Università degli Studi di Padova

Dipartamento di ingegneria meccanica

TESI DI LAUREA

Life Cycle Assessment

of the Car of the Race Up Team

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Abstract

In light of the on going climate change discussion, sustainability considerations are currently taking more prominent role in material selection decisions for automotive applications.

This paper deals with the Life Cycle Assessment of a product. The product chosen is a racing car, designed and built by students of the Università degli Studi di Padova.

The first part of this thesis shows all the Life Cycle Assessment theory and concepts necessary for understanding the later analysis and results interpretation.

The second part deals about the Life Cycle Assessment of the car and showing the all calculations and procedures necessary for achieving some results.

The main goal of this research is analysing the environmental impact of the materials and processes needed for the production of this car. This study is going to include an exhaustive analysis of the impact of each subsystem that is composed in the car in order to be able to analyse each part of it although the importance of knowing the environmental impact of the global car.

Summary

Summary of figures

Summary of tables

1. Foreword

1.1. Motivation

In the context of finishing my master in industrial engineering with the specialisation in mechanics, I have chosen the Life Cycle Assessment of a product (LCA) because environmental impacts on design, extraction of raw materials and the production are under valuated. Nowadays the idea of environmental impact is about the use of the product and not so much about the actual creation.

The chance that was given by doing my research on a race car, developed by a team of students, increased my motivation.

This team, The Race Up Team which is existing of around 40 students of University of Padova, is competing in a specific competition. In order to compeet in this competion, the team has to construct a single seated car with uncovered wheels, and follow a specific set of rules.

The finality of the results is to find out which of the parts and construction processes of the car have the highest impact on the environment. So next year's Race Up Team can try, in the construction of the new car, to avoid the use of the most polluting products or processes. If the results of this thesis are used, this research can have a direct impact in decreasing the ecological footprint of the new car. This can be counted as an extra motivation for my research.

As a mechanic engineer, my knowledge about environmental issues and LCA was not self-complacent and that's why I was strongly motivated on study deeply this field in my thesis.

1.2. Prerequisites

In order to develop this LCA research some requisites are needed.

Access and availability of the information of the production processes and the materials used are needed. First of all, it’s the Race Up Team that provides all specific information about the materials used and production methods they apply in the constructing of the car. Secondly, databases are providing all information and characteristics of the materials and processes used.

Thirdly, software is needed that calculates the environmental impact of the different materials and production used.

At last, personal skill and knowledge is needed. The one who is doing the Life Cycle Assessment needs to have a background in industrial engineering. Knowledge about materials, fabrication, processes and data analysis are strongly recommended qualities.

2. Introduction

2.1. Goal of the thesis

The main goal of this thesis is to apply the Life Cycle Assessment methodology, following the ISO normative, in a single-seated race car built by a team of engineering students.

The principal goal is to study the impact of each system the car is composed of. Certainly it would be interesting to explore the global impact of the car but due to the lack of records about LCA applied in other cars of the same category as the car of the study, it is impossible to compare.

Subsequently the aim of the study is not about understanding the global impact of the car. It would be useful in the case of having precedents of Life Cycle Assessments aplicated in other cars of this type to compare them, but since the idea of applying a LCA in a car of the Race Up Team is completely new there is no common basis for comparing cars. This means that impact comparations are going to be between parts of the same car, not between two different cars.

This Life Cycle Assessment is a document addressed to the team of Race Up with the aim of knowing which components have more environmental impact. In this way, the next generation of cars developed by Race Up Team, can incorporate improvements by using other materials for those parts with more impact.

2.2. Scope of the thesis

The scope of this thesis is an LCA study of the Race Up Team's race car. Therefore it will have to become clear in the conclusions which parts of the car have a bigger impact on the environment, and which parts of the environment (very generically system) will be most affected by the product. The scope of the thesis does not include a long list of products and processes that would have a less impact on the environment in order to reduce the ecological footprint of the car. After the LCA study, some suggestions and advises can be made about the materials, but this is not the main aim of this study. The thesis will just point out which parts and processes have which impact. It’s the task of next year’s Race Up Team to do something with my results.

It is important to clarify that not all processes are included in this LCA study. It will include the data that was available and given by the Race Up Team. This means I include the processes they used in there construction. On the other hand, the components that were bought by the team will only accounted as the weight of the material and not the process of creating the component. Including this processes that where used the create this components would make the thesis too extensively. For example for a bolt, the weight of the steel will be taken in to account but the energy used in the milling processes will not be used.

3. Life Cycle Assessment

3.1. Introduction at LCA

Life cycle assessment (LCA) is a technique to measure environmental impacts associated with all stages of a product's life, from-cradle-to-grave. This methodology is well defined in ISO 14040 and 14044. LCA considers the entire life cycle of a product, from the start as a raw material extracted over the acquisition and transportation, through the energy that is put in the production and manufacturing, to the use and the final processing for disposal at the end of its life.

Thanks to such a systematic overview and perspective, the potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.

LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, obviously, beyond the scope of the LCA. Other tools can be combined with an LCA for more or other kind of research.

LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit. [1]

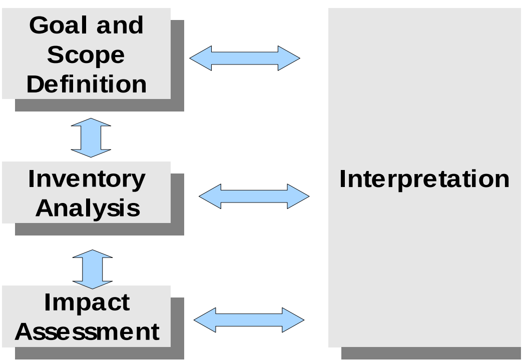


Image 1: The four phases of the LCA

3.2. Phase 1: The goal and scope definition

Like all models of reality, it’s important to understand that a model is a simplification of reality, and along with all its simplifications, this means that the reality will be distorted in some way. The challenge for a LCA researcher is therefore to develop models in such a way that the simplifications don’t influence reality too much so the distortions have to be kept as small as possible. The best way to deal with this problem is to carefully define the goal and scope of the LCA study before starting the project. The goal and scope can’t be seen as static, adjustments can be made during the LCA if it seems that the initial choices are not optimal or practical.

According to the ISO14044 guidelines, in the phase of the scope definition of the LCA a functional unit has to be considered. This unit shall be consistent with the goal and scope of the study. One of the primary purposes of this functional unit is to provide a reference to which the input and output data are normalized. Therefore the functional unit has to be clearly defined and measurable. When the functional unit has been chosen, the reference flow shall be defined. Comparisons between systems can be made on the basis of the same functions, quantified by the same functional unit in the form of their reference flows. Knowing reference flow as a measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit. [2]

There are several cut-off criteria in LCA practice to decide which inputs include in the assessment. The three most used are:

- Mass: an appropriate decision in LCA would involve using mass as a criteria. After defining the cut-off percentage, if the mass is more than this fixed value it has to be included. If it is lower it won't take into account. when using mass as a criterion, would require the inclusion in the study of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled.

- Energy: an appropriate decision, when using energy as a criteria, it would require the inclusion in the study of those inputs that cumulatively contribute more than a defined percentage of the product system's energy inputs.

- Environmental significance: decisions on cut-off criteria should be made to include inputs that contribute more than an additional defined amount of the estimated quantity of individual data of the product system that are specially selected because of environmental relevance.

3.3. Phase 2: Life cycle inventory analysis (LCI)

The most demanding task in LCA-studies, is the data collection. Although a lot of data is available in databases, it appears that a few processes or materials can't be found or that they aren't available, it's also possible that the available data isn't representative. Depending on time and budget, there are a number of strategies to collect such data. It is useful to distinguish two types of data [4]:

1. Foreground data: which refers to specific data needed to model in the system. Typically it's data that describes a particular product system or a particular specialised production system. Confidentiality issues can be important barriers. Sometimes emission data can reveal certain technical or commercial secrets.

2. Background data: this consist of the data for generic materials, energy, transport and waste management systems. This data is usually found in databases and literature.

3.4. Phase 3: Life cycle impact assessment (LCIA)

3.4.1. Featured tools

SimaPro: is the most commonly used software. It has some features that facilitate the development of LCA studies. Developed by: PreProduct Ecology Consultants, Amersfoort, the Netherlands.

Umberto: is a very powerful and flexible tool for LCA and analysis of material and energy flows used in the industry. Developed by: ifeu- Institute for Environmental Informatics Hamburg GmbH and ifeu – Institute for Energy and Environmental Research Heidelberg

GmbH.

ECO-it: software for the implementation of ecodesign. Developed by: PreProductEcology Consultants, Amersfoort, the Netherlands.

ECO-edit: allows you to edit or create databases for ECO-it. Developed by: PreProductEcology Consultants, Amersfoort, the Netherlands.

EcoScan 3.0: A program to easily analyse environmental impacts and costs of products. Developed by:TNO Industrial Technology, Eindhoven, Netherlands.

TEAM: powerful and flexible program for LCA. Developed by: TheEcobilanGroup, Arundel, United Kingdom

EcoLab: is a powerful software for LCA studies. Developed by: NordicPort, Göteborg, Sweden.

GREET Model: software tool developed by the Transport Research Center, Argonne National Laboratory, University of California. The tool consists of a multidimensional spreadsheet developed in Microsoft Excel.

ATHENA Model: practical tool, easy to use in making decisions and providing high quality environmental help choose between different options. Developed by: Athena Sustainable Materials Institute, Ottawa, Canada.

KCL-ECO 3.01: software for the application of LCA. Developed by: Oy Kesuslaboratorio-Centrallaboratorium Ab (KLC). Espoo, Finland.

Design System 4.0: tool for environmental impact assessment and product development sostenibiles. Developed by: AssessEcostrategy Scandinavia AB, Göteborg, Sweden.

GaBi 4: software for the life cycle analysis. Developed by: Institute for Polymer Testing and Polymer Science (IKP), University of Stuttgart in co-operation with PE Europe GmbH (PE), Dettingen/Tech

EPS: Environmental Priority strategies in product design, it was developed by the Centre for Environmental Assessment of Product and Material Systems of Chalmers University of Technology

Summary of principal software's characteristics:

Tools	Criteria					
	Interface	Data Management	Flexibility	Calculations and comparisons	Importation/ Exportation	Impact Analysis
EPS	YES	NO	YES	YES	NO	YES
CML 2	NO	YES	NO	YES	YES	YES
UMBERTO	NO	NO	YES	YES	YES	YES
GREET	YES	YES	YES	YES	NO	NO
TEAM	YES	YES	NO	YES	YES	YES
SIMA PRO	YES	YES	YES	YES	YES	YES

Table 1: Characteristics of principal softwares

For the data management procedures there are different data bases grouped in libraries and also different methods to calculate the impact assessment:

General libraries (Database): Buwal 250: (Swiss), ETH-ESU (Swiss), Franklin: USA, Idemat 2001 Europe, Industry data European data, LCA Food DK Denmark, Ecoinvent (Swiss&Europe)

Impact assessment methods: Eco-indicator 99, EDIP97, EDIP2003, EPS 2000d, (Dutch) LCA Hanbook, IMPACT 2002 (+), LIME, (SWISS) ECOSCARCITY, JEPIX, TRAC.

