be used instead, if the results are not relevantly changed. If such alternatives are not available, alternative processes/

systems of the not required co-function in a wider sense should be used for substitution. For the case of waste and end-of-life treatment, the avoided primary production of the reused part, recycled good or recovered energy shall be substituted with the simplification of substituting the average primary route market consumption mix of the market where the secondary good is produced. The above is a summary of the main concepts involved. The practitioner shall verify with the provisions 6.5.4 of the general ILCD Handbook that the specific case of interest does not fall within one of the special cases described therein.

VI. SHALL: Use allocation if neither subdivision nor system expansion can be applied. Provisions 7.9.3 of the general ILCD Handbook shall be used in this case.

VII. SHALL: For comparative studies of Situation A, the main model for each of the compared alternatives shall each be complemented with assumption scenarios of reasonably best and reasonably worst cases. Optionally further assumption scenarios can be defined. Uncertainty calculation shall be performed, unless it has already been used to derive the reasonably best and worst case scenarios. These scenarios serve to later perform the sensitivity check[4]. The interested parties shall be involved towards a best attainable consensus on the definition of the reasonably best and reasonably worst case assumption scenarios (and uncertainty calculation) that can in principle vary all data and method provisions and assumptions for Situation A except for the "shall" provisions and assumptions / conventions. It is recommended to also perform and report such assumption scenarios and uncertainty calculations for non-comparative LCI and LCA studies. In Situation B, the assumption scenarios and uncertainty calculation can in principle vary all data and method provisions and assumptions including the "shall" provisions and assumptions / conventions of the ILCD Handbook, while not those of ISO 14040 and 14044.

6.4 System boundaries

The system boundaries define which parts of the life cycle and which processes belong to the analysed system, i.e. are required for providing its function as defined by its functional unit. They separate the analysed system from the rest of the technosphere. At the same time, the system boundaries also define the boundary between the analysed system and the ecosphere, i.e. define across which boundary the exchange of elementary flows with nature takes place (ILCD 2010). Overall, a precise definition of the system boundaries is important to ensure that all processes are actually included in the modelled system and that all relevant potential impacts on the environment are appropriately covered.

However, while the detailed identification of all the processes within the system boundary can only occur in the LCI phase, the definition of the system boundaries must occur in the scope definition as this clarifies which key activities will be part of the study and helps planning the implementation of

[4] More information on sensitivity checks will be given in the final version of the guidelines in a dedicated chapter on “Interpretation” (in development).

the study. For this reason, specific guidance on which process to include in the LCA of electric vehicles and of their components will be given in Chapter 7 whereas the definition of system boundaries will be treated in the following paragraphs.

6.4.1 Derivation of system boundaries for e-mobility applications and cut-off criteria

System boundaries are defined in order to identify the activities which will be included in the analysis, assuming the object of interest to be working in normal or abnormal condition, but not covering the impacts from accidents or similar events(ILCD 2010). When deriving system boundaries for the LCA of electric vehicles or of their components two aspects should be taken into account. Firstly, as already mentioned, even if the specific focus of the analysis is on one specific component for electric vehicles, in most cases only an analysis addressing the whole vehicle and the consequences of possible part-system interactions would return meaningful results. Secondly, due to impacts which can derive, for example, from the electricity generation for the use phase and considering the large share of valuable materials contained in a vehicle which can be recovered in the end-of-life phase (an aspect in continuous evolvement also from a regulatory point of view; see, for example, Directive 2000/53/EC of the European Parliament on the end-of-life of vehicles) only a complete cradle-to-grave approach, comprising production, use and end-of-life phase, can really capture all the relevant environmental aspects related to electric vehicles and possible interdependencies amongst these. Hence, the main activities which should be part of the LCA of an electric vehicle are shown in Figure 3.

