TECHNICAL DOCUMENT
TECHNICAL ASPECTS OF THE SECTOR
Publication Level 3

LIFE CYCLE ASSESSMENT APPLIED TO A VEHICLE OR A VEHICLE EQUIPMENT - METHODOLOGICAL RECOMMENDATIONS

1. INTRODUCTION AND GENERAL CONTEXT

In its Green Deal project, the EU clearly highlights the need for an environmental vision based on the complete product life cycle. Faced with climate issues, States and the European Union have defined carbon neutrality trajectories considering all the contributions of industries and products.

Although the current regulatory environment does not currently define a requirement to conduct life-cycle assessment in the automotive sector, regulatory projects have already been identified:

- Article 50 of Regulation EU 2019/631 on exhaust CO2 emissions provides the publication of a method for accounting CO2 emissions from vehicles over their entire life cycle from 2023 (link: EUR-Lex - 32019R0631 - EN - EUR-Lex (europa.eu))
- The regulatory draft repealing Directive 2006/66 on the end-of-life of batteries requires the publication of the carbon footprint of batteries from 2024. Definitions of carbon footprint thresholds will be then defined leading to the identification of different classes of batteries according to the performance of their carbon footprint.

The European Commission has been conducting research on life cycle assessment for several years. A comprehensive comparative life cycle assessment study of different vehicle technologies was conducted by RICARDO in 2020 on behalf of the Commission (link: Template for studies (europa.eu)).

Today, most of car manufacturers carry out life cycle assessments. The results feed into external communications actions and/or are used in the strategic choices of the company.

The main communications carried out today are aimed at an institutional audience in connection with the company's brand image. The LCA results are then communicated through the groups' CSR policy, in the annual report, or on the websites. These communications can also accompany technological choices or major innovations.

LCA results can also be used for business purposes through questionnaires from non-financial rating agencies for investors. B2B tenders also consider some of these results.

In the current context of stricter environmental requirements, for the automotive sector, it seemed appropriate to share within the sector the methodological hypotheses allowing to objectively measure the environmental impacts of the various automotive technologies implemented today and in the future.

This document summarizes the main methodological recommendations referring to the PFA for carrying out studies of life cycle assessment. This document can be used as a reference framework for the exchange of environmental data between players in the automotive value chain.

Examples of baseline studies dealing with Vehicle Life Cycle Analysis:

- ***Determining the environmental impacts of conventional and alternatively fueled vehicles through LCA*** – European Commission – 13/07/2020
- ***Analyse de Cycle de Vie relative à l'Hydrogène*** (***Hydrogen Life Cycle Assessment - Hydrogen Production and Light Mobility Use)*** – ADEME – September 2020 (Sphera & Gingko21)
- ***A global comparison in life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*** - ICCT Georg Bieker – July 2021

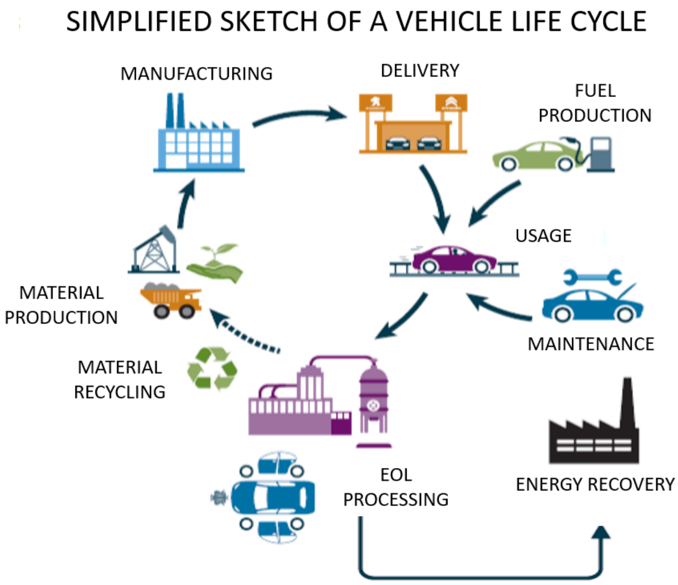
2. PRESENTATION OF LCA METHODOLOGY AND APPLICATIONS

2.1 LCA Methodology

Life Cycle Assessment (LCA) is a method for quantifying the environmental impacts of products at all stages of their life cycle, namely, the extraction of raw materials (energy and non-energy) necessary for their manufacture until their disposal at the end of life, through all the intermediate steps. The framework for these studies is defined in **the international standards ISO 14040/44**.

The approach developed in USPs is :

- **Multi-stage** since it takes into account all phases of the life cycle of a product;
- **Multicriteria**, as long as the results are represented in a way that reflects a variety of environmental issues;
- **Multi-component,** since it takes into account the product but also its packaging, the products associated with its use, etc.;
- **Functional**, as the environmental impacts are calculated in relation to the service provided by the product, represented by a functional unit.



The method is recognized and standardized by ISO 14 040 and 14 044, and distinguishes four stages, each associated with an interpretation phase making the method iterative (see Figure 1):

1. Definition of the objectives and fields of study
2. Inventory of incoming and outgoing flows
3. The assessment of impacts
4. The interpretation

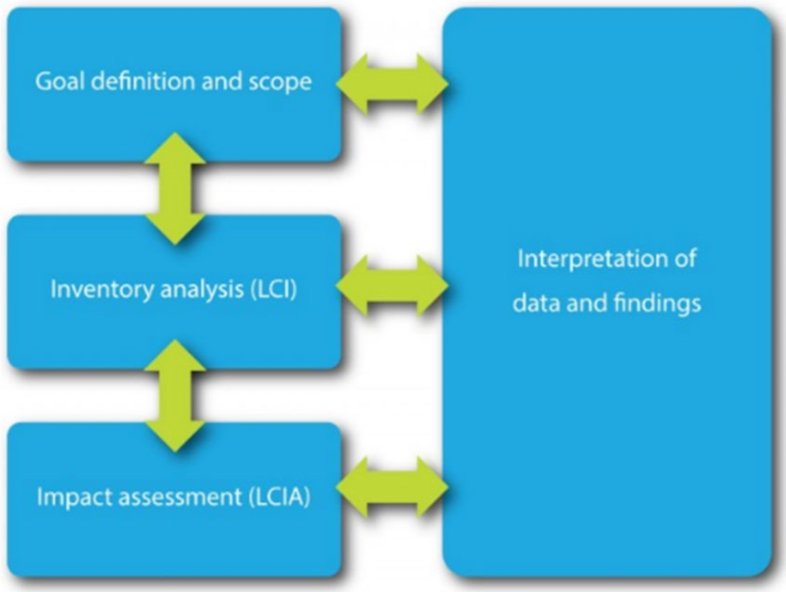


Figure 1. Steps in a life cycle analysis according to ISO 14040

The major challenge of using the LCA is to identify the main sources of environmental impacts and to avoid or, if necessary, arbitrate the transfers of these related to the various alternatives considered.

2.2 Purpose of LCA Studies

The Life Cycle Assessment studies covered by these methodological recommendations are targeted at complete vehicles or vehicle components/systems. These are mostly comparative studies such as the LCA study comparing a newly developed vehicle and the vehicle it replaces, or two vehicles with different technical equipment (engines, materials, functionalities, etc.)