3.4.2. Eco-indicator 99

Eco-indicator 99 is one of the most widely used impact assessment methods for LCA-studies. It’s the successor of Eco-indicator 95, which was the first endpoint impact assessment method, and allowed the environmental load of a product to be expressed in one single score.

In the Eco-indicator 99 the term “environment” is defined with three types of damage [5]:

1. Human Health. This category handles about the number and duration of diseases, and life years lost due to premature death caused by environmental causes. The effects included are: climate change, ozone layer depletion, carcinogenic effects, respiratory effects and ionising (nuclear) radiation. This category is expressed as the number of life years lost and the number of years disabled. These are combined as Disability Adjusted Life Years (DALYs). This index that is also used by the World bank and the WHO.

2. Ecosystem Quality. This category expresses the effect on species diversity, specially for vascular plants and lower organisms. The effects included are: ecotoxicity, acidification, eutrophication and land-use. This category is expressed as the loss of species in a certain area over a certain time.

3. Resources. In this category is included the extra energy needed in the future to extract the same quantity of mineral and fossil resources. This category is expressed like the extra energy needed for future extractions of mineral and fuel fossils.

The following effects that might be relevant in some cases are not included:

- Human Health: Noise, endocrine disrupters and non carcinogenic or non respiratory effects of some substances like heavy metals

- Ecosystem Quality: The greenhouse effect and ozone layer depletion (both are included in Human Health) and the effect of phosphates.

In general these shortcomings will not have a very big effect, but in specific cases, for instance when systems that produce high noise levels, or emit large amounts of heavy metals or phosphates, the Eco-indicator value may misrepresent the environmental load.

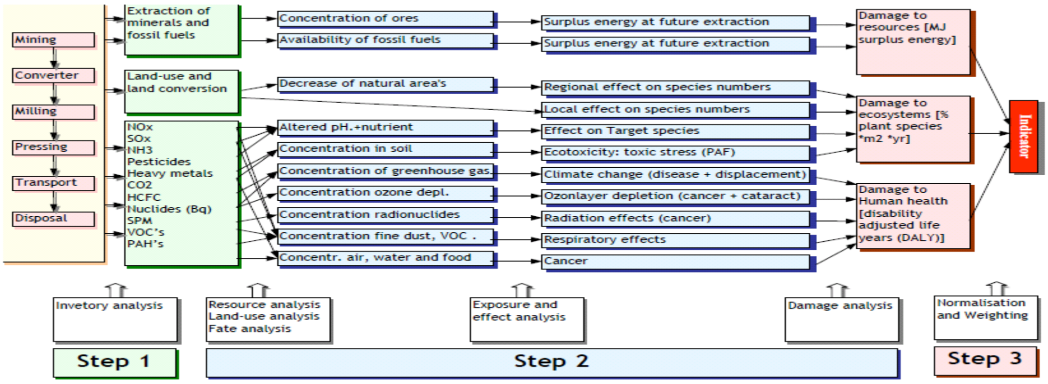


Image 2: Detailed representation of the damage model.

The method of working with standardised Eco-indicators is not new. The method was introduced in the Eco-indicator 95 project. The most important difference between the updated 99 version and its predecessor is that the methodology for calculating indicators are improved and that the list with indicators has been expanded. The scientific basis for the methodology has much improved, the damage model and therefore the reliability has been improved. Next to this also the concept of the methodology has changed. The Eco-indicator 95 used a mixture of damage modelling and the Distance to Target approach. The Eco-indicator 99 has no longer this Distance to Target principle in its results. Instead it applies the fully developed damage approach. [7]

Other important improvements are: the procedure for the weighting between the damaged categories is clearer and more explicit; it contains also a better definition of the damage models. Thorough description and specification of the uncertainties and assumptions, inclusion of the fate (dispersion and degradation) of emissions in the environmental compartments, much wider range of emissions and effects, like resource depletion, land use and ionising radiation.

As a result of these changes the results of Eco-indicator assessments may have a different outcome when the 99-method is applied instead of the Eco-indicator 95 method. The most important causes that are affecting this different outcome are: first, the inclusion of resource depletion therefore processes that require oil, gas or certain minerals will be higher valuated;

secondly, the inclusion of land-use, hereby will agricultural production processes have a higher valuation; thirdly, introduction of dispersion and degradation of substances, therefore will substances with a shorter lifetime will have a less impacted to the Eco-indicator scores.

It is important to point out that Eco-indicator 95 and 99 values are not compatible. This means it is not possible to mix old and new indicators in one analysis. It is also not possible to give a conversion factor.

During the design process, the designers have to analyse, out of a vast number of available option, which are the best options and solutions according the finality of their task. To enable them to make more environmentally aware designs it must be possible to include the environmental aspects of the products chosen in the analysis and selection of design options. The standard Eco-indicator values have been developed as an instrument to do just that; they are meant to be a tool for designers. It is a tool to be used in the search for design alternatives that are more environmentally friendly and is intended for internal use. The standard Eco-indicator values are not intended for us in environmental marketing, for environmental labelling or for proving in public that one product is better than another one. It is also not intended as an instrument for the Government to be used for setting standards and drawing up guidelines [7].

The standard Eco-indicator values can be regarded as dimensionless. The name used is the Eco-indicator (Pt). In the Eco-indicator lists the unit milli-point (mPt) is usually used. The absolute value of the points is not so relevant as the main purpose is to compare relative differences between products or components. The scale is chosen in such a way that the value of 1 Pt is representative for one thousand of the yearly environmental load of an average European inhabitant.

3.4.3. Damage assessment units

As it has been explained before, Eco-indicator 99 defines three types of environmental damage: Human Health, Ecosystem Quality, Resources.

Each damage category consists of a number of impact categories all measured in the same units. This structure facilitates the interpretation of the results, and allows to do the analysis of each damage category separately, without applying any subjective weighting. The figure bellow illustrates the grouping of categories.

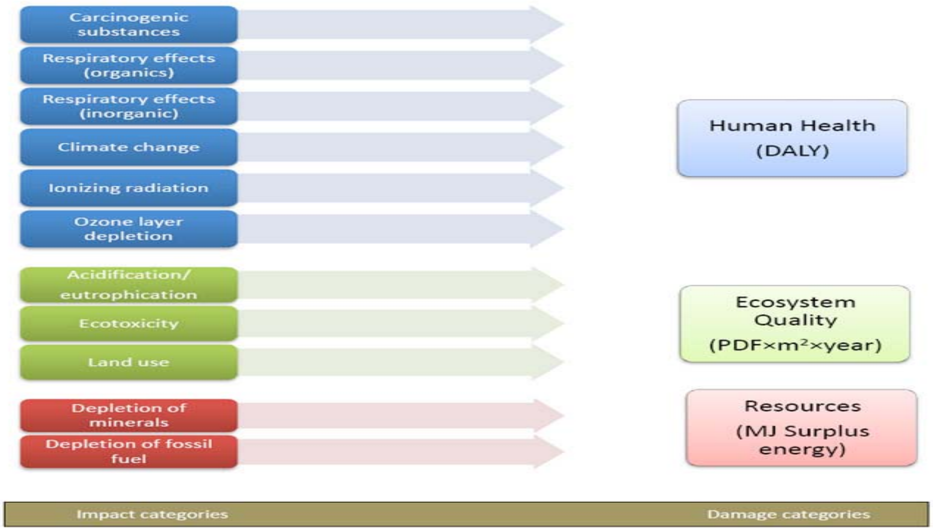


Image 3: Grouping damage categories

Human Health: The Human Health damage category takes into account respiratory and carcinogenic effects, ozone layer depletion, greenhouse gas and ionizing radiation. Damage to human health is expressed in DALY (Disability Adjusted Life Years), which is the number of disability years caused by exposure to toxic material multiplied by the "disability factor", a number between 0 and 1 that describes severity of the damage (0 for being perfectly healthy and 1 for being fatal). [8]

Ecosystem Quality: Damages of ecosystem quality include ecotoxicity, acidification, eutrophication and land use. They are expressed as a percentage of the species that are threatened or have disappeared in a certain area due to the environmental load during a year. The Ecotoxicity is characterized in Potentially Affected Fraction (PAF) of species in relation to concentration of the toxic materials. The PAF expressed in the percentage of the species that are exposed to the toxic emission. The higher the concentration, the larger the number of species that are affected. Acidification and Eutrophication are characterized in

Potentially Disappeared Fraction (PDF), which is a probability of the plants species to disappear from the area as a result of acidification and eutrophication. Since it is not possible to determine whether the damage is caused by changes in the nutrient level or by acidity, these two impact categories are combined. Land use is also characterized by PDF, which refers to the change in the numbers of all species on the occupied land and at the natural area in the surroundings. The total units of the Ecosystem Quality are PDF times area times year [PDF×m2×year]. [8]

Resources: The Eco-indicator 99 methodology only analyses non-renewable resources such as minerals and fossil fuels. It models the decrease of the concentration of the mineral resources in the Earth's crust and calculates the amount of energy needed to extract the mineral in a future in relation to the concentration. The units of Resources damage category are "surplus energy" in MJ per kg extracted material, and it is related to the expected increase of extraction energy per kg of extracted material. [8]

3.4.4. Optional steps

Normalisation, grouping and ranking are used to simplify interpretation of the result. These steps are regarded as optional steps in ISO 14040.[4]

Normalisation is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is achieved by dividing the impact category indicators by a "Normal" value. There are different ways to determine the "Normal" value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result the number of inhabitants in that area.

In order to avoid weighting, while making results easier to interpret, impact category indicators must be grouped and ranked:

- Impact category indicators that have some common features may be presented as a group. For example, it can be formed groups of impact category indicators with global, regional and local significance.

- Ranking refers to a procedure, where impact categories are sorted by a panel in a descending order of significance.

- Both procedures can be used to present the results.