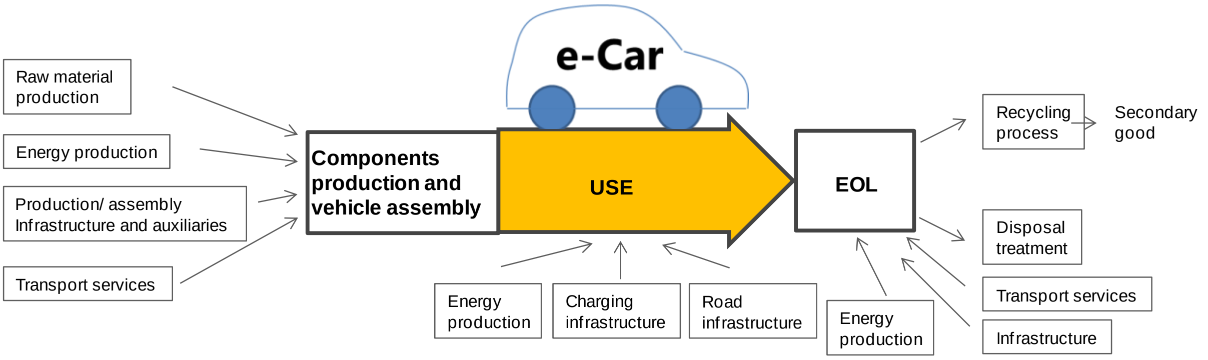

Figure 3: System boundary for the LCA of an electric vehicle.

It should be noted that system boundaries in Figure 3 are indicated indirectly. Per definition, the system boundary is where the exchange of elementary flows with nature occurs. Instead, for simplicity, in Figure 3 the key activities within the system boundaries for the LCA of an electric vehicle are shown. The exact system boundaries can be derived following the supply chain and applying the cause and effect relation to each single activity, until the level of elementary flow exchange is reached. This means that the system boundaries implied through Figure 3 include, for example, the mining of the resources required for the production of raw materials as well as the infrastructure required for the mining, or the resources required for building the production/ assembly facilities.

Of course, different processes within the life cycle of a vehicle or of a component will have different relevance in terms of the overall impacts caused. Processes which are irrelevant with respect to the total impacts can be completely “cut-off” in order to be able to invest more time and resources in the modelling of elements which have a high relevance. However, in cutting-off processes, an estimate of the potential excluded % of impacts has to be quantified in order to ensure that the system has been sufficiently well described. Clearly, this percentage can only be estimated since the 100% of the total impact is unknown. Further, it may be difficult to identify from the beginning the relevance of processes. This paradox can be solved through the iterative nature of LCA and reaching an estimate of the 100% impact coverage working with worst-case dataset approximations (which can be compiled with fewer efforts compared to a high quality dataset) for those datasets which are expected not to be relevant in the overall system. During the first iteration, the study would mainly comprise data for the most relevant processes and approximations for the minor ones. Based on this first analysis and analysing the percentage of contribution of all processes, some of the supposed minor ones might turn out to be more important than expected and require to be included with a proper, complete and high quality dataset. Repeating these iterations, a reasonable estimate of the 100% impact through high quality data for relevant and low quality approximation datasets for not relevant datasets which may be cut-off can be obtained. This allows to roughly quantify the % contribution of the cut-off processes. The above mentioned procedure has to be repeated, until the % of impact contribution from the cut-off process is small enough with respect to the goal of the study.

Provisions 6.4.1: Derivation of system boundaries for e-mobility applications and cut-off criteria

I. SHALL: In general, even if the focus of the study is on a specific component, the LCA shall analyse the impacts in the context of the entire vehicle with a cradle to grave perspective. If a different approach is used (analysis of isolated component or elimination of specific life cycle phases) due to particular goal and scope requirements, then the reasons for this have to be explained and documented.

II. SHALL: Focus on normal or abnormal behaviour but not include accidents or similar events(ILCD 2010).

III. SHALL: Include in the system boundaries of the study all the relevant activities required for the accurate description of the life cycle under analysis. This shall include, amongst other things:
-Extraction/ refining/ production of raw materials including the required infrastructure
-Energy production and the respective infrastructure
-The component/ vehicle manufacturing and assembly facilities (manufacturing equipment, buildings, etc.,)
-The component/ vehicle recycling and disposal including the required infrastructure (recycling/ disposal equipment, buildings, etc.,)
-The transport services required throughout the life cycle
-The road and charging infrastructure required for the use phase of the vehicles

IV. SHALL: Quantify and document the cut-off criteria chosen for the goal of the study. The chosen cut-off criteria shall be considered with respect to all environmental impacts included in the study as well as energy and mass.

6.5 Preparing the basis for the impact assessment

During the Life Cycle Impact Assessment (LCIA) phase, the gathered LCI data is used to calculate an ensemble of indicators which set the base for the interpretation of the environmental impacts associated with the object of the study. To date, a number of established LCIA methods for various environmental impacts are available in literature or directly in LCA software and are commonly used in LCA studies. The choice of what is covered by the LCIA shall be taken in the scope definition in order to ensure that relevant and matching data is then collected in the LCI modelling phase.