The objectives associated with carrying out these studies can be distinguished on two levels:

Technical level

- Model a vehicle over its life cycle while capitalizing on the necessary data sources;
- Identify the sources or stages of the life cycle contributing to the impacts;
- Highlight the sources of transfers of environmental impacts;

Communication level

- Communicate the results of studies to justify from an environmental point of view the technical and technological choices;
- Have environmental profiles to position different types of technologies/vehicles;
- Communicate results within the automotive value chain (for example from an OEM to a supplier) based on shared methodological assumptions.
- Communicate the results to consumers to provide them with information on the environmental profiles of the proposed products.

2.3 Targeted Audience for these studies

These studies may be the subject of :

- In-house communication of the company carrying out the study;
- Communication In the context of a customer-supplier relationship;
- Communication Within the PlateForme Automobile;
- Communication With professional automotive associations (ACEA, VDA, EUCAR) or other organizations;
- Communication With public institutions;
- Communication To the general public.

In accordance with the recommendations of ISO14 040/44, any external communication of life cycle analysis results must be subject to prior critical review by external experts to the company.

2.4 Tools and Databases

To carry out these evaluations it is necessary to use dedicated tools. The tool that is most often used today in the industrial sector and especially in the automotive sector is the *GaBi ts* tool developed by the Sphera software company. It allows systemic modelling of vehicles, from a database of processes of different types (for example: manufacture of steel sheets, manufacture of gas oil or petrol, injection of plastic, production of electricity according to the mix of different countries, etc.). The software also includes different methods for calculating impacts such as CML (Centrum voor Milieukunde Leiden), ReCiPe, or some recommended by the European Commission's *International Reference Life Cycle Data System* (ILCD) manual.

Other tools such as SIMAPRO (developed by Pre Sustainability) and OPEN LCA (freeware) or other databases such as ECOINVENT can be used. The use of the GaBi repository (software and databases) is however recommended by the PFA experts, especially in the case of comparative LCAs.

In order for LCA results to be comparable, it is essential that the reference data on which they are based are homogeneous and representative. Some systems have established standards specifying the scopes and processes to which their evaluations must refer. For example, the Tire Industry Project has developed a Product Category Rules for the tire industry. This PCR proposes a list of reference components by associating them with an environmental footprint by default on several categories of impacts and identifies also the Ecoinvent processes on which the LCAs of the sector must rely.

As the automotive sector mobilizes a wide variety of technologies and production lines, the development of a dedicated framework for calculation scoping will be long and complex. However, it seems essential. This document can be considered as a first step in this direction.
It is expected that its future versions will include a list of reference impact values for usual categories of materials.

In all cases, the studies should specify the origin of the data used and verify their applicability on a case-by-case basis when they come from PCR.

3. METHODOLOGICAL RECOMMENDATIONS

The recommendations described in this chapter make it possible to conduct a Life Cycle Analysis in accordance with the recommendations of the standards 14040/44. As already stated, compliance with the standard will need to be critically reviewed before any external publication of the LCA results.

The LCA approach for vehicles or automotive equipment is the attribute approach. In addition, the results presented will not include elements relating to the avoided impacts.

In case of an estimate of avoided impacts is made in comparison with a reference scenario, this estimate will have to be the subject of a separate additional report.

3.1 Functional Unit Definition

The functional unit is the common unit used as a reference to express the environmental balance of a product. It quantifies the results of an LCA study in relation to the service provided.

For a complete vehicle, the functional unit is defined by its use over a distance and over several years. The following table defines the assumptions to be considered depending on the segment of the vehicle concerned (available for ICE and Electrified Vehicles).

It is based on the current practices of manufacturers and on the values adopted by the "Ricardo LCA 2020" Study (see reference at the end of Chapter 1).

Segment	Mileage (k km)	Lifespan
A-SEGMENT	**150**	**15 years**
B-SEGMENT		
C-SEGMENT	**225**	
D-SEGMENT		
E-SEGMENT	**270**	
F-SEGMENT		
CDV / VAN1-VAN2	**270 / 300**	

The functional unit used for the study of a part/system will be defined based on the function provided by the element taking into account the functional unit of the vehicle integrating the element.

In the case of cradle to gate part/system study, the study will be performed on the part/system. Usage and end of life will not be taken into account.

3.2 Modelling systems and life cycle stages

The vehicle study takes into account all the stages of their life cycle, from the extraction of the raw materials used in their composition, to their disposal at the end of their life.
The steps are as follows:

- Production of the materials and components of the vehicles and/or systems assessed;
- Delivery of parts, raw materials and components from suppliers to the production plant of the vehicle or system under investigation;
- The manufacture of the vehicles or systems studied in the production plant of the vehicle or system;
- If applicable, distribution of the system from the production plant of the system to the customer (who may be another supplier or manufacturer);
- The downstream delivery of the vehicle from the terminal plant to the last delivery center;
- The production of fuel or electricity;
- The use of vehicles taking into account consumption, combustion emissions and vehicle maintenance;
- End-of-life treatment of the vehicle and/or system studied in accordance with the treatment required by the End-of-Life Vehicle (ELV) Regulations (Directive 2000/53/EC (link: 2000/53/EC)

- If applicable, additional uses related for example to the second life of equipment/batteries

At each stage of the life cycle, incoming flows (energy/material consumption, etc.) and outgoing flows (releases to water/air/soil, waste generation, etc.) are considered.

3.3 System Boundaries

For each of the studies carried out, the data included and excluded from the system for the study in question must be defined.
Recommendations on the data to be considered in these LCA vehicle studies:

Table 1. Description of System Boundaries

Data	Inside boundaries	Outside boundaries	Comments
Research and development and tertiary (administration/marketing) activities		X	The infrastructure related to these activities is considered as not specific to the vehicles studied, and amortized.
Commuting and travel business for employees		X	These travels are considered not specific to the vehicles studied, and amortized.
Extraction of raw materials and shaping of components	X		These data are considered through the mass and material composition of the parts/vehicles studied.
Manufacturing of supplier infrastructure and tools	Optional	X	Depending on the purpose of the study and the innovative nature of the process studied, the environmental impacts of the manufacturing of certain infrastructures may be considered. But in the majority of cases it will be considered that the infrastructures of the suppliers and the equipment are amortized.
Upstream transport to tier 1 suppliers for the complete vehicle or upstream of the NRF of the plant of the component under investigation	X		Kilometric data and associated modes of transportation
Transport from the tier 1 supplier to the manufacturer's plant for a complete vehicle, or upstream suppliers from the plant of the component under investigation	X		Kilometric data and associated modes of transportation
Manufacture of vehicles in the terminal plant or manufacture of the component studied within the corresponding plant	X		The data considered are generally taken from the environmental reporting of the plant considered
Manufacture of packaging for the logistics of parts returning to the plant	X	X	Sustainable packaging not considered. Recommendation to take lost packaging into account.