In these methods, the category indicators are defined close to one of the three endpoints to achieve an optimum environmental relevance. The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same. This allows addition of the indicator results by group. This fact means that the indicator results can be presented as three indicators at endpoint level without any subjective weighting. The figure bellow shows this procedure.

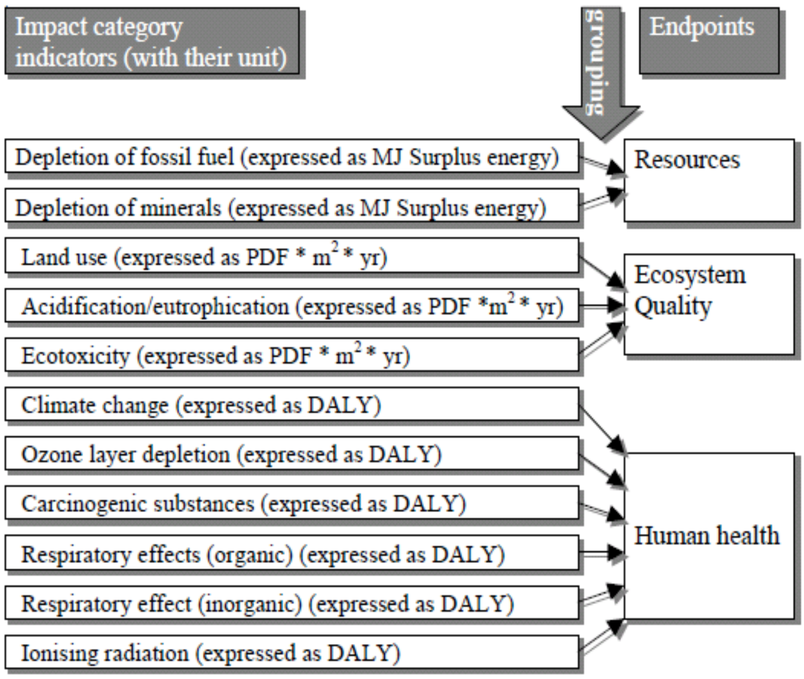


Image 4: Illustration of the grouping option on the Eco-indicator 99 method. This procedure allows reduction of the number of impact categories to just instead of 11, without the need of subjective weighting.

In the weighting phase the normalised category results are: assigned numerical factors according to their importance, multiplied by these factors and finally aggregated in a single “impact score”.

Weighting is the most difficult step in life cycle impact assessment, especially for midpoint methods. In the Eco-indicator 99 methodology, the weighting problem was the starting point of the development. Some of the problems associated with weighting have been reduced or solved, but the weighting step will always remain difficult. An interesting approach has been developed using a weighting triangle. This triangle can be used to present the weighting problem on a case-by-case basis to stakeholders. It is interesting that it can be used to take a decision without actually knowing the weights.

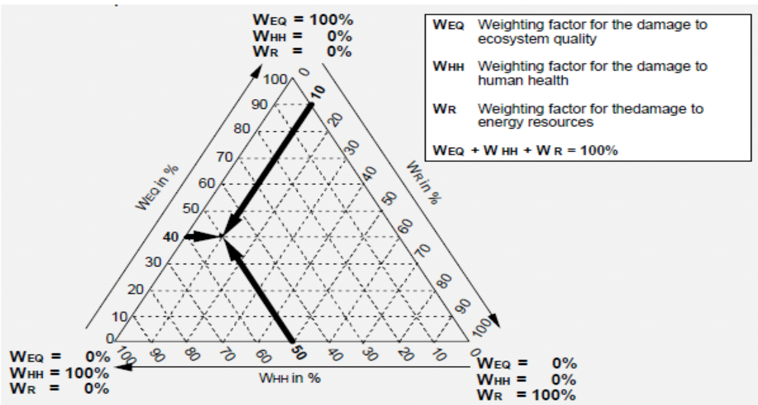


Image 5: Triangle tool for weighting procedure

The triangle will be used to demonstrate the result of the ranking performed by the respondents.

When a respondent states that Human Health is more important than Ecosystem Quality and the Ecosystem Quality is more important than Resources, we can interpret this as:

1. Human Health (HH) must have a weight higher than 33%, because otherwise EQ or R would by definition get the highest factor.

2. Resources must have a weight that is lower than 33%, otherwise it would become higher than either HH or EQ.

3. Ecosystem Quality (EQ) must have a weight lower than 50%, otherwise it would get higher than H at R=0.

This reasoning can be shown graphically in the triangle as a grey area in figure 6.

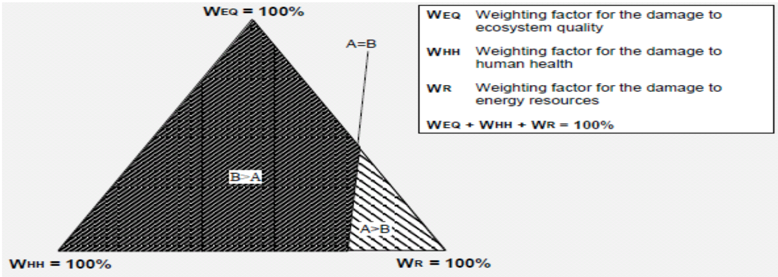


Image 6: Line of indifference in the weighting triangle and the two sub-areas (B>A means that alternative B is environmentally superior to A and eco-index A is higher than B)

3.5. Phase 4: Life cycle interpretation

Probably the most readable and practical standard is the last of the four LCA standards is the interpretation. In essence it describes a number of checks you need to make in order to see if the conclusions you want to draw from the study are adequately supported by the data and by the procedures used. This chapter describes the most important procedure, and shows how it is supported in SimaPro.

3.5.1. Uncertainty

Uncertainty analysis is known as a systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability.

All data in life cycle models have some uncertainty. Three main types can be distinct:

1. Data uncertainties. In theory they are relatively easy to handle, as such uncertainties can be expressed as a range or standard deviation. Statistical methods, such as Monte Carlo techniques can be used to handle these types of uncertainties, and calculate the uncertainty in the LCA results.

2. Model uncertainties. Uncertainty on the correctness of the model refers to the fact that there is not one way to make a model of reality. In each LCA, one will have to

make more or less subjective choices in order to make a model.

3. Data uncertainties: incompleteness. Uncertainty caused by incompleteness refers to the unavoidable data gaps. Important issues are: system boundaries (it is not easy to apply system boundaries and cut-off-criteria), incomplete data sheets (often data will be partially available) and mismatch between inventory and impact assessment (sometimes inventory data that is collected does not have a characterisation value).

Because of the second and third types of uncertainty, is difficult to apply a uniform system to deal with uncertainties in LCA. The best solution is combining the Monte Carlo analysis for data uncertainties with sensitivity analysis for model uncertainties.

3.6. Environmental effects of products

Each product damages the environment in some extent. Raw materials have to be extracted, the product has to be manufactured, distributed and packaged. Ultimately they have to be disposed. Furthermore, environmental impacts often occur during the use of products because the product consumes energy or material. If we wish to assess product's environmental damage, all it's life cycle phases must therefore be taken in account and be studied. An environmental analysis of all the life cycle phases is defined as a Life Cycle Assessment, or LCA.

Upon today, the use of life cycle assessments in the design processes has been faced by two major problems. The first one is that the result of a full life cycle assessment is difficult to interpret. Within a life cycle assessment it’s for instance possible to determine the amount of greenhouse gasses it has produced, acidification and other environmental problems while the total environmental impact remains unknown. The reason is the lack of mutual weighting of the environmental effects. And the second problem is that in general the careful collection of all the environmental data in a product's life cycle is complex and time-consuming. As a result extensive LCAs cannot usually be carried out during a design process. [7]

3.7. Uses of LCA

A survey, held in 2006 under LCA professionals, pointed out the areas in which the LCA is mostly used. The results where as follow: 18% for supporting business strategy and 18% in research and development; 15% uses LCA's as an input to product or process design; 13% in education and at last 11% uses it for labelling or product declarations. LCA will probably be continuously integrated into the design of products in order to implement an environmental methodology.

Big corporations are using LCA for themselves and in their products, and governments are developing or supporting the development of national databases for LCA's. It's important to note that there is a growing use of LCA for ISO Type III labels called Environmental Product Declarations. This third type of motivation of doing a LCA provides a basis for assessing the relative environmental merits of competing products. This certification plays a major role in today's industry. Independent certification can show a company's dedication to safer and environmental friendlier products to customers. LCA also has major roles in environmental impact assessment, integrated waste management and pollution studies. [6]

3.8. Variants of LCA

Some variants of LCA can be found, depending on the established scope and also the potential data available.

Cradle-to-grave is the full Life Cycle Assessment of a product or process from the extraction of raw materials ('cradle'), through manufacturing and use, to disposal phase ('grave'). This assessment examines the product's net environmental burden, including the consumption of raw materials and energy, emissions to air and water, and solid waste generation.

Cradle-to-gate is the assessment of a partial product life cycle from resources extraction ('cradle') to the factory gate before being transported to the consumer ('gate'). In this methodology the use phase and disposal phase of the product are not considered. These kind of assessments are usually the basis for environmental product declarations (EPD).

Cradle-to-cradle is a specific kind of cradle-to-grave assessment In this case the end-of-life disposal step of the product is a recycling process. This method is used to minimize the environmental impact of products by using sustainable production, and disposal practices. Allocation of burden for products in cradle-to-cradle production systems present considerable challenges for the LCA.

Gate-to-gate is a partial assessment looking at only one added process or material in the entire production chain. Gate-to-gate studies can later be linked in their appropriate production chain to form a complete cradle-to-gate analysis.

Well-to-wheel is a kind of LCA used for transport fuels and vehicles. This analysis is often discomposed in stages entitled "well-to-tank" and "tank-to-wheel". The first stage, called the “upstream” stage, incorporates the production and processing of the fuel and also the fuel delivery or energy transmission. While the stage that deals with vehicle operation itself is usually called the "downstream" stage. Usually the well-to-wheel analysis is used to assess total energy consumption, or the energy conversion efficiency and emissions impact of motor vehicles.