Overall, the first step in LCIA is to evaluate, from the LCI data and through models of environmental mechanisms, a number of indicators describing impact categories. These indicators address a specific environmental aspect. The following impact categories shall be checked per default for relevance for the study(ILCD 2010): Climate change, (Stratospheric) Ozone depletion, Human toxicity, Respiratory inorganics, Ionizing radiation, (Ground-level) Photochemical ozone formation, Acidification (land and water), Eutrophication (land and water), Ecotoxicity, Land use, Resource depletion (metals, minerals, fossil and renewable energy sources, water).

The impact categories can then be further processed into the three areas of protection (ILCD 2010):

- Human Health
- Natural environment
- Natural resources

Typically, impact categories are also called midpoint indicators while the three areas of protection are referred to as endpoint indicators. The exact types and numbers of impact categories taken into account in a study can vary depending on its goal and scope. Figure 4 shows a summary of the LCIA framework within the ILCD (ILCD 2010).

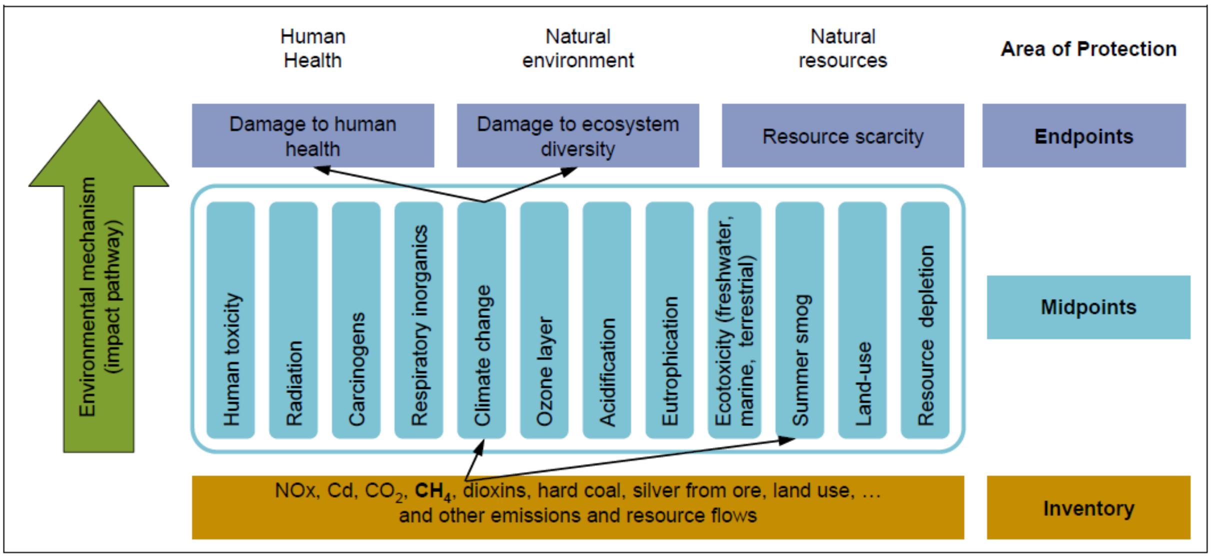

Figure 4: LCIA framework within the ILCD (ILCD 2010).

It is outside the scope of these guidelines to detail how the various impact categories and areas of protection can be calculated. For more information on the background of LCIA, the reader is referred to the General ILCD Handbook (Paragraph 6.7 and chapter 8), to two specific ILCD Documents:

- “Framework and requirements for Life Cycle Impact Assessment (LCIA) models indicators”
- “Recommendations for Life Cycle Impact Assessment in the European context”

And other LCIA specific references which can be found on the website of the ILCD platform: http://lct.jrc.ec.europa.eu/assessment/publications.

Particularly, in paragraph 6.7 of the general ILCD Handbook, general guidance on how to address, amongst other things, inclusion of non-standard impacts and non-standard elementary flows, spatial and other differentiation/ modification of impact factors, dealing with missing flows, etc., can be found. Here, the topic is mainly how to choose LCIA methods.

In the context of electric mobility (and of conventional mobility as well since comparisons amongst these two technologies are often object of LCA studies), the large variety of different processes involved makes it difficult to suggest a sub-ensemble out of the impact categories listed above. Different emissions and wastes are produced in production, use and end-of-life. Also, a broad spectrum of resources is consumed during production (in forms of materials like, for example, metals and minerals as well as energy vectors) and the use phase (mainly in form of, both, renewable and non-renewable energy vectors). Hence, in order to have sufficient data for the interpretation phase, all three protection areas should be covered in the analysis[5].