Manufacture of auxiliary materials for manufacturing (cutting oils, gloves, etc.)	Optional	X	Often integrated into the database processes used
Treatment of manufacturing waste in terminal plant or equipment plant	X		Waste streams and associated treatment pathways
Manufacture of terminal plant infrastructure and tools or equipment manufacturing plant	X	X	The infrastructures related to the terminal plant of vehicles produced in large series are not taken into account because already depreciated from an environmental point of view in relation to the life of the equipment and the volumes produced. Case-by-case consideration of specific tools for studies targeted on parts
Transport of vehicles from terminal to delivery centers.	X		Kilometric data and associated modes of transportation
Fuel manufacturing	X		Data on the manufacture of the various fuels come from the GABI database
Emissions of pollutants in use (emissions regulated under the EURO standard)	X	Other forms of unmeasured emissions.	The issues considered as specified in the § concerned
Operation of the aftersales network and distribution of parts and accessories		X	Not considered
Manufacture of maintenance elements related to the use of vehicles	X		Data from manufacturers' recommendations (maintenance book), according to a "normal" use of vehicles. The "accident" scenario is not considered.
Particulate emissions from tire wear, brake pads	Optional	X	Not yet standardized vehicle life cycle data. To be considered depending on the purpose of the study and data availability
End-of-life treatment according to the ELV system	X		ignored: transport of the auto hulks to the crusher, disassembly operations and depollution of the ELV center integrated: transport of the vehicle to the ELV center, regulatory treatment of hazardous waste neutralization (fluids, air conditioning gases), crushing of auto-hulks, incineration and/or landfilling of waste. For materials placed at the disposal of a recycling process, the boundary stops at the disposal of a ELV center or shredder. Recycling and incineration rates can be derived from theoretical calculations (recyclability approval) or from reporting data (Ex: rates derived from the latest report of the ELV observatory published by Ademe).

3.4 Cut-off criteria

In accordance with the recommendations of ISO 14040 and 14044, a cut-off criterion is set for each study. This cut-off takes into account the environmental impacts of the elements which compose it to avoid an omission that is too important in terms of flow. It is 99% by mass, that is, the total of the omitted flows must not exceed 1% by mass. For example, materials known to have high impact potential are excluded from this cut-off (for example, precious materials or electronics). As stated in the previous § a number of elements are not taken into account in the study.

3.5 Environmental impact indicators

The recommended environmental impact indicators are specified below. It is recommended to use these indicators as a minimum in a full LCA study. These indicators are calculated according to the latest versions of the CML and ReCiPe methods.

- Indicators calculated using CML 2001 – Jan 2016:
  - Acidification Potential (AP): This indicator characterizes the increase in acidifying substances in the lower atmosphere that cause acid rain and the decline of some forests. This indicator is expressed as the quantity of sulphur dioxide equivalent (kg SO_2-Eq.);
  - Eutrophication Potential (EP): The introduction of nutrients in the form of nitrogenous or phosphatic compounds disturbs ecosystems by promoting the proliferation of certain species (algae). The direct consequence is a decrease in the oxygen content of the aquatic environment, which has an impact on flora and fauna. It is measured in the equivalent amount of phosphate (kg PO_4^{3-}-Eq.);
  - Global Warming Potential (GWP) 100 years: This indicator characterizes the average atmospheric increase in anthropogenic substances such as carbon dioxide (CO2), methane (CH_4), nitrous oxide (N2O), etc. These emissions disrupt the atmospheric balance and contribute to global warming. This indicator is expressed as carbon dioxide equivalent (kg CO2-Eq.). Biogenic carbon is taken into account and subtracted from the total CO2-Eq emission value.
  - Photochemical Ozone Creation Potential: It characterizes the phenomena leading to the formation of ozone and other precursor oxidizing compounds in the lower atmospheric layer, ozone formed at this level has adverse effects on human health and plants. It is expressed in the amount of ethene equivalent (kg C_2H_4-Eq.);

Impact indicators related to the use of resources can be used. Recommended indicators are:

  - Abiotic Depletion Potential (elements) This indicator is intended to measure the extraction of natural mineral resources considered as non-renewable, which are consumed at a rate higher than the time required for their natural production. It is measured in the amount of antimony equivalent (kg Sb-Eq.);

- Indicators calculated with the 2016 ReCiPe method:
  - Metal depletion potential (MD): Like the ADPe indicator, this indicator aims to measure the impact of depletion of mineral natural resources. However, the ReCiPe approach complements that of CML, which is essentially physical, with an economic approach. It is measured in quantity of iron equivalent (kg Fe-Eq.);

- Flow indicator:
    - Primary Energy Demand (PED): This flow characterizes the total amount of energy, renewable or non-renewable.

The "Ozone Depletion Potential" indicator is not chosen because the associated impacts are very low and do not represent an issue for the automotive industry.

Contrary to the *International Life Cycle Data* (ILCD) recommendation to consider the indicator “Particulate matter / Respiratory inorganic products” or “Particulate matter / respiratory inorganics” for automotive products, it is proposed not to consider it because, on the one hand, it is very low during the use phase, and on the other hand, the particulate emissions from tires or brake pads are not yet the subject of standardized measures. This indicator should be added when the emission measures are reliable and standardized.

As the methods of impact calculations evolve regularly, the recommended indicators will have to evolve. In this context, PFA members planned to examine EF 3.0 to see to what extent it could replace some or all of the methods currently advocated.

3.6 Data Quality Requirements

According to the [1]*International Reference Life Cycle Data System* (ILCD) manual, the indicators of the quality of the inventory data used must be evaluated according to:

- Their technological, geographical and temporal representativeness;
- Their faithfulness and accuracy;
- Their completeness;
- Their coherence and methodological relevance.

3.7 Methodological recommendations for the Life Cycle Inventory

The life cycle inventory data collection phase consists in gathering information on all the components considered in the study, the manufacturing processes considered, the mileage travelled for logistics, the consumption and emissions related to the use of cars, the maintenance of the vehicle during its lifetime, and the end-of-life disposal processes by the recycling systems concerned. The recommendations for the data collection methodology and inventory are described for each stage of the life cycle in the following paragraphs.

VEHICLE/COMPONENT MANUFACTURING DATA

The manufacturing phase consists of the following steps:

[1] Publications Office of the European Union. International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment: Detailed Guidance. Website, 26 April 2011. https://publications.europa.eu/en/publication-detail/-/publication/325e9630-8447-4b96-b668-5291d913898e/language-en

- Manufacture of all components of the complete vehicle or system under investigation,
- Assembly of the vehicle within the terminal plant or manufacture of the component concerned by the study

Manufacturing data on the components of the vehicle or system under investigation

The mass and material data of parts and components are partly derived from data collected via IMDS. The granulometry (and therefore the number of materials considered to describe a vehicle or a subset) must be sufficiently detailed to separate the materials that have significantly different production or implementation impacts.

- For example, flat steel is systematically distinguished from long steel or cast iron. However, depending on the study, it may or may not be possible to distinguish between the different categories of flat steel.
- A minimum distinction should be made between the different families of polymers (PA, POM, PE, PP, ABS, PVC, etc.) and the types and quantities of filler added to them.
- We will also distinguish the main metals: copper, flat aluminum, cast aluminum, flat steel, long steel, lead, chromium, magnesium, cobalt, nickel, PGM, etc.
- Some compounds such as electronics or active ingredients in traction batteries will not be "exploded" at each of the components to keep track of the highly emitting production process.

Emissions from all the shaping and assembly stages of the different materials will need to be modelled and integrated. When it is not possible to obtain the actual data for these steps, generic and representative modelling of their implementation will be applied to each material (plastic injection, metal cutting, melting of the irons, etc.). It will include energy consumption and related products, yield losses, treatment of production scraps, pollutant emissions, etc.

If the location is unknown, the average energy mix of the economic zone where the vehicle is produced will be considered (Europe, China, Latin America, etc.).