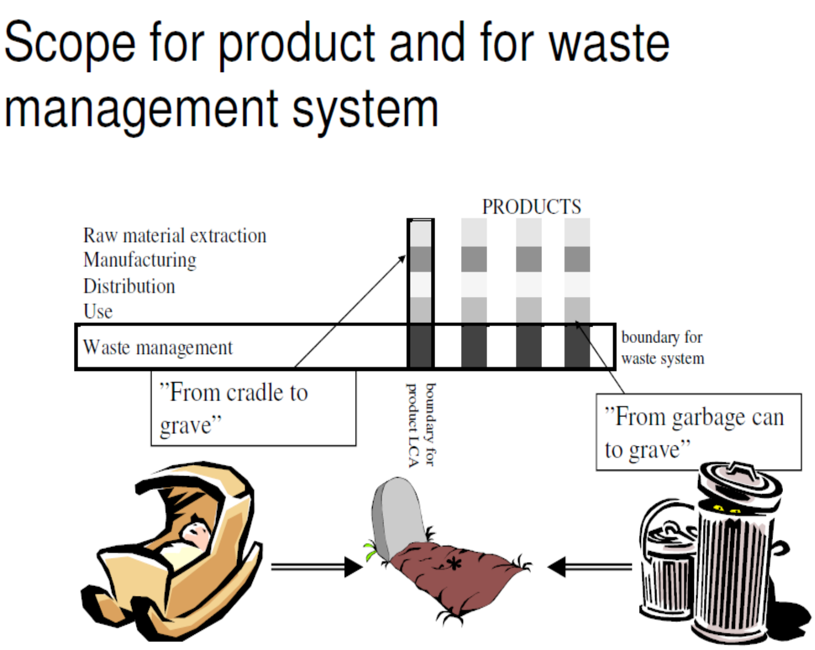


Image 7: Waste management of a product

4. Race Up car

4.1. Formula SAE and Race Up Team

Image 8: The Race Up Team with the car MG0712

Formula SAE is a student design competition organized by the Society of Automotive Engineers (SAE, also known as SAE International). The competition first took place in 1978 and was originally called SAE Mini Indy. Each student team designs, builds and tests a prototype based on a series of rules, whose purpose is both to ensure on-track safety (the cars are driven by the students as well as themselves) and to promote clever problem solving. The prototype race car is judged in a number of different events. The points schedule for most Formula SAE events are: Design Event (150 points), Cost & Manufacturing Analysis Event (100 points), Presentation Event (75 points), Acceleration Event (75 points), Skidpad Event (50 points), Autocross Event (150 points), Fuel Economy Event (100 points), Endurance Event (300 points), Total Points Possible (1000 points).

In addition to these events, some sponsors of the competition provide awards for superior design accomplishments. Best use of E-85 ethanol fuel, innovative use of electronics, recyclability, crash worthiness, analytical approach to design, and overall dynamic performance are some examples of the awards given. At the beginning of the competition, the vehicle is checked for rule compliance during the Technical Inspection. Its braking ability, rollover stability and noise levels are checked before the vehicle is allowed to compete in the dynamic events (Skidpad, Autocross, Acceleration, and Endurance).

The representatives of the University of Padova are a team of around 30 students, the Race Up Team, divided in 8 groups, each one specialised in one part of the car. Last year, participating with the car of this study, the team achieved the 35th position of overall 80 participants in Hockenheim and the 14th position of 40 participants in Varano.

4.2. Summary of rules for the competition

The following paragraphs are summing up the rules fixed by the Formula SAE organisation for every team that participates in the competition.[3]

Student Competition:

Formula SAE has relatively few performance restrictions. The team must be entirely made up of active college students (including drivers) which places obvious restrictions on available work hours, skill sets, experience, and presents unique challenges which professional race teams do not have to face with a paid, skilled staff. This rule implies that the rest of the regulations can be much less restrictive than most professional series.

Students are allowed to receive advice and criticism from professional engineers or faculty, but all of the car design must be done by the students themselves. Students are also solely responsible for fundraising, though most successful teams are based on curricular programs and have university-sponsored budgets. Additionally, the points system is organized in a way that multiple strategies can lead to success. This supports to a great variety among cars, which is a rarity in the world of motorsports.

Engine:

The engine must be a four-stroke, Otto-cycle piston engine with a displacement no greater than 610cc. An air restrictor of circular cross-section must be fitted downstream of the throttle and upstream of any compressor, no greater than 20mm for gasoline engines or 19mm for ethanol-fuelled engines. The restrictor keeps power levels below 100 hp in the vast majority of FSAE cars. Most commonly, four-cylinder 600cc sport bike motors are used due to their availability and displacement, however many teams preferred to use smaller V-twin and single-cylinder engines. Though it is permitted, very rarely do teams build an engine from scratch, such as Western Washington University's 554cc V8 entry in 2001.

Suspension:

The suspension is unrestricted if for safety regulations are accomplished. Most teams opt for four-wheel independent suspension, almost universally double-wishbone. Active suspension is legal.

Aerodynamics:

There are few regulations or requirements on aerodynamics. Most teams do not build aerodynamic packages as the speeds involved in FSAE competition rarely exceed 60 mph (97 km/h), and design judging tends to frown upon aerodynamic parts that do not have definite test data, usually in the form of wind tunnel testing or at least computational fluid dynamics analysis. Therefore most cars that do utilize aerodynamic down force tend to develop their entire car around the aerodynamic package, including massive wings and under trays. The benefit of a well-developed aerodynamic package is evident; depending on how fast the course is, the slowest aero-package cars sometimes run several seconds per lap faster than any of the non-aero cars. But, on windy days, at the drag strip, or especially in the fuel economy event, aero cars can suffer significantly.

Weight:

There is no weight restriction. The weight of the average competitive Formula SAE car is usually less than 500 lb (230 kg) in race trim. However, the lack of weight regulation combined with the somewhat fixed power ceiling encourages teams to adopt innovative weight-saving strategies, such as the use of composite materials, elaborate and expensive machining projects, and rapid prototyping. In 2009 the fuel economy portion of the endurance event was assigned 100 of the 400 endurance points, up from 50. This rule change has marked a trend in engine downsizing in an attempt to save weight and increase fuel economy. Several top-running teams have switched from high-powered four-cylinder cars to smaller, one- or two-cylinder engines which, though they usually have much less power, allow weight savings of 75 lb (34 kg) or more, and also provide much better fuel economy. If a lightweight single-cylinder car can keep a reasonable pace in the endurance race, it can often make up the points lost in overall time to the heavier, high-powered cars by an exceptional fuel economy score.

Example: At the 2009 Formula SAE West endurance event, third-place finishers Rochester Institute of Technology completed the endurance course in 22 minutes, 45 seconds with their four-cylinder car, while fourth-place finishers Oregon State University finished in 22 minutes, 47 seconds with their single-cylinder car; this gave RIT 290.6 of 300 points for the race portion of the event and OSU 289.2 points. However, OSU used the least fuel of any car (.671 US gal (2.54 l), or 20.3 mpg-US(0.116 l/km) over the entire endurance race) and received the full 100 points for fuel economy, while RIT used 1.163 US gal (4.40 l) (11.75 mpg-US (0.2002 l/km)) and was thus only awarded 23.9 of the available points. RIT went on to win the overall competition by only 8.9 points over OSU, having scored slightly better in all of the other dynamic events.

Safety:

The majority of the regulations pertain to safety. Cars must have two steel roll hoops of designated thickness and alloy, regardless of the composition of the rest of the chassis. There must be an impact attenuator in the nose, and impact testing data on this attenuator must be submitted prior to competing. Cars must also have two hydraulic brake circuits, full five-point racing harnesses, and must meet geometric templates for driver location in the cockpit for all drivers competing. Tilt-tests ensure that no fluids will spill from the car under heavy cornering, and there must be no line-of-sight between the driver and fuel, coolant, or oil lines.

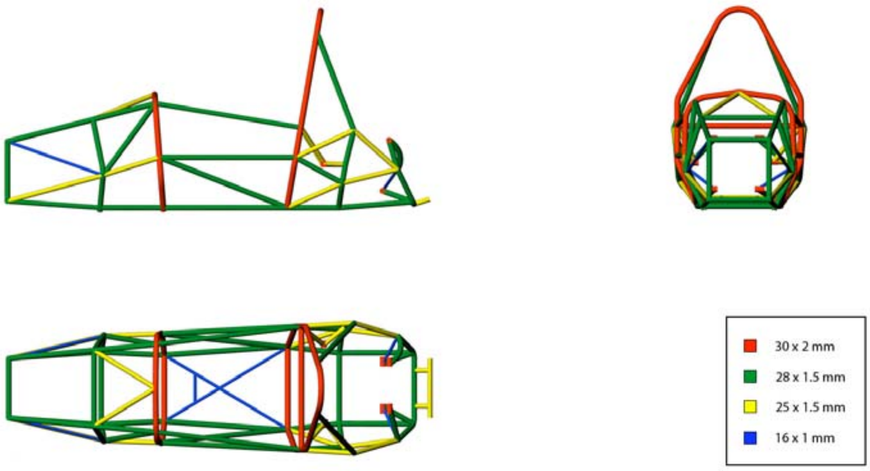
4.3. The Race Up car 85

The car 85, also known as MG0712, is the fourth car designed by the Race Up Team. It is composed by the following sub-systems: Frame & Body, Brake system, Engine & Drivetrain, Instruments & Wiring, Miscellaneous, Steering System, Suspension, Wheels & Tires.

Image 9: The MG0712 car

1. Frame & Body

The frame and body system serves to shape the car thus giving it a structure. The system can be splited in 167 components or materials, among them the pedals, frame tubes, throttle controls and floor pan.



1	Telaio		1	Steel 25CrMo4	
Posizione	Descrizione		N° Pezzi	Materiale e note	
08/05/12	Disegnato	Controllato	Approvato	Quote senza indicazione di tolleranza: UNI ISO 2768-m	Scala: 1:20
Data	N. Colombo	V. Formilan, E. Storti	M. Soccal		
Firma					
Università degli Studi di Padova - Race UP Team Via Gradenigo, 6/A - 35131 PD www.raceup.net - info@raceup.net			Titolo disegno: Coloured Frame Tubes		Formato: A4
			Codice disegno:		

Image 10: Frame tubes that compose the Frame&Body system

2. Brake system

The brake system is the instrument responsible for stopping the car whenever it is needed the circuit for giving to the car the brake reaction when it is needed. The system is divided in 102 little components and materials. The simplified scheme of the system's operating is shown in the following figure.