Overall, LCIA methods should be chosen whose models are scientifically and technically valid and which are internationally accepted. As far as possible, LCIA methods which cover all impact categories should be preferred as opposed to covering all the categories through various methods. If, due to the particular goal and scope of the study, only a selection of impact categories is chosen, then this must be documented appropriately as also discussed in paragraph "5.2 Methods, assumption and impact limitations".

Below, the provisions concerning the preparation of the basis for the impact assessment are presented. First, a general reference to the corresponding provisions of the general ILCD Handbook is made. Some of these are repeated here and, occasionally, modified. When this is the case, this is indicated and the version presented here shall be assumed as valid.

Provisions 6.5: Preparing the basis for the impact assessment

I. SHALL: Refer to provisions 6.7 "Preparing the basis for the impact assessment" in the general ILCD Handbook.
II. SHALL (Modified compared to provisions 6.7 of the general ILCD): Analyse by default the following impact categories and provide characterization factors on midpoint level. It is recommended that these are also used to derive category endpoint factors that are coherent with the midpoint level and that cover all relevant damages to the three following areas of protection(ILCD 2010):
Impact categories (midpoint level):

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[5] During the first eLCAr workshop, general agreement was expressed towards the fact that all relevant issues should be included in the analysis, where relevant was defined as those indicators that show large differences between the compared technologies. The use of single-score indicators was also discussed. While some participants described such indicators as useful, it was remarked that ISO 14044 forbids these methods in comparative assertions intended to be disclosed to the public and that the use of single score methods alone was not an option for any LCA.

- Climate change
- (Stratospheric) Ozone depletion
- Human toxicity
- Respiratory inorganics
- Ionizing radiation
- (Ground-level) Photochemical ozone formation
- Acidification (land and water)
- Eutrophication (land and water)
- Ecotoxicity
- Land use
- Resource depletion (metals, minerals, fossil and renewable energy sources, water)

Category endpoints(ILCD 2010):

- Damage to human health
- Damage to ecosystem
- Depletion of natural resources

III. MAY: Focus mainly, in reporting the results and in the detailed analysis of the key contributions, on the impact categories showing large differences between the compared alternatives.

IV. SHALL: If only a sub-set of impact categories is analysed (e.g. Carbon footprint studies), due to the particular goal and scope of the study, then this must be documented, considered during interpretation and reported accordingly. This shall already be mentioned in the "Methods, assumption and impact limitations " section.

V. SHALL: Distinguish between renewable and non-renewable resources in the analysis of energy resource depletion.

VI. SHALL: Avoid the use of single score methods.

6.6 Technological, Geographical and Time-related scope and data representativeness.

During the scope definition technological, geographical and time-related constraints must be identified and declared. This will help the practitioner in the planning of the data collection and in identifying the correct data sources.

A key concept in this context is the one of data representativeness. The results of an LCA will only comply with the goal and scope of the study if the environmental impacts have been derived through data which, too, complies with the goal and scope of the study. This aspect is taken into account through the representativeness of the data, meaning how well the collected inventory data represents the “true” object under study(ILCD 2010). In order to be able to identify the most representative data for the study (meaning the overall system as well as the sub-processes within), it is therefore necessary to define what its main technological, geographical and time-related characteristics are.

Technological, geographical and time-related scope delimitations are 3 slightly different but very intertwined concepts. In terms of LCI data modelling, technological representativeness describes how well the collected data for a process actually represents its true technological or technical characteristics. In the context of transport studies, a typical example could be the comparison of different engine technologies. Say a study is interested in comparing the environmental impacts of two current best-in-class passenger cars, the first, a BEV, the second an ICEV with a petrol engine. The technology level for these vehicles would be “state of the art” and the data describing it in an LCA would need to reflect those technologies. Evaluating the impacts deriving from the emissions in the use phase of the ICEV using data for a EURO 3 engine, for example, would mean to use data which is not representative of today’s “state of the art” engine technology.

This holds not only for the overall system, but also for the sub-processes used to build the system. In the analysis of the production of an electronic component, using “technical quality silicon” instead of “chip-grade silicon” for the processors in the device is likely to lead to unreliable results.

With geographical representativeness the focus is set on the influence which local characteristics can have on the LCI. The choice of the electricity mixes is just one example which is particularly relevant in the context of electric vehicles. If a study is set in France, then the impacts deriving from electricity production in the use phase will depend on the specific electricity production technologies used in France and on the imported electricity. An average European electricity mix would not be representative in that case. The same holds for data describing the production of the materials used for the production of the vehicle or component and imported from other countries. Typically, the same item produced in different countries may lead to different environmental impacts due to different technologies used. All this must be considered during the LCI phase.