The "cradle to gate" models of the materials and associated processes can be derived from the *GaBi ts* database or from any other LCA database (Ecoinvent, etc.) to be specified. The precise data recommended by the PFA will be updated later.

Data relating to the manufacturing plant of the vehicle or system under investigation

The environmental impacts associated with the vehicle or system assembly site will be taken into account. Most of industrial sites are subject to detailed environmental reporting to meet regulatory or normative constraints (ISO9001, ISO 14 001). These reports should inform on energy consumption, emissions in the air, in water and on the quantities of waste generated.

These emissions shall be reported to the system/vehicle under investigation. Thus, if different systems/vehicles are produced in the plant, an allocation rule will have to be defined depending for example on the volumes of vehicles studied produced (body-assembly plant).

Data related to logistics

Upstream logistics concerns:

- For a complete vehicle: transport from the tier 1 supplier to the terminal plant.
- For a system/equipment: transport from the supplier of rank N+1 to the assembly plant N of the assessed system.

The downstream logistics corresponds to:

- For complete vehicles for transport from the terminal plant to the delivery centers. An average additional value of transportation to the point of sale will be considered.
- For a system/ equipment: transport from the factory to its direct customer.

The distance travelled and the mode or modes used must be taken into account.

For example, the following data from the GABI ts database may be taken into account for the life cycle inventory:

- ➔ Upstream:
  - Road transport: GLO Truck, Euro 0 - 6 mix, 20 - 26t gross weight / 17.3t payload capacity u-so {30eef797-312a-447a-9272-4d271ac60289}
  - Shipping: EU-28 Container ship ocean incl. fuel, 27,500 dwt payload capacity, ocean going agg Sphera {7d4c6dee-3d6b-4fbf-a496-2354450a1a14}
  - Rail transport: GLO Rail transport cargo - average, light train, gross tonne weight 500t/ 363t payload capacity u-so Sphera 0e18387f-9a65-4a6c-87d6-89404f330a10}
  - Air Transport: EU-28 Plane (cargo) incl. fuel, 65 t payload agg Sphera {28b6ad2c-e13e-4322-a443-771a7e7d16a2}
- ➔ Downstream:
  - Road transport: GLO Truck-trailer, Euro 0 - 6 mix, up to 28t gross weight / 12.4t payload capacity u-so Sphera {068528f0-f90c-48d1-bcd2-9fb42313d124}
  - Shipping: GLO Ro-ro-ship, 1,200 to 10,000 dwt payload capacity u-so Sphera {ab57e962-8f35-461b-9d25-5bbc3ed9c07c}
  - Rail transport: GLO Rail transport cargo - average, average train, gross tonne weight 1,000t / 726t payload capacity u-so Sphera {0b5bac50-540d-421c-a175-84ae4c06c7b0}

Data related to usage: Driving Stage

The Driving stage takes into account the fuel consumption and exhaust emissions of the vehicle throughout its lifetime, in line with the definition of the functional unit.

The consumption and emission data are taken from the certified data on the certification cycle of the sales area: for Europe the WLTC cycle (Worldwide harmonized Light vehicles Test Cycles).

Regarding both electricity and fuel consumption, the combined consumption (low, medium, high, and extra-high phases) is used and averaged between High and Low values of the interpolation family studied.

Regarding plug-in or extended range hybrid vehicles, the value used is the combined consumption (4 phases) and weighted consumption (2 modes of maintaining or exhaustion of load) according to the rules validated by WLTP (Worldwide Harmonized Light Vehicles Test Procedure) and applying the

Utility Factor of the geographical area in question. A sensitivity without battery recharge will be systematically presented.

For electric vehicles, this is "plug-in" consumption and not just engine consumption. It incorporates losses related to the charge and discharge of the battery.

Tank to Wheel data: tank to wheel
The emissions data are derived from the certified European Certification Cycle (WLTC) data. Based on this cycle, fuel consumption and pollutant emissions are monitored, in particular within the framework of EURO and CO[2]$_2$[3] regulations.

- Exhaust emissions:
    - Emissions of CO_2,
    - Emissions of CO,
    - NO_x emissions,
    - HC Emissions,
    - HC+NO_x emissions,
    - Particulate Matter Emissions (PM 10).
- SO2 emission:
    - It will be estimated from the consumption of the vehicle and the maximum allowable Sulphur threshold in the fuel in the usage area.

Well to tank data: from well to tank

The production of fuel, or electricity, must be taken into account. The recommended reference data are based on the work of the JEC and on data from the GABI ts tool.

- Production data for gasoline and diesel (E10, B7)
  Two assessment methods can be used to measure the environmental impact of these fuels:
  - "Marginal" method: used mostly by fuel producers. The purpose of this method is to assess the impact of additional fuel production.
  - "Attributional" method: it considers the average impact of the production of a given quantity of fuel. This is the recommended method for conducting vehicle life cycle analysis.

  WtW V5 JEC Report:

[2] The standards define a maximum emission threshold for each pollutant. This threshold depends on the fuel (gasoline or diesel), the date of placing on the market and the category of the vehicle.
[3] The European Union has set CO2 emission thresholds for passenger vehicles of 130 g/km in 2015 and 95 g/km in 2020.

Table 1. Summary. Refinery allocation results based on extended literature review[4]

	Consequential "Marginal" (gCO_{2eq}/MJ)			Attributional "Average" ($g\ CO_{2eq}/MJ$)			
	JEC (1) (Concawe)		JRC paper (2017)	Aramco paper (4)		JRC paper(2)	Sphera (2020)
	JEC v4 (1)	**JEC v5 (3)**	JRC (2)	Standard mass allocation	Customized allocation (4)*	EN (2)	Mass & Energy
Gasoline	7	**5.5**	5.8	10.2	7.6	5.7 - 5.8	9.6
Diesel	8.6	**7.2**	7.2	5.4	6.8	5.8 -	3.4

As indicated and consistent with the findings of the work conducted by the JEC with the participation of EUCAR, the "attributional" method will be used for the assessment of environmental impacts related to the production of gasoline and diesel fuels. The data available in the GABIts database agree with this method.

- Electricity Generation Data:

The impacts to take into account should include the construction, maintenance and dismantling of electricity generation and distribution facilities. They will also include distribution losses. The databases present in the LCA implementation tools, in particular GaBi ts offer inventory values for the electricity mix by country or region and take into account all the impacts related to infrastructure, distribution losses, etc.[4]

The electric mix to take into account by default is that of the economic sales zone of the vehicle (Europe, China, South America, Japan, etc.). Sensitivities may be presented on mixes from certain countries or production sectors (renewable mixes for example). The geographical area should always be specified.

Two scenarios can be used to assess electricity generation impacts:

1) The electricity produced in the launching/selling year of the vehicle. When the assessment of impacts of this precise year is absent from the databases, it can be approximated by a weighted average between the last real value made available and the first value projected in a conservative (not very evolutive) scenario.

2) Electricity generated throughout the life of the vehicle, for example by using detailed electric impact projections year by year or by taking a projected value at half the life of the vehicle. The projections used must be conservative (ie: the GaBi 'little improvement' scenario type).

[4] For information, the emission values presented by the IEA (International Energy Agency) generally do not include the construction and maintenance phases of the means of production or the losses related to distribution.