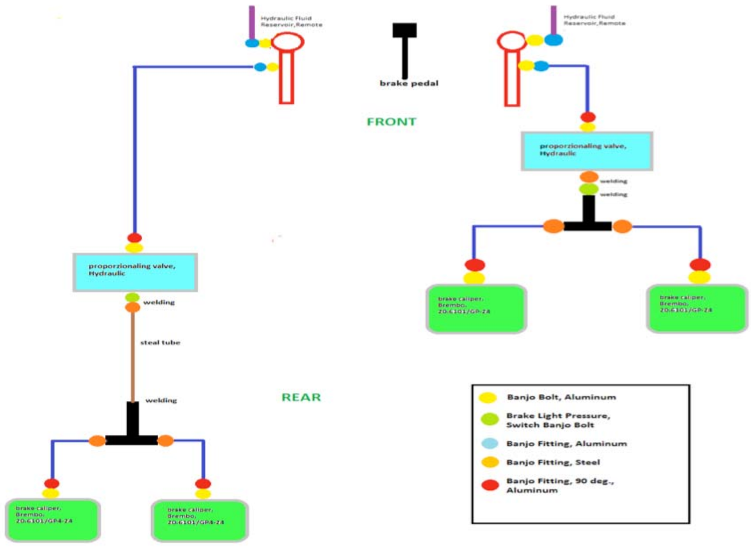


Image11: Diagram of the brake system

3. Engine & Drivetrain

This system refers to a group of components that generate power including the engine, transmission, differential, fuel tank, fuel lines, radiator, chain among others. The engine&drivetrain system is splited in 416 little components or materials.

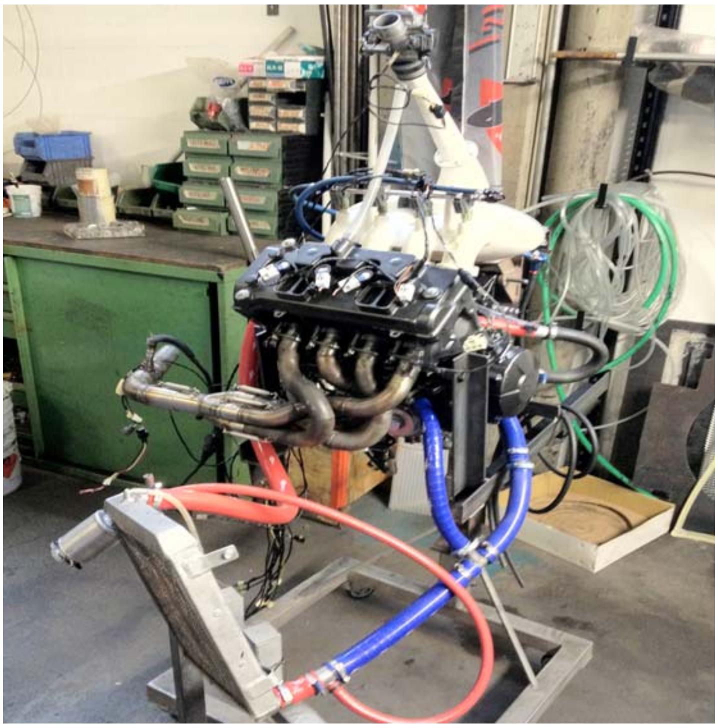


Image 12: Engine system

4. Instruments & Wiring

The instruments&wiring system is the responsible of all the electrical connections and controls of the car. The system can be splited in 352 components or materials including in the most common wires, connectors and tire wraps.

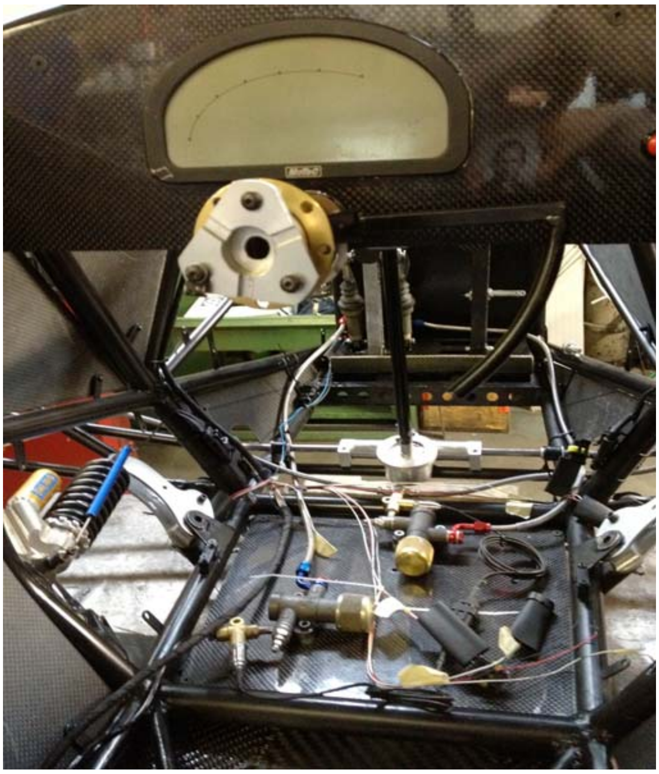


Image 13: Components of the frame&body system

5. Miscellaneous

The miscellaneous system includes the impact attenuator, paint frame, paint body, shields, fire wall, driver's seat, headrest, padding and harness driver of the car. The system can be splited in 176 components or materials.

Image 14: driver's seat, one of the components of miscellaneous system

6. Steering System

The steering system describes the collection of components which allow a vehicle to follow the course desired by the driver. The system can be splited in 110 components and materials.

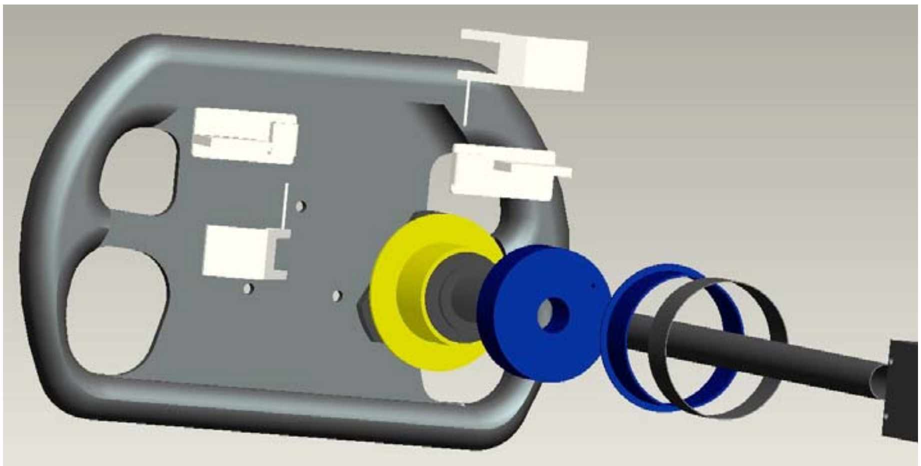


Image 15: Assembly steering system

7. Suspension

The suspension system connects the vehicle to its wheels and allows a relative motion between the two. This system serves a dual purpose: contributing to the vehicle's rod holding/handling and braking for good active safety and driving pleasure, keeping the vehicle occupant comfortable from road noise, bumps and vibrations. The system can be splited in 186 components and materials.

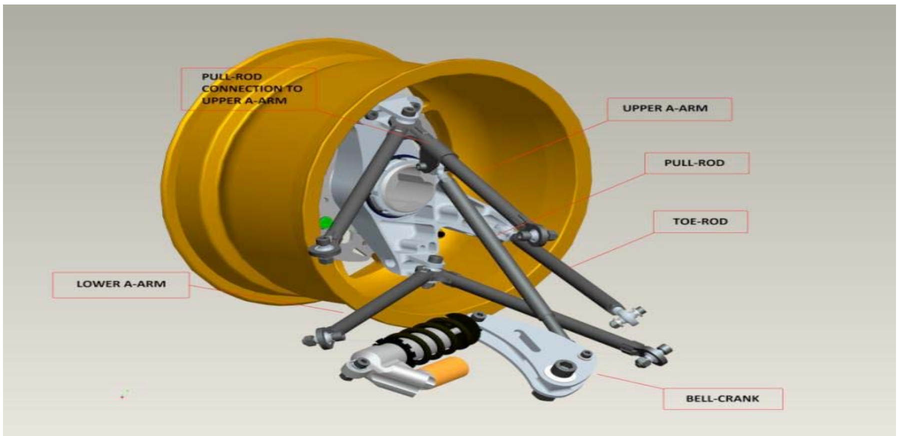


Image 16: Assembly suspension system

8. Wheels & Tires

The wheels&tires system is the responsible to transmit the rotary movement to the floor thus keeping the car going. It can be splited in 36 components.

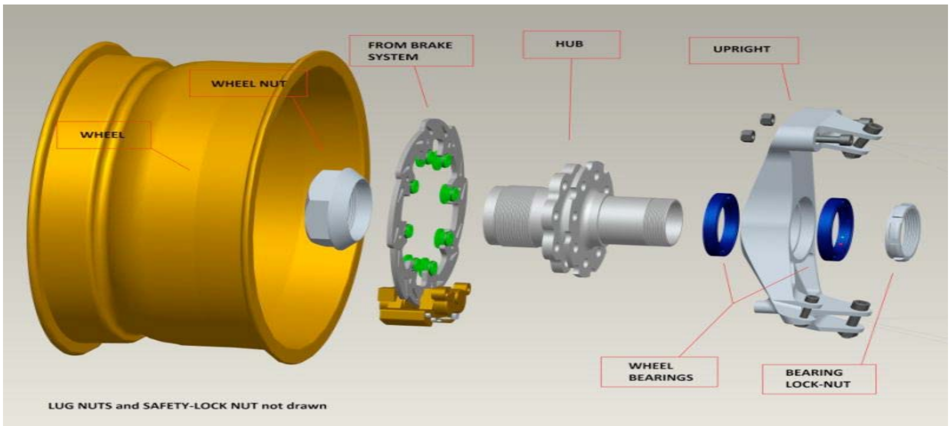


Image 17: Assembly wheels

5. Life Cycle Assessment of the Race Up car

5.1. Goal and scope definition

When doing a Life Cycle Assessment of a car it is necessary to define the goal of the LCA mainly to discover the impact of each system the car is composed of.

Obviously it would be interesting to explore the global impact of the car but due to the lack of records of Life Cycle Assessment applied to other cars of the same category as the car of the study, it is impossible to compare them. It would be interesting in case of having precedents of Life Cycle Assessments applied in other cars of this type so comparison would be possible, but since the idea of applying a LCA in a car of the Race Up Team is completely new, there is no common basis for comparing cars. Therefore comparisons are going to be between several parts of the same car, not between two different cars.

Concerning the definition of the system considered in the study, the vehicle annually built by the Race Up Team is bounded to the technical rules established for the competition particularly explained in part 4.2 and 4.3., it's aim is namely being able to participate in the competition and to accomplish different phases, explicitly described in part 4.1.