Similar aspects are related to time representativeness. The inventory of a process or system that is to represent a certain time context (e.g. present or near future situation, “2025”, or for a baseline past scenario “1990”) is to be based on data that sufficiently appropriately represents that declared time. Clearly, the strong link between technological and time representativeness is particularly evident here, since technologies which may be “state of the art” today, may be obsolete in a few years.

In this context, a key element is also representativeness with respect to the validity of the study. If a study compares two current technologies with a clear focus of validity on a limited time period (e.g. comparison of two products already on the market), the most recent data describing the two technologies would be the most representative choice. If, instead, a study aimed at addressing scenarios which may have a long duration (e.g. strategic decisions which may lead to the building of infrastructure with a life time of 30 years) considerations on how technology developments over the period might influence the data must be made.

Overall, only defining during the scope definition, what constraints may come due to technological, geographical and time-related representativeness can the practitioner effectively plan data collection.

Of course, during the LCI phase it may turn out that some desired level of data representativeness may not be reached due to lack of data and that some less representative data has to be used. This is only acceptable if the results, interpretation and conclusions of the study are not relevantly affected and with appropriate documentation. If there is a relevant influence on the results due to a possible non-appropriate choice of data, then this has to be clearly documented and taken into account in the interpretation and reporting phase.

Below, key provisions on representativeness are given which are essential for planning the development of the study. More information on this topic will be given in paragraph on Planning data collection in Chapter 7.

Provisions 6.6: Technological, Geographical and Time-related scope and data representativeness.

I. SHALL: Clearly identify the required technological representativeness for the data concerning the main object of the study (e.g. current technology, future technology, etc.). Starting from the identified representativeness for the overall system, the specific representativeness for each sub-process of the system shall be then identified during the LCI phase.

II. SHALL: Clearly identify the required geographical representativeness for the data concerning the main object of the study (e.g. specific nation, Europe, etc.). Starting from the identified representativeness for the overall system, the specific representativeness for each sub-process of the system shall be then identified during the LCI phase (e.g. Main object produced in a specific European nation, but some raw materials imported from other countries).

III. SHALL: Clearly identify the required time-related representativeness for the data concerning the main object of the study (e.g. past, current, near future, etc.). Further, the temporal validity of the data shall also be consistent with the goal and scope of the study.

IV. SHALL: If, during the LCI phase, it occurs that some aspects of representativeness cannot be satisfied then this shall be documented. Particularly, if the lack of representativeness relevantly affects the computed environmental impacts then this shall be addressed in the interpretation, conclusions and recommendations of the study. The practitioner shall not allow that the use of less representative data disfavours any competitors' products in particular(ILCD 2010).

6.7 Comparison between systems

Throughout this chapter, a number of specific recommendations on various topics have been given in the context of comparative LCA studies and in particular comparative studies intended to be disclosed to the public. Due to the impacts which results from such studies can have on stakeholders (building of new infrastructure, influence on markets, etc.) the key aspects of comparisons of systems are here summarized again. Sometimes a distinction between “comparative assertions” and “comparisons” is made in the LCA. The first one implies a precise assertion on the superiority or equivalence of one system with respect to the other. The latter only presents the results for the two systems without making a specific assertion. Since the assertion may often be directly derived from the results even if it is not clearly stated, the recommendations presented here shall be considered valid for both types of studies.

6.7.1 Functional unit, considered alternatives and assumptions

Overall, in defining the details of a study addressing the comparison of two alternatives, the issue of consistency is at the core of a meaningful and (as much as possible) fair end result. Firstly, this must be taken into account when considering “what to compare”. Consistency here means the equivalence of the functional unit of compared alternatives and the non-misleading selection of the compared alternatives (ILCD 2010).

To make two examples, in the context of equivalence of functionality, the comparison of a small city car, designed for short urban trips, with a large family car suitable for long distances, is problematic since these two objects are clearly designed for two different functions and are (or, at least should be!) used in different situations. In terms of consistency of alternatives, when comparing a BEV with an ICEV, after making sure that for each technology a similar vehicle type is chosen, the same technology level should be used for the two alternatives. It would not be consistent to compare a prototype, emission optimized Euro 6 ICEV with a BEV equipped with a low efficiency electric motor and power electronics and a lead acid battery. The alternatives should be comparable in terms of the function they fulfil and their overall characteristics (level of technology, quality, price class, etc.).