- Assessment of the use phase to a subsystem:

When studying a subsystem or a vehicle equipment, it is sometimes necessary to assess the impacts of the use phase related to that subsystem alone.

  - Difference between two systems:

It is often a question of assessing the impacts of an alternative system in relation to those of the reference system (mounted on a vehicle with defined characteristics).

To do so, priority will be given to obtaining information from the manufacturer regarding the difference in consumption between the vehicle equipped with the alternative system and the reference vehicle.

In the absence of data specific to the vehicle studied, we can refer to the table below:

WLTC consumption	Petrol Internal Combustion Engine	Electric vehicle
	Deviation in l/100 km	*Deviation in kWh/100 km*
Mass: +10 kg without GMP adaptation	+ 0.016	+ 0.028
SCx: + 10/1000 m2	+ 0.024	+ 0.10
Tires: +1 kg / t veh [5]	+ 0.099	+ 0.45
Conso Elec 12v: +100 w	+ 0.066	+ 0.26

  - Assessment of the use phase of a system (equipment) in absolute terms:

The rule presented above will be used, based on a reference without any system. For example, the impact of using equipment weighing 5 kg on a segment C thermal vehicle will be assessed as follows: 0.016 (l/100km) x 5 (kg) / 10 (kg) x 225 000 (km) / 100 (km) x 2.916 (kg CO_2/l fuel)[6] = 52.5 kg CO_2eq

The aerodynamic consumption component will not be included in the assessment of the equipment use phase. Indeed, it is impossible to estimate the SCx of the vehicle where a piece of skin would be missing, and the internal parts have no effect on this value. The effects of aerodynamic consumption will only be attributed to the manufacturer, who is solely responsible for the choice of design.

  - Exhaust Pollutants:

The emissions of CO_2 and SO_2 will be considered as proportional to the fuel consumption because related to its characteristics.

For other pollutants, there is no evidence that their emissions are proportional to consumption. Consequently, the assessment of impacts related to differences in system definition (mass variation,

[5] The rolling resistance coefficient (CRR) characterizes the hysteretic losses of the tire, which represent one of the main contributions to the energy efficiency of the tire. It corresponds to the rolling resistance force (FRR) in relation to the load carried by the tire, and is expressed in kg/t. The difference in consumption is related to an average vehicle: the value must not be multiplied by the assumed mass of the vehicle.
[6] JEC Data V5

power consumption, etc.) will not include variations in emissions of these pollutants. Similarly, the evaluation of the use phase of the parts will not include these emissions.

Data related to usage: Service Step

The production and processing of products necessary for the maintenance of the vehicle during its lifetime are included in the scope. The necessary information comes from the recommendations of manufacturers and OEMs. They are partly specified in the vehicle maintenance books.

Maintenance can meet two different needs:

- Maintenance (such as draining): regular maintenance of the vehicle and consumable. The minimum items to consider are : engine oil, oil filters, 12V battery, engine coolant and traction battery, air conditioning gas (*)
- Replacement of wear parts (such as tires or brake linings), whose renewal depends heavily on the driver's driving mode. Reference should be made to the theoretical change frequencies specified in the maintenance book where they exist. The minimum elements to take into account are : tires, brake linings and windscreen wipers.

The number of renewals considered for each item will be specified.

Vehicle end-of-life data

Reminder: Directive 2000/53/EC of 18 September 2000 on End-of-Life Vehicles (ELV) sets the recycling and recovery rates for UFVs, with the following rates since 2015:

- 95% reuse and mass valorization of ELV.
- Including a minimum of 85% reuse and mass recycling of ELV.

1- Choice of method:

Several methods can be used to model the end-of-life and recycling of vehicles.

a. The "Cutt-off method":

A stock of recovered materials from end-of-life materials is made available to the Technosphere for the manufacture of recycled products. No impact (neither positive or negative) is taken into account when recovered material is sent to the stock or when recovered material is taken from the stock. This means that:

- The impacts related to the production of virgin material are attributed to the product that uses this virgin material,
- The impacts related to the collection and recycling process (transformation of the recovered material into usable secondary raw material) are attributed to the product using the recycled material,
- No impact is attributed to the recovered material from the stock and used to produce the recycled material *through* the recycling process,
- No credit is given to the material sent to the stock.

b. <u>The "Avoided Impact Method":</u>

The impacts avoided through the provision of materials that will be recovered and recycled at the end of the initial use of the vehicle are evaluated in comparison with the impacts of virgin material production. To avoid double counting of this "credit", the rules of its allocation between the company who makes the recyclable materials available and the company who uses the recycled materials are established.

The European Commission proposes a methodological framework to be applied in this case: the Circular Footprint Formula (CFF) which also integrates the recovery of credits due to energy production related to waste incineration (see **Product Environmental Footprint Category Rules Guidance** Version 6.3 May 2018 available on the European Commission website).

c. <u>Recommendation:</u>

The method recommended in the vehicle LCA study is the cut-off method.

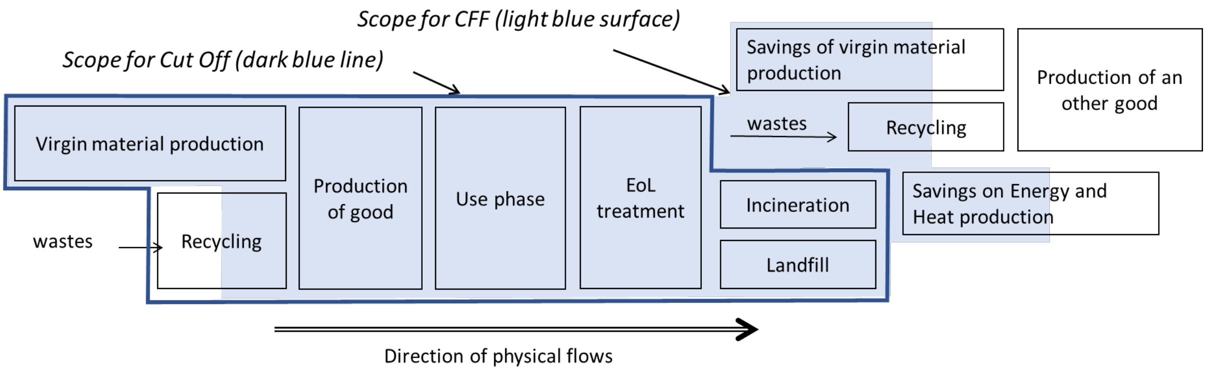
Indeed, the implementation of the CFF requires collecting a large amount of data and setting many parameters that have not yet been discussed or agreed upon within the automotive industry. However, their values have a major influence on the results and the default values proposed by the JRC (see the **CFF_Default_Parameters_March2018** document available on the European Commission website) are not adapted to the automotive sector, which is very specific (product life span, specific end-of-life processing sector, recycling obligations specified in a dedicated directive, etc.).

In the current state and in the absence of a suitable PEFCR for the automotive sector, the inventory method will be the reference method used for calculating impacts, particularly for comparative studies. No "credit" related to recycling or energy generation through incineration will be considered.

It will be possible to present the results of the CFF application in sensitivity. In this case, the potential impact avoided will not be subtracted from the initial impacts but presented next to it. Details of the parameters implemented should be specified. Their determination may be based on the parameters A and B proposed by default in the annexes of the PEFCR Guidance and on the recovery or recycling rates disseminated by the ELV observatory of the ADEME.