In order to be able to improve the cars that will be construct by the next years Race Up teams, it is necessary to define the functional unit of the LCA which can be used as a reference number in proceeding LCA's. In this case, the functional unit is the amount of kilometers that the vehicle is going to achieve during its life. The Race Up Team considers that the vehicle of this study has a mileage of 150 Km. This functional unit is defined in the goal of the study and is going to be useful for the possible future LCA studies of other versions of the car. In this thesis it is not going to be the main subject.

This Life Cycle Assessment is a document addressed to the team of Race Up with the aim of knowing which components have which environmental impact. In this way, the next generation of cars developed by Race Up Team, can incorporate improvements by using other materials with a less impact on the environment then the materials that are used today.

In this Life Cycle Assessment there are no problems of allocation that have to be further described. Allocation is defined as parting the input and output flows of a process or a product system between the product system under study and others. In this case, the Race Up Team only builds one product. They do not divide resources between several products being built at the same time. The only product of the Race Up Team is the vehicle regarded in the study, so there is no necessity of splitting input or output flows.

The level of environmental damage caused by unit processes or the system as well as the amount of material and energy flow used in the system have to be excluded from the study and are considered as Cut-Off-Criteria. The Cut-Off criteria serves to decide which inputs to include or not to include in the system thus determining the scope of the study. In this case, it is important to clarify that not all processes are included in this LCA. The available data is the one given by the Race Up Team. For this reason, all the processes they do, are included in the study. The processes not included are the ones related to a component that the team buys. For example, a bolt is counted as the weight of the steel but what is not taken in account is the process of milling and other procedures to produced the bolt. Since the availability of data and information is limited, the scope of a study has to be clearly defined in advance. Summing up, the input of the system is considered as material and weight of several parts of the car and furthermore all processes the Race Up Team accomplished to build the car. Processes related to the construction of pieces that are bought are not going to be regarded as inputs of the system.

This kind of LCA is the Cradle-to-gate variant, where the assessment takes into account the energy from the extraction of raw materials to the final product built. In this methodology, use phase and disposal phase of the product are not considered. This is because the vehicle of the study won't do a many kilometres, and for this reason the impact assessment needs to focus on the production of the vehicle in spite of the using of it.

5.2. LCI

Life Cycle Impact is the second phase of LCA. As it has already been stated in the chapter 3.3, data collection is the most demanding task in performing LCA's.

About the two types of data:

1. Foreground data refers to specific data needed to model the system. Around 80% of the data collected stems from a document called *Cost final.* In this document all materials and weights are well described. 20% of the components are not well defined but were provided by the technical advisor of the Race Up Team with an error of 5g.

2. Background data is data concerning generic materials, energy, transport and waste management systems. This is data that can be typical found in databases. Data bases used in this project are: ETH-ESU 96 System processes, ETH-ESU 96 Unit processes, IDEMAT 2001, Industry data 2.0, USA input output Database 98.

Foreground data has been introduced in the software used for this LCA as image 18 shows. The libraries used for the background data are: ETH-ESU 96 System Processes, ETH-ESU 96 Unit Processes, IDEMAT 2001, Industry data 2.0, USA Input Output Database 98.

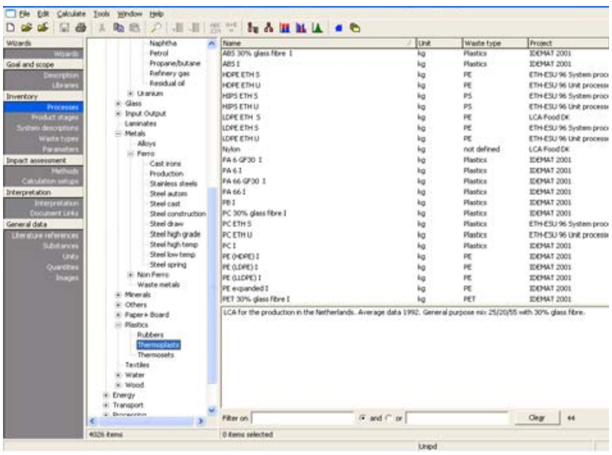


Image 18: SimaPro software

Some materials could not been found in these databases. In order to reach a model that is as close as possible to the reality, some approximations have been done: PVC instead of tape, epoxy resin instead of adhesive, acrylonitrile instead of paint and polymethacrylimide instead of structure foam.

5.3. LCIA

The so called inventory analysis phase is followed by impact assessment. As already explained in part 3.4. of this document the ISO 14040 standard defines an LCA as a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system through its life cycle. In this definition impact assessment is declared as an integral part of an LCA. Life cycle impact assessment is defined as the phase in the LCA that serves to understand and evaluate the magnitude and significance of the potential environmental impacts of a product system.

The impact assessment methods are described in ISO 14042. In this standard a distinction is made between:

- Obligatory elements: classification and characterisation.
- Optional elements: normalisation, ranking, grouping and weighting.

In the following parts classification and normalisation procedures are precisely explained. Between the optional elements, normalisation procedure has been chosen because it provides the biggest veracity of results. As it has been said in the part 3.4.3, weighting it is the most controversial phase of the LCA because of the possible subjective criteria.

The following figure presents a general overview of the structure of an impact assessment method. The LCI results are characterised to produce a number of impact category indicators. According to ISO, one must document the environmental relevance of each indicator by describing the link to the endpoints. Endpoints can be selected by the practitioner, as long as the reasons for including or excluding endpoints are clearly documented.

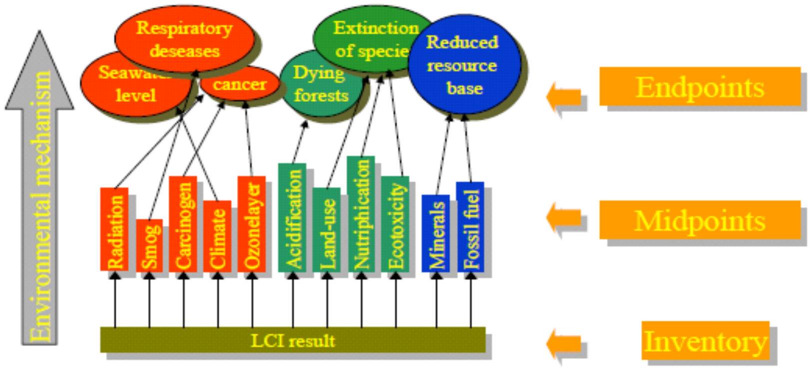


Image 19: Structure of an impact assessment method

5.3.1. Classification

The first obligatory procedure of Life Cycle Impact Assessment is the classification. The inventory result of an LCA usually contains hundreds of different emission and resource extraction parameters. Once the relevant impact categories have been determined, the LCI results must be assigned to these impact categories. For example CO_2 and CH_4 are both assigned to the impact category “Global warming”, while SO_2 and NH_3 are both assigned to the impact category “Acidification”. It is possible to assign emissions to more than one impact category at the same time; for example SO_2 may also be assigned to an impact category like “Human health”, or “Respiratory diseases”. [4]

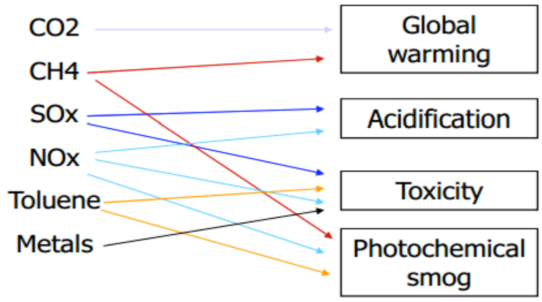


Image 20: Substances can contribute to more than one problem

In this project, for each sub-system (frame&body system, engine&drivetrain system, brakes system, electrical, miscellaneous, steering, suspension and wheels&tires) of the global system (car) these following categories are being analysed: Carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, fossil fuels.

5.3.2. Characterisation

The second procedure that must be done in the LCIA phase is the characterisation. Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterisation factors. These factors should reflect the relative contribution of an LCI result to the impact category.

1. Frame&Body System:

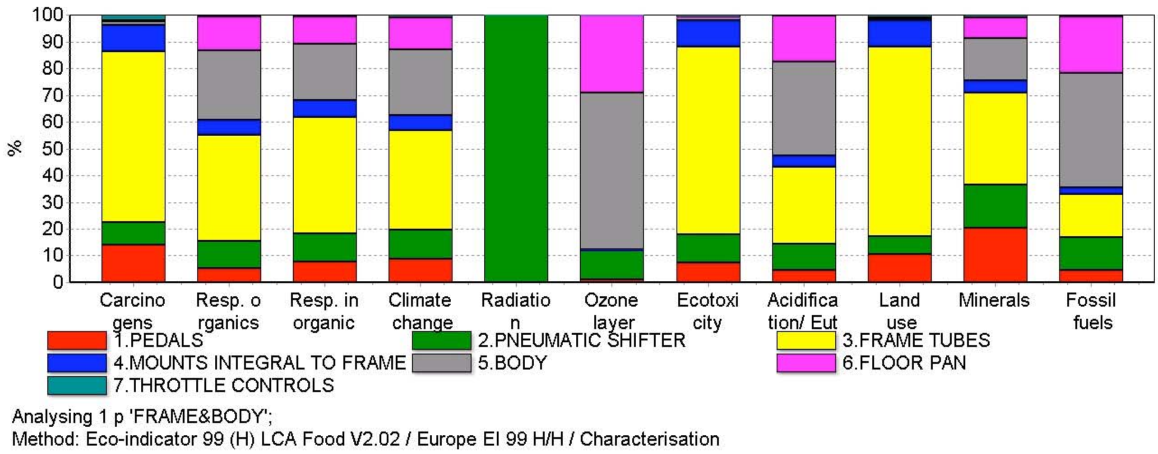


Image 23: Graphic of characterisation results of the Frame&Body System

In this graphic it is shown that the only system with impact in radiation is the "Pneumatic shifter" (this is because of the component Paint ETH S) whereas the "Body" has a greater impact on the Ozone Layer. "Frame Tubes" are present in all categories.

In this figure results of LCI are expressed in units of DALY,PDF×m2×year, MJ surplus. These units are explained in the point 3.4.3.