Of course, there are studies in which, particularly in the comparison of various products within the same technology, the goal and scope aim at addressing exactly these points (for example, differences to a change in the level of technology or of the quality of materials) which shall then be clearly documented and taken into account in the interpretation phase. Nevertheless, in the inclusion or exclusion of compared alternatives, it should be ensured that the comparative assertion is not misleading by leaving out existing or even widely used alternative products that may perform environmentally clearly better than the compared alternatives (ILCD 2010).

Similarly, the choice of scenarios and of the assumptions shall be done such that none of the alternatives is favoured with respect to the other. In the choice of the scenarios, this requires to take into account the application context as part of the functional unit, as it may render products with the same general functional unit to perform differently: E.g. The comparison of a hybrid-vehicle with internal combustion engine and propulsion battery / electric motor with a conventional vehicle with internal combustion engine will vary if, in the use phase, only urban, short distance operation or only extra-urban, long-distance operation is taken into account. In the definition of scenarios, the influence of particular operation patterns must be considered carefully. Hence, first, the general technical specification of such products needs to be transformed into a functional unit that considers average or specific operation conditions of the product. Please note however that for comparative assertions that will be published, the choice of a specific application context may fulfil the criteria of misleading goal definition, e.g. by using very unusual application contexts. Studies that look into a-typical or otherwise specific scenarios shall highlight this fact visibly in the interpretation including when drawing conclusions and giving recommendations, as well as in the executive summary (ILCD 2010).

The same applies to the assumptions made in the development of the scenarios. Even though this holds for all assumptions in the study, a key topic is the one of durability. Cars and their components have life times which can typically be expressed in km or in years. When in the life cycle of a system the various components have different life times, a substitution/ maintenance strategy must be defined. In the definition of the various life times and of the substitution/ maintenance strategy the alternative object of comparison must be treated equally.

6.7.2 Methodological and data consistency

Consistency is also required in the methods and data used for the two alternatives (ILCD 2010). In the choice of, among other things, system boundaries, data representativeness, data quality, cut-off criteria, LCI modelling, LCIA methods the same principles need to be adopted for the various alternatives so that no misleading bias is produced.

In the context of LCIA methods it has to be remembered that the ISO and ILCD framework define special requirements on the choice and coverage of impact categories for the case of comparative studies intended to be disclosed to the public in order to avoid making conclusions on the environmental superiority or equivalence of one alternative with respect to the other without having analysed all relevant environmental impacts. As such comparisons based on only selected indicators or impact categories (e.g. carbon footprint studies) should be avoided. Studies which chose to limit the analysis to selected impact categories shall highlight in the interpretation, conclusions and recommendations that the comparison is not suitable to identify environmentally preferable alternatives.

6.7.3 Scenarios in support of comparisons

Reasonably best case / most likely case / reasonably worst case scenarios (plus optionally other scenarios) shall be performed for comparison of systems: data and method assumptions should be varied to investigate the robustness of the results (ILCD 2010). Such scenarios support the later results interpretation. For comparative micro-level decision support studies (i.e. Situation A), examples for such method and data assumptions are inventory data values, parameters, relevant flow properties, relevant system properties / aspects of the functional unit, but also method assumptions including method approaches such as the mix of substituted process used in system expansion, allocation criteria, and the like; the "shall" provisions shall still be met however.

Uncertainty calculation shall be used to support the comparison of systems, especially to identify whether differences can be considered significant or too small to justify the superiority of one system over the other (ILCD 2010). For comparative meso/macro-level decision support studies (i.e. Situation B), a more extensive use of scenarios is necessary to ensure that the decision support is robust. In difference to Situation A, in Situation B and here exclusively for the assumption scenarios also the shall provisions of this document can be changed.

The choice of which parameters are used in the definition of the best / most likely / reasonably worst case scenarios of course depends on the precise object of the study and on its goal and scope. In the context of passenger cars, examples of parameters which could be suitable are: vehicle consumption, vehicle life expectancy, battery life expectancy, efficiencies of the components used in the system, recycling rates, etc. For some studies the availability of materials could be an issue which requires scenario analysis. Again, it is up to the practitioner to understand which parameters are crucial for the results of his study and should be verified through best, expected and worst case analysis.

In the development of the scenarios, a close collaboration with interested parties should be pursued in order to achieve the best possible consensus.

Since most of the recommendations on comparisons concern general aspects of LCA, the reader is referred to the provisions of the general ILCD Handbook.