It should be noted that not considering credits related to recycling at the end of the life of the vehicle allows to fully benefit from the least impact of the recycled materials implemented in the system/ vehicle studied.

d. <u>The scope chosen:</u>



In the diagram above, the perimeter chosen, "cut off", is materialized by the dark blue line.

Upstream, it integrates the production of virgin materials from the mine and that of recycled materials since the provision of waste to recyclers.

Downstream, it includes regulatory end-of-life treatments for vehicles (depollution, crushing). For the waste that will be recycled, the scope stops at the disposal of the recyclers. For waste that will be incinerated or landfilled, these last two phases are included in the perimeter. Potential avoided emissions from incineration are not accounted for within the scope.

e. <u>End-of-life processing stream rates:</u>

The integration of end-of-life processing of materials, primarily incineration, has a major influence on the LCA outcome. For vehicle comparison calculations, the end-of-life pathways to be taken into account are specified in the following table (based on the ELV material decomposition proposed in ISO 22628):

7 materials	Components	Standard 22628	End-of-life stream to be considered by default
Components and fluids	Fluids	Reusable or recyclable	Recycled
	12V Battery	Reusable or recyclable	Recycled
	Oil filters	Reusable or recyclable	Recycled
	LPG Tank	Reusable or recyclable	Recycled
	CNG Tank	Reusable or recyclable	Recycled
	Tires	Reusable or recyclable	Recycled
	Catalysts	Reusable or recyclable	Recycled
Ferrous and non-ferrous metals		Recyclable	Recycled
Polymers		Recyclable or recoverable	Polyolefins: Recycled Other: Incinerated
Elastomers		Recyclable or recoverable	Incinerated
Glass		Recyclable	Recycled
MONM (Modified Natural Organic)		Recyclable or recoverable	Recycled
Other		Recyclable, recoverable or undefined	Landfill

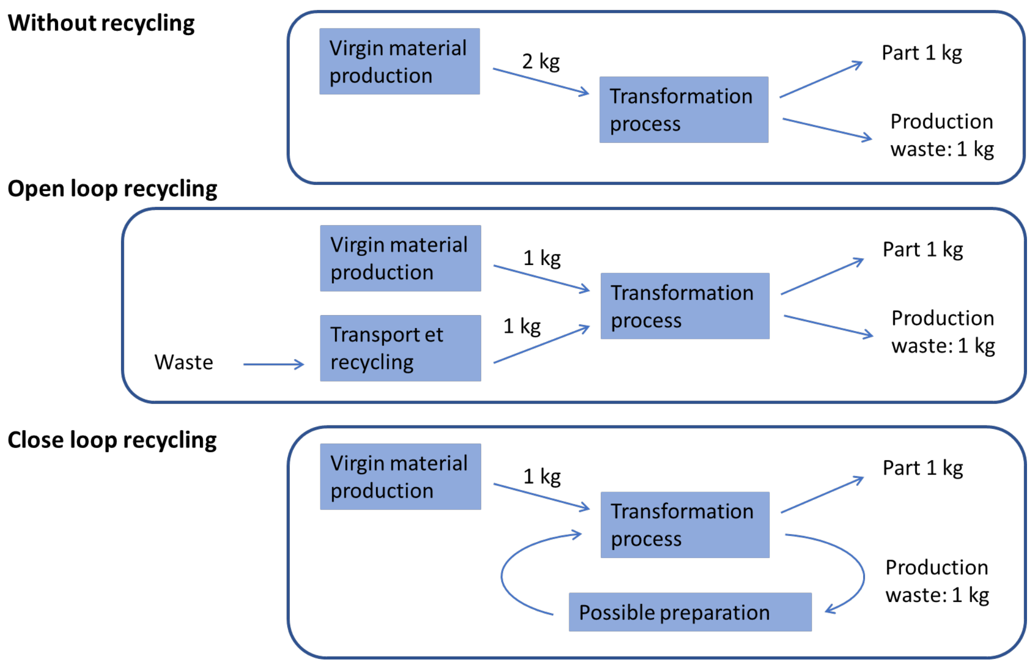
In the case of more targeted studies (subset, innovation, specific assemblies to improve recyclability, etc.), more detailed and representative projections of the treatments planned for the end-of-life horizon of the vehicles studied may be used.

Modelling production waste

All the materials supplied are included in the calculation of impacts, even the part that ends in production waste. Recycling these wastes to other stakeholders does not result in a reduction in production emissions.

On the other hand, any use of recycled material made from both production and post-consumer waste brings the full benefit of the least impact of their development.

Closed recycling loops: they are modelled, whether they are internal to the production site or they integrate external recyclers. They generally increase the efficiency of recycling processes.



Data on second life and other uses of traction batteries

In the case where the design of the traction battery makes it possible to use other than the vehicle for the number of kilometers associated with the segment (see chapter 3.1.2), the total impacts from the manufacture and end-of-life of the battery can be distributed and allocated to these different uses.

The allocation rule should be based primarily on physical quantities (such as returned MWh or deterioration of battery capacity) or on economic quantities (resale value).

4. INTERPRETATION AND FORMALISATION OF LCA RESULTS

The formalization of the results should allow the identification of the impacts of each phase of the life cycle:

- Manufacturing phase of parts and materials, with distinction of the traction battery if applicable,
- Logistics phase (parts transport and vehicle distribution),
- Production phase in the vehicle or system assembly plant
- Phase of use:
  - Well to tank phase: including impacts from fuel or electricity production
  - Tank to wheel phase: including vehicle exhaust impacts
  - Vehicle maintenance phase
- End of life phase of the vehicle

Each phase can be analyzed by identifying the predominant impact indicators, transfers of environmental impacts, etc.

Examples of graphs illustrating LCA results:

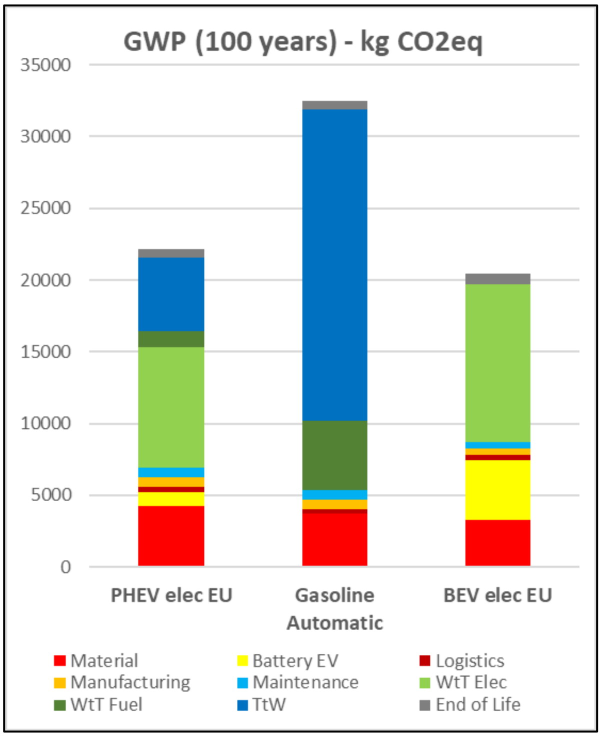


Figure 1: Impact Global warming of 3 vehicles segment B expressed in kg CO2 eq over the entire life cycle.