Impact category	**Unit**	**Total**	**1.PEDALS**	**2.PNEUMATIC SHIFTER**	**3.FRAME TUBES**	**4.MOUNTS INTEGRAL TO FRAME**	**5.BODY**	**6.FLOOR PAN**	**7.THROTTLE CONTROLS**
Carcinogens	DALY	2,81E-006	3,914E-007	2,443E-007	1,786E-006	2,749E-007	4,154E-008	1,43E-008	5,72613E-008
Resp. organics	DALY	1,19E-007	6,084E-009	1,245E-008	4,726E-008	6,737E-009	3,088E-008	1,53E-008	6,95811E-010
Resp. inorganics	DALY	6,78E-005	5,221E-006	7,221E-006	**2,946E-005**	4,254E-006	1,415E-005	6,96E-006	0,00000053
Climate change	DALY	1,90E-005	1,694E-006	2,023E-006	7,089E-006	1,074E-006	4,615E-006	2,27E-006	2,06182E-007
Radiation	DALY	4,17E-009	0	4,167E-009	0	0	0	0	0
Ozone layer	DALY	1,38E-007	1,622E-009	1,505E-008	1,225E-010	4,335E-011	8,112E-008	3,99E-008	4,00892E-011
Ecotoxicity	PAF*m2yr	17,784329	1,30277189	1,8662466	**12,4721684**	1,76491236	0,17157084	0,0446387	0,1620198586
Acidification/ Eutrophication	PDF*m2yr	4,3614983	0,20063569	0,428307	1,25553993	0,18111215	1,52566425	0,748242	0,0219972888
Land use	PDF*m2yr	3,2582128	0,34129732	0,2236018	2,30027971	0,32810192	0,02468614	0,0039377	0,0363083421
Minerals	MJ surplus	4,4128546	0,89349433	0,7097525	1,52058666	0,21279764	0,69645787	0,3343607	0,0454048739
Fossil fuels	MJ surplus	160,7841	7,59520006	19,494692	26,0785387	4,03101508	**68,6222927**	34,079312	0,8830513262

Table 2: Characterisation values of impact categories of each subsystem of Frame&Body

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics has the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. Regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Summing up the conclusions of these last two graphics, the focus points that cause the highest impact in the first sub-system are: the frame tubes (with a 2,95E-05 DALY of respiratory effects inorganics and 12,47PDF*m2yr of ecotoxicity) and the body (with a 68,62 MJ surplus).

2. Brakes System:

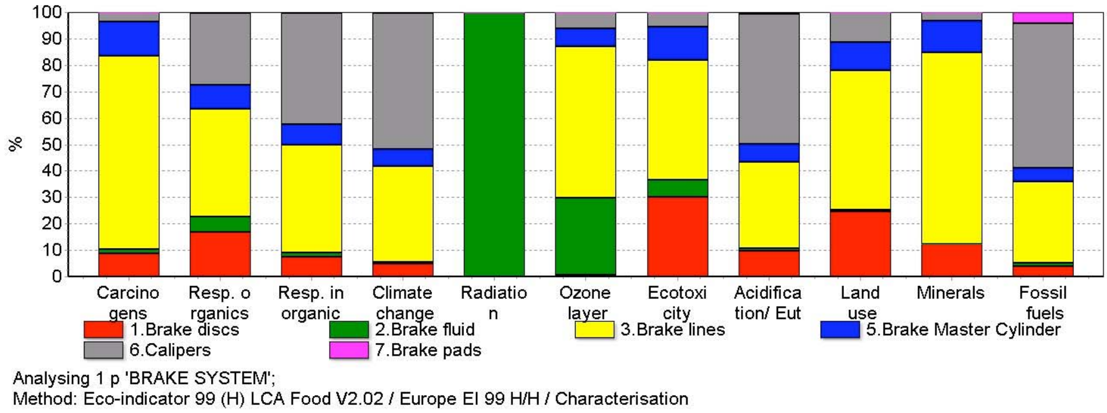


Image 22: Graphic of characterisation results of the Brakes System

This graphic shows that “Brake fluid” is the component that impacts on radiation (this is due to the existence of the component *EPDM rubber ETH S*). And also that the “Brake lines” system has a big impact in all the other categories. It is followed by “Calipers”.

Impact category	**Unit**	**Total**	**1.Brake discs**	**2.Brake fluid**	**3.Brake lines**	**5.Brake Master Cylinder**	**6.Calipers**	**7.Brake pads**
Carcinogens	DALY	8,04E-007	7,14E-008	1,28E-008	5,86E-007	1,04E-007	2,90E-008	0,00E+000
Resp. organics	DALY	1,14E-008	1,90E-009	6,74E-010	4,62E-009	1,03E-009	3,12E-009	1,90E-011
Resp. inorganics	DALY	**1,65E-005**	1,25E-006	2,35E-007	6,72E-006	1,27E-006	6,91E-006	7,00E-008
Climate change	DALY	7,10E-006	3,35E-007	5,02E-008	2,58E-006	4,55E-007	3,64E-006	3,43E-008
Radiation	DALY	1,18E-009	0,00E+000	1,18E-009	0,00E+000	0,00E+000	0,00E+000	0,00E+000
Ozone layer	DALY	9,85E-010	6,73E-012	2,86E-010	5,64E-010	6,71E-011	6,06E-011	0,00E+000
Ecotoxicity	PAF*m2yr	**1,63E+000**	4,87E-001	1,08E-001	7,35E-001	2,07E-001	8,80E-002	0,00E+000
Acidification/ Eutrop	PDF*m2yr	5,53E-001	5,30E-002	6,18E-003	1,81E-001	3,75E-002	2,72E-001	3,10E-003
Land use	PDF*m2yr	7,80E-001	1,93E-001	3,47E-003	4,13E-001	8,20E-002	8,87E-002	8,73E-004
Minerals	MJ surplus	2,72E+000	3,32E-001	1,51E-003	1,98E+000	3,25E-001	8,53E-002	0,00E+000
Fossil fuels	MJ surplus	**3,41E+001**	1,33E+000	4,07E-001	1,05E+001	1,82E+000	1,87E+001	1,41E+000

Table 3: Characterisation values of impact categories of each subsystem of Brakes System

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause the highest impact of this second sub-system are: calipers (with a 6,91E-06 DALY of respiratory effects inorganics and 18,67 MJ surplus of fossil fuels), brake lines (with 0,73 PDF*m2yr of ecotoxicity).

3. Engine&Drivetrain system:

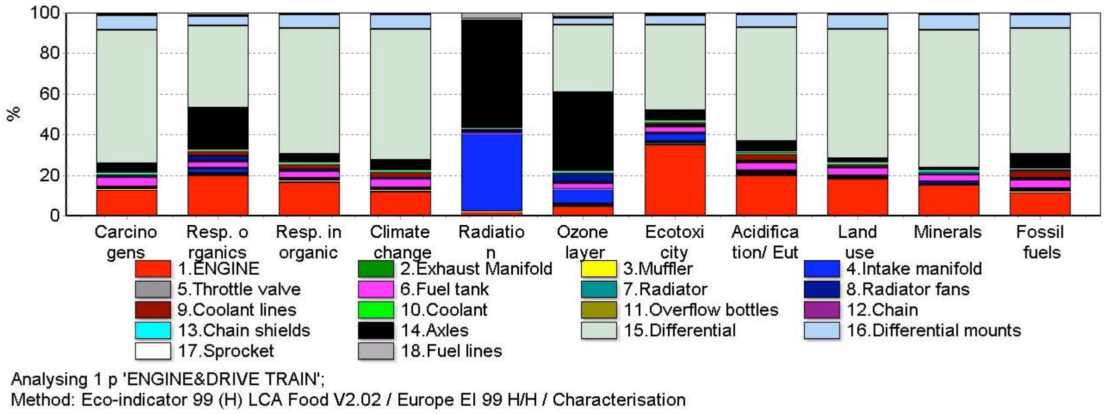


Image 23: Graphic of characterisation results of the Engine&Drivetrain System

This graphic shows that “differential” is the component with the highest impact in all categories in exception of the Radiation category which is mainly caused by “Axles” and “Intake manifold”. Also it can be conclude that “Engine” has a quite important impact in almost all the categories.

Impact category	**Unit**	**Total**	**1.ENGINE**	**2.Exhaust Manifold**	**3.Muffler**	**4.Intake manifold**	**5.Throttle valve**	**6.Fuel tank**	**7.Radiator**
Carcinogens	DALY	0,0001338	1,68E-005	4,852E-007	1,50E-007	1,15E-006	6,970E-007	6,34E-006	7,684E-007
Resp. organics	DALY	1,33E-006	2,66E-007	9,436E-009	6,42E-009	2,61E-008	6,734E-009	3,69E-008	6,022E-009
Resp. inorganics	DALY	**0,0016047**	0,0002617	1,301E-005	3,18E-006	7,89E-006	1,163E-005	5,79E-005	1,078E-005
Climate change	DALY	0,0006095	7,31E-005	3,109E-006	7,62E-007	2,77E-006	4,784E-006	2,57E-005	3,500E-006
Radiation	DALY	5,90E-007	1,13E-008	0	0	2,28E-007	0	0	1,301E-009
Ozone layer	DALY	2,05E-007	9,91E-009	1,920E-010	1,95E-009	1,46E-008	5,423E-010	5,44E-009	8,945E-010
Ecotoxicity	PAF*m2yr	**178,87335**	62,662939	2,03044838	1,0388167	6,876599	0,78373599	5,4647074	0,7531747
Acidification/ Eutrophication	PDF*m2yr	44,193826	8,706584	0,40536475	0,1513042	0,2715651	0,36128028	1,6638846	0,26998995
Land use	PDF*m2yr	92,950868	16,857171	0,55476957	0,1965901	0,3422972	0,54244751	3,407406	0,56918764
Minerals	MJ surplus	470,71925	70,680259	5,6279112	0,433375	0,7068941	2,45741953	15,429187	5,1864766
Fossil fuels	MJ surplus	**2593,4352**	291,77038	13,2901259	4,5278469	17,140394	21,7538429	108,9819	14,7995391

Table 4: Characterisation values of impact categories of each subsystem of Engine&Drivetrain System

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause the most impact of this third sub-system are: the differential (with a 6,91E-06 DALY of respiratory effects inorganics and 18,67 MJ surplus of fossil fuels) and the brake lines (with 0,73 PDF*m2yr of ecotoxicity).