Provisions 6.7: Comparison between systems

I. SHALL: Apply all provisions reported in box "6.10 Comparison between systems" from the general ILCD Handbook.

6.8 Identifying critical review needs

A critical review is an independent analysis of the LCA which can help identifying errors, problems, inconsistencies, etc., concerning all aspects of the study. A critical review is mandatory for comparative studies intended to be disclosed to public but is also beneficial for in-house applications since, overall, critical reviews can enhance the quality, credibility and value of the study(ILCD 2010).

Various types of review requirements exist which depend on the goal, scope and decision context of the study. It is useful already during the scope definition to decide whether a critical review will be done, and, if so, which form of review and performed by whom. This early decision will allow the data collection, documentation and reporting of the LCI/LCA study to be tailored to meet the requirements of the review, typically shortening and lowering the overall effort.

Specific guidance on the appropriate review schemes in the ILCD framework is given in the document "Review schemes for LCA". The minimum requirements on reviewer qualification are, too, given in the separate document "Reviewer qualification". Both documents can be found on the "publication" section of the ILCD framework: http://lct.jrc.ec.europa.eu/assessment/publications.

Provisions 6.8: Identifying critical review needs

I. SHALL: Identify in the scope definition whether a critical review shall be performed and if so(ILCD 2010):

a) Review type: Decide along the provisions of the separate document “Review schemes for Life Cycle Assessment (LCA)” which type of review is to be performed as minimum.

Note that an accompanying review can be beneficial. For Situation B, it can moreover help to organise the best attainable consensus among interested parties, which is required for certain scope decisions (see provisions of chapter 6.5.4).

b) Reviewer(s): It is recommended to decide at this point who is/are the reviewer(s). The minimum requirements on reviewer qualification are given in the separate documents "Reviewer qualification".

6.9 Planning reporting

Reporting is a vital element of any LCA. Without clear and effective documentation to experts and communication to decision makers, LCAs can be subject to erroneous and misleading use and will not contribute to improving environmental performance. Reporting shall be objective and transparent, and there should be a clear indication of what has and what has not been included in the study and which conclusions and recommendations the outcome of a comparative study supports.

Various types of reporting solution exist and how to address reporting should already be decided during the scope definition in order to ensure that the required documentation will be collected throughout the project.

The form and levels of reporting depends primarily on three factors(ILCD 2010):

- the type of deliverable(s) of the study,
- the purpose and intended applications of the study and report, and
- the intended target audience (especially technical or non-technical and internal or third-party/public).

Next to general purpose reports that will be sketched in this chapter, the various applications of LCA may have their own, specific form of reporting (e.g. Environmental Product Declarations (EPDs) or the reporting of indirect effects in Environmental Management reports of sites or companies, etc.). These will not be addressed in this document as they are out of the scope. Please refer to the respective application to identify the specific reporting needs.

Forms of reporting

Three principally different forms of reporting are relevant that are often used also in combination[6] (ILCD 2010):

- a "classical" detailed project report, i.e. an often comprehensive text document typically with graphics and tables and that provides all relevant details e.g. on the analysed system(s) or developed LCIA methods, and the project in which the work was done. It is directed at LCA experts, but should contain an executive summary for non-technical audience. The full report provides detailed documentation about the system (or LCIA methods), their modelling, on assumptions and – especially in case of comparative assertions – on interpretation including conclusions and recommendations, if any. Confidential information can be foreseen to be documented in a separate, complementary report that is not published but only made available to the reviewers under confidentiality. If the detailed report is used for third party information, it shall contain a reference (preferably a hyperlink) where any related review reports can be easily accessed.
- a more condensed and formalised, electronically exchangeable report in form of a data set. A data set is suitable for documenting individual unit processes or systems (as Process data set) but not for documenting the outcome of comparisons. It is also suitable for LCIA methods (LCIA method data set). This form is also directed at LCA experts, mainly as data input for use in other LCA studies. As an electronic data set it allows other users importing the inventory and other technical details without manual transfer of values to their LCA software, i.e. limiting errors and directly using the inventory data (or impact factors) for modelling and analysing their own systems.
- a very condensed Executive Summary report of e.g. 1 to 2 pages that condenses the detailed project report to its essence in non-technical language. Note that this report is the one that should also be used in the detailed project report. If it is used as separate report for third-party information it shall contain a reference (preferably a hyperlink) where the detailed report and any related review reports can be easily accessed.

Whenever the final output type of the study is a data set or when data sets are developed and should stay available for subsequent uses, the most useful way of reporting is to combine a well documented Process data set or LCIA method data set (being a condensed version of the detailed report) and the detailed report and any review reports as electronic attachment to that data set.