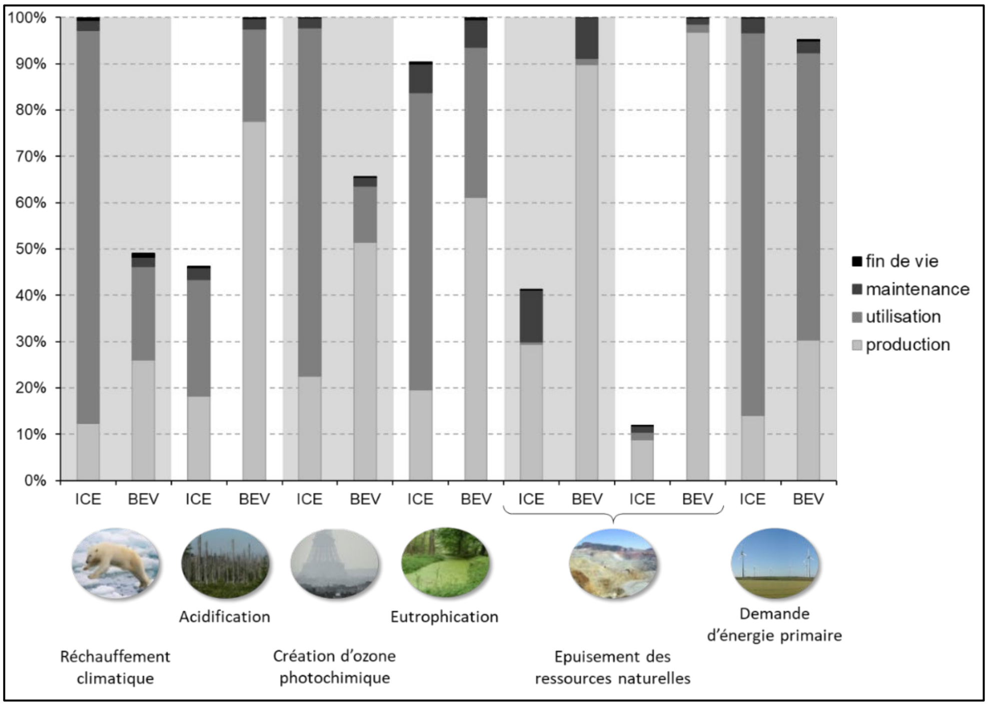


Figure 2: Distribution of different impacts according to the production, use, maintenance and end-of-life phases for two ICE or electric vehicles of the same segment.

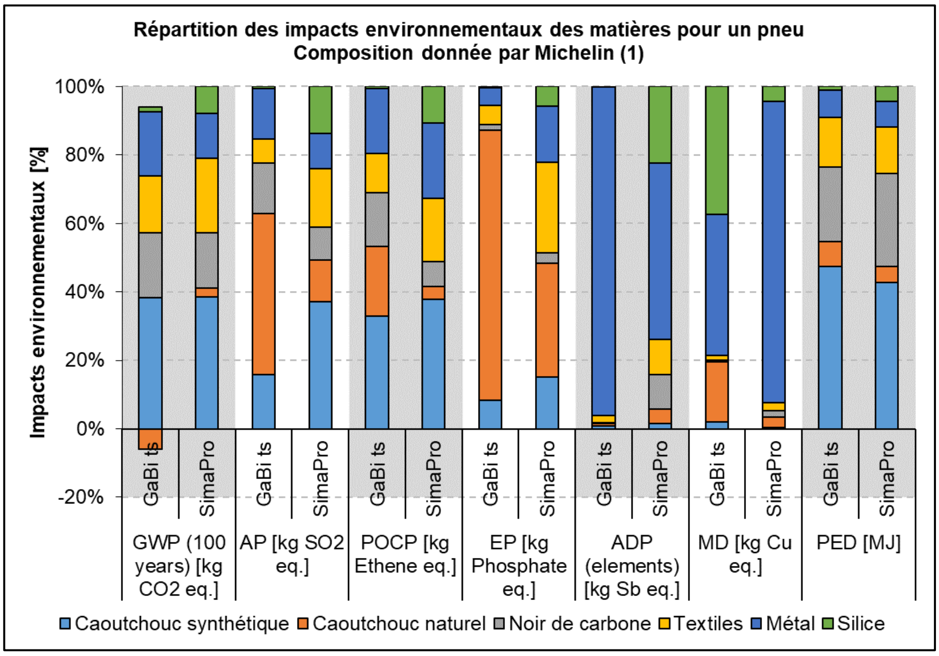
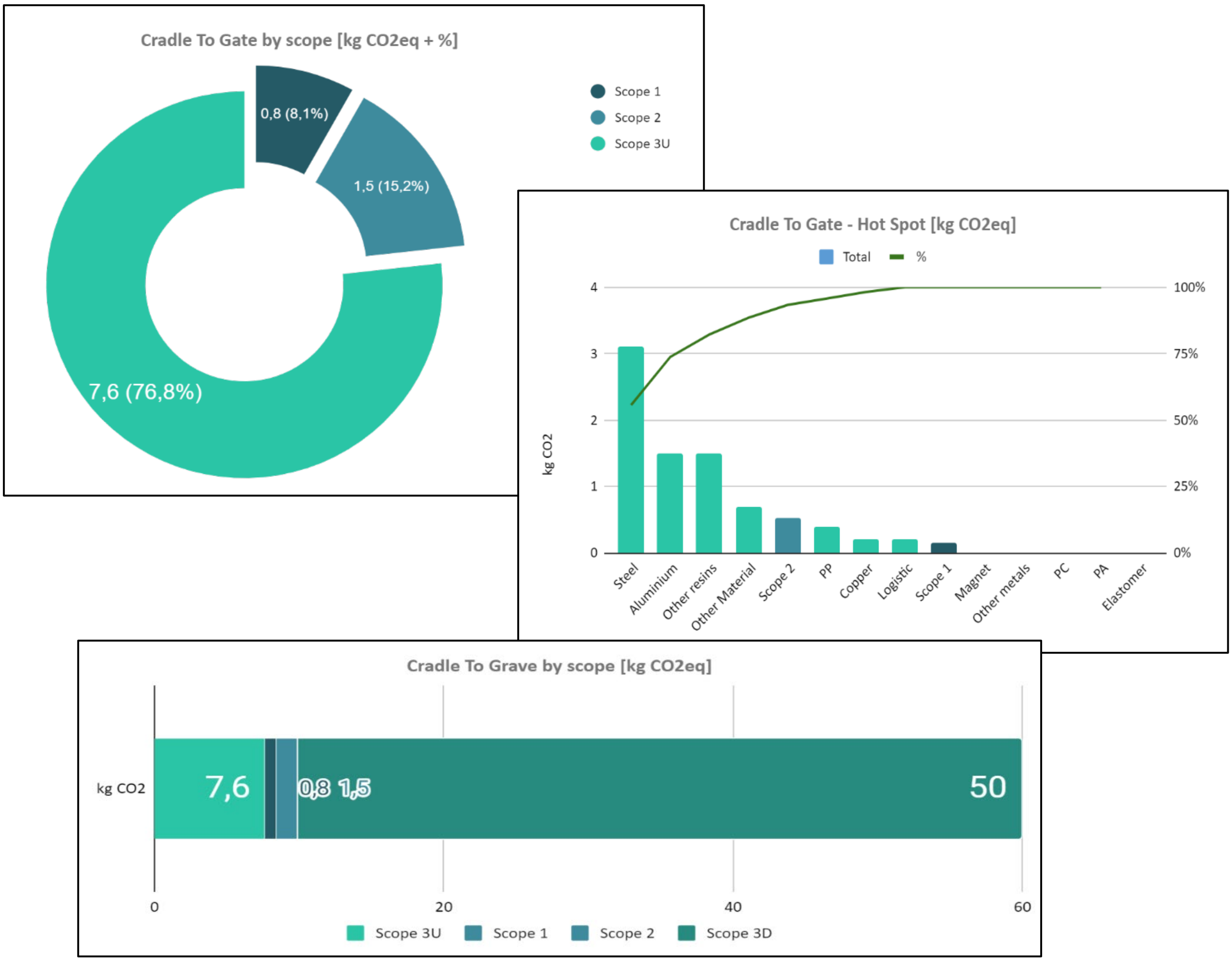


Figure 3: Comparison of impacts due to the production of the main materials used in the manufacture of a tyre, according to different databases.



Figures 4, 5, 6: global warming potential of production alone (cradle to gate) or of production and use (cradle to grave) of automotive equipment (damper).

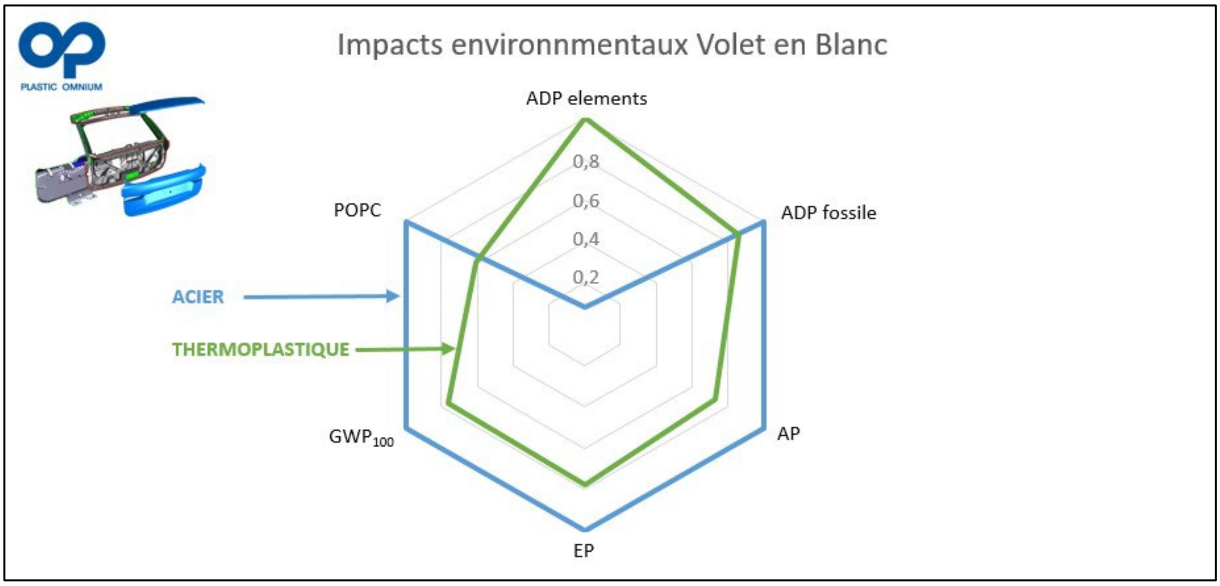


Figure 7: Comparative analysis of 2 technologies (steel vs reinforced polypropylene) for a rear flap fitted to an ICE SUV covering 150,000 km.

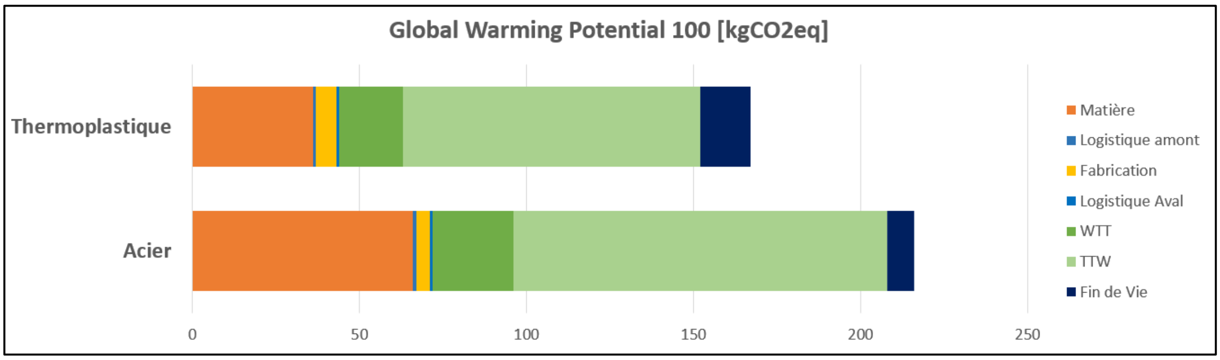


Figure 8: The GWP100 indicator is broken down by phase of the rear flap life cycle in white.

5. ACV CONSULTING COMPANIES

The list below offers the names of several entities *(Companies, Technical Research Centres, Associations, Organizations)* with significant LCA experience in the automotive field and performing certifications, studies, critical reviews and trainings. It is intended as a guide and is not exhaustive.

- Carbone 4: An independent consultancy specializing in low-carbon strategy and adaptation to climate change. https://www.carbone4.com/

- EVEA: S.A.S cooperative product life cycle specialist. https://evea-conseil.com/en

- QUANTIS: Independent consultancy specializing in supporting companies on environmental solutions. https://quantis-intl.com.

- SPHERA: Company providing a database for LCA implementation, ESG performance tools and service activities. https://sphera.com/

- BUREAU VERITAS: Consultancy, providing software for making environmental footprints (LCA) of your products and services in accordance with the requirements of ISO 14 040/44 and your communication media. https://www.bureauveritas.en/

- SOLINNEN: Company offering expertise and environmental support services, more specifically on life cycle analysis and eco-design. https://solinnen.com/

- GINKO21: Eco-design and eco-innovation consulting and training firm. https://www.gingko21.com/

- CETIM: Centre Technique des Industries Mécaniques. https://www.cetim.fr/

- LIST: The Luxembourg Institute of Science and Technology (LIST) is a Research and Technology Organisation (RTO) whose mission is to develop prototypes of competitive and market-oriented products/services for public and private actors. https://www.list.lu/

- IFPEN: IFP Energies Nouvelles (IFPEN) is a player in research and training in the fields of energy, transport and the environment. https://www.ifpenergiesnouvelles.fr/

- SCORELCA: An association based on collaboration between industrial, institutional and scientific actors in order to promote positive, shared and recognized development of global environmental quantification methods; In particular, life cycle analysis and their application. https://www.scorelca.org/

- ECOSD: Association whose main aim is to promote exchanges in order to create and disseminate knowledge in the field of Eco-design of Systems for Sustainable Development (EcoSD). https://www.ecosd.en/en/

- TUV: Reliable conformity assessment organization. https://www.tuv.com/

- AFNOR: First Certification organization. https://certification.afnor.org/

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