Levels of reporting

Three levels of reporting should be distinguished (ILCD 2010):

- reports or data sets for internal use,
- reports or data sets for external use (i.e. to be made available to a limited, well defined list of recipients with at least one organisation that has not participated in the LCI/LCA study), and

[6] More information will be given in the final version of the guidelines in a „Reporting“ chapter (in development).

- comparative assertion reports that are foreseen to be made available to the (non-technical) public.

More details on the different levels of reporting and the specific requirements for each of them are presented in the "Reporting" Chapter (in development, see footnote 6).

Provisions 6.9: Planning reporting

I. SHALL: Identify in the scope phase (and based on the goal, scope and intended audience of the study) which form of reporting shall be used:
   a. Detailed report
   b. Data set
   c. Data set plus detailed report
   d. Non-technical executive summary

II. SHALL: Identify in the scope phase (and based on the goal, scope and intended audience of the study) which level of reporting shall be used:
   a. Internal
   b. External (but limited, well defined recipients)
   c. Third-party report, publicly accessible
   d. Report on comparisons, publicly accessible.

6.10 Scope definition example[7]

The practitioner in charge for realising the study described in the goal definition[8] must now define the scope of the study. As decided in the goal definition, the comparison between the two battery types will be made on the base of the vehicle produced by the key customer of the company (Customer X). This vehicle weights (without battery) 1200kg and is designed to have a range of 120km and a life expectancy of about 240'000km. While the life expectancy for battery type A is known to be 240'000, the one of battery type B is estimated to be around 180'000km. Further, since these systems would be used in the near future, the time scope is set between 2012-2022. Taking all these factors into account, the practitioner defines following functional unit and reference flow:
Functional unit: 240'000 km driving in compact car of 1200 kg mass without battery, fuelled with average European electricity generated between 2012 and 2022, with battery A or B and a range of 120 km per charge in real world driving.
Reference flow: Driving 1km in an electric compact car of 1200kg (without battery) and life expectancy of 240.000km in Europe between 2012 and 2020 with a Battery Type A (B) and corresponding driving range of 120km in real world driving.

[7] The numbers presented in the examples have been invented for didactical purposes.
[8] See draft chapter „Goal definition" available on the eLCAr website.

The practitioner then addresses the issues of the Life Cycle Modelling framework:
Supply chains: Having realised that the comparison falls within Situation A, the practitioner prepares for a data collection which will require to depict the existing supply chains involved in the production of the systems.
Multifunctionality: Remembering the ISO hierarchy for solving multifunctionality, the practitioner recognizes the need to also collect data regarding the treatment of co-products in multifunctional systems, in case multifunctionality could not be solved through subdivision and needed to be addressed with system expansion and substitution. In case that system expansion should also not be possible, he prepares to define an allocation strategy and collect the required data, if need be.
Scenarios: Based on his knowledge of the battery technologies under study, two key parameters are identified by the practitioner which may fluctuate in the new type of battery (B): its effective energy density and the life time. For both parameters a fluctuation of, respectively, ±15% and ±30% could be expected. The exact values will depend on the optimization of the production process. The practitioner defines the positive shifts as favourable (since, in case of the energy density, a lower amount of battery would be needed while, for the battery lifetime, a more reliable system would be produced. The practitioner therefore decides to analyse worst case scenarios with -15% energy density and -30% life expectancy and best scenarios with +15% and +30%, including all possible combinations: (-15%,
-30%); (-15%,0%); (0, -30%); (0%, 0%); (+15%,0%); (0, +30%); (+15%, +30%).

The subsequent steps concern system boundary definition, LCIA methods and representativeness:
System boundary: The practitioner opts for a full cradle-to-grave approach and initial cut-off criteria of X%.
LCIA methods: As already defined in the Goal phase, the practitioner limits the analysis to the Carbon Footprint due to the strong scoping nature of the study.
Technological, Geographical and Time-related scope and data representativeness: The study addresses current technologies of high quality (both, for the vehicle as well as the batteries) which are supposed to be suitable for the market between 2012 and 2022. The devices are produced in Europe and are thought for that market.

After having verified that all special recommendations for the comparison of systems have been respected, the practitioner finally identifies review and reporting needs:
Critical Review needs: The study is intended for a technical internal audience (the research and development unit of the company). As such, there would be no need for a critical review of the study. However, to verify the correctness of the study, the practitioner decides that he will submit the study to an independent external review.
Reporting: The form of an internal detailed report is chosen in order to give as much information as possible for the subsequent decisions of the company.