4. Instruments&Wiring

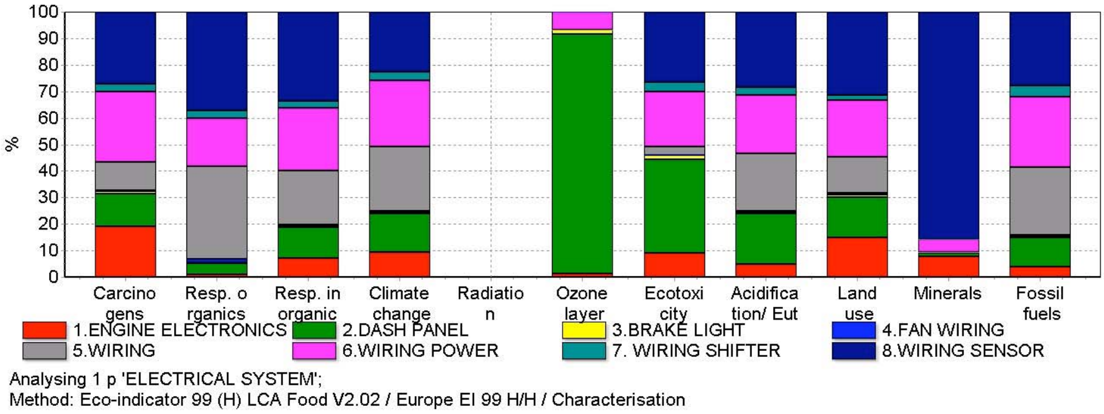


Image 24: Graphic of characterisation results of the Instruments&Wiring System

This graphic shows that there is no impact on radiation. It also shows that the “Dash panel” system has a big impact on the ozone layer. About Minerals, “Wiring sensor” is the component that influences the most. And that “Wiring power” and “Wiring” have a constant impact in almost all categories.

Impact category	Unit	Total	1.ENGINE ELECTRONICS	2.DASH PANEL	3.BRAKE LIGHT	4.FAN WIRING	5.WIRING	6.WIRING POWER	7. WIRING SHIFTER	8.WIRING SENSOR
Carcinogens	DALY	1,37E-006	2,60E-007	1,70E-007	9,90E-009	4,47E-009	1,48E-007	3,62E-007	3,99E-008	3,72E-007
Resp. organics	DALY	3,50E-007	2,91E-009	1,49E-008	1,52E-009	3,94E-009	1,23E-007	6,34E-008	1,01E-008	1,30E-007
Resp. inorganics	DALY	**5,70E-005**	4,00E-006	6,75E-006	2,84E-007	2,07E-007	1,15E-005	1,35E-005	1,47E-006	1,93E-005
Climate change	DALY	1,37E-005	1,27E-006	2,03E-006	7,47E-008	4,14E-008	3,32E-006	3,45E-006	4,27E-007	3,10E-006
Radiation	DALY	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000
Ozone layer	DALY	1,41E-008	1,91E-010	1,27E-008	2,36E-010	0,00E+000	0,00E+000	9,32E-010	8,10E-013	5,19E-012
Ecotoxicity	PAF*m2yr	**2,83E+000**	2,52E-001	9,99E-001	5,05E-002	9,46E-004	8,99E-002	5,81E-001	1,03E-001	7,52E-001
Acidif./ Eutroph.	PDF*m2yr	2,23E+000	1,05E-001	4,27E-001	1,46E-002	9,46E-003	4,85E-001	4,90E-001	6,21E-002	6,37E-001
Land use	PDF*m2yr	1,32E+000	1,96E-001	2,04E-001	1,21E-002	5,32E-003	1,83E-001	2,81E-001	2,65E-002	4,16E-001
Minerals	MJ surplus	2,14E+001	1,66E+000	3,09E-001	1,78E-002	5,35E-006	6,63E-004	1,04E+000	7,91E-003	1,84E+001
Fossil fuels	MJ surplus	**1,87E+002**	7,00E+000	2,06E+001	8,75E-001	1,28E+000	4,77E+001	4,97E+001	7,71E+000	5,23E+001

Table 5: Characterisation values of impact categories of each subsystem of Electrical System

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause more impact of the fourth sub-system are: the wiring sensor (with a 1,93E-05 DALY of respiratory effects inorganics and 5,23E+01 MJ surplus of fossil fuels) and the dash panel (with 9,99E-01 PDF*m2yr of ecotoxicity).

5. *Miscellaneous*

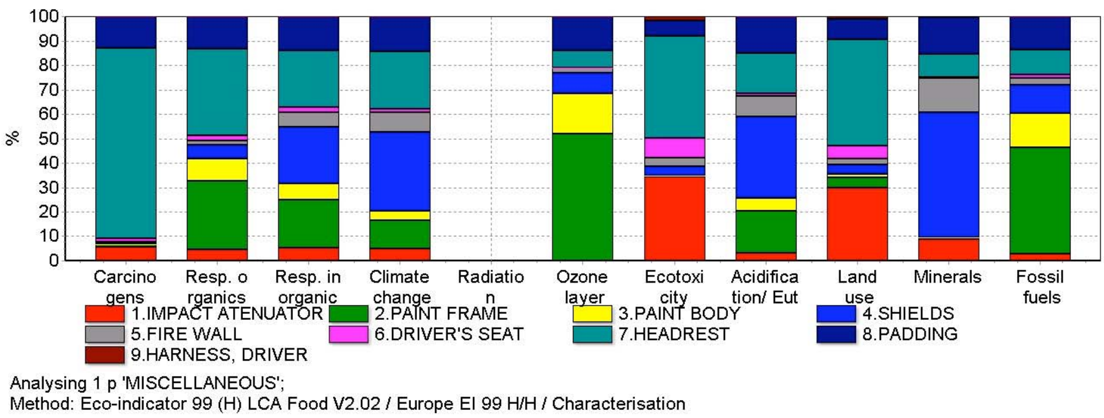


Image 25: Graphic of characterisation results of the Miscellaneous System

Impact category	Unit	Total	1.Impact atenuator	2.Paint frame	3.Paint body	4.Shields	5.Fire wall	6.Driver's seat	7.Headrest	8.Padding	9.Harness driver
Carcinogens	DALY	5,19E-006	2,88E-007	5,07E-008	1,63E-008	2,33E-008	2,74E-008	6,66E-008	4,05E-006	6,69E-007	3,04E-009
Resp. organics	DALY	4,08E-007	1,81E-008	1,15E-007	3,69E-008	2,36E-008	6,20E-009	9,71E-009	1,44E-007	5,41E-008	8,08E-011
Resp. inorganics	DALY	**4,58E-005**	2,36E-006	9,14E-006	2,93E-006	1,07E-005	2,63E-006	9,52E-007	1,07E-005	6,35E-006	5,06E-008
Climate change	DALY	1,07E-005	5,29E-007	1,24E-006	3,97E-007	3,49E-006	8,51E-007	1,54E-007	2,51E-006	1,54E-006	1,21E-008
Radiation	DALY	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000
Ozone layer	DALY	6,98E-007	6,51E-012	3,62E-007	1,16E-007	5,68E-008	1,48E-008	8,50E-013	5,08E-008	9,73E-008	2,01E-013
Ecotoxicity	PAF*m2yr	1,34E+000	4,63E-001	5,15E-004	1,65E-004	5,13E-002	5,10E-002	1,06E-001	5,62E-001	8,45E-002	2,13E-002
Acidif./ Eutroph.	PDF*m2yr	**3,32E+000**	1,03E-001	5,69E-001	1,82E-001	1,10E+000	2,81E-001	3,99E-002	5,46E-001	4,96E-001	2,15E-003
Land use	PDF*m2yr	3,51E-001	1,05E-001	1,50E-002	4,79E-003	1,27E-002	8,70E-003	1,86E-002	1,53E-001	2,94E-002	3,94E-003
Minerals	MJ surplus	9,31E-001	8,22E-002	5,77E-003	1,85E-003	4,74E-001	1,30E-001	4,90E-003	8,65E-002	1,41E-001	4,01E-003
Fossil fuels	MJ surplus	**4,30E+002**	1,16E+001	1,87E+002	6,00E+001	5,05E+001	1,25E+001	4,70E+000	4,46E+001	5,85E+001	4,47E-002

Table 6: Characterisation values of impact categories of each subsystem of Miscellaneous System

This graphic shows that there is no impact on radiation. It also shows that the “Paint frame” system has a big impact on the ozone layer and in Fossil fuels. About Minerals, “Shields” is the component that influences the most. And that carcinogens it is about a 80% caused by “Headrest”.

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, acidification/eutrophication has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

If we take the conclusions of these last two graphics together, the focus points that cause most impact of the fifth sub-system are: the headrest (with a 4,05E-06 DALY of carcinogens), shields (with a 1,1 PDF*m2yr of acidification/eutrophication) and paint frame (with a 1,87E+02 MJ surplus of fossil fuels).

6. Steering system

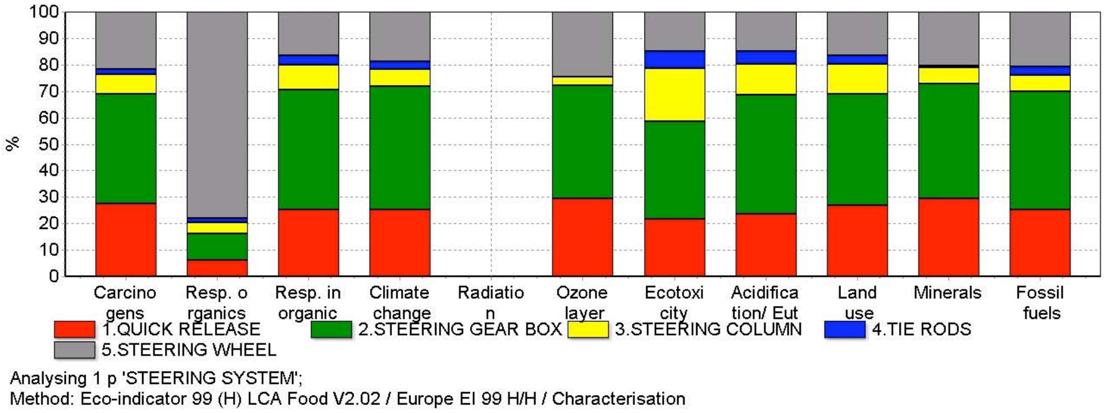


Image 26: Graphic of characterisation results of the Steering System

This graphic shows that there is no impact on radiation. It also shows that the "Steering wheel" system has the 80% of impact in respiratory effects organics. And "Steering box" has a constant impact in almost all categories.

Impact category	Unit	Total	1.Quick release	2.Steering gear box	3.Steering column	4.Tie rods	5.Steering wheel
Carcinogens	DALY	1,98E-006	5,48E-007	8,17E-007	1,49E-007	3,75E-008	4,32E-007
Resp. organics	DALY	7,49E-008	4,66E-009	7,55E-009	3,12E-009	1,19E-009	5,84E-008
Resp. inorganics	DALY	**2,57E-005**	6,48E-006	1,17E-005	2,34E-006	9,33E-007	4,24E-006
Climate change	DALY	9,50E-006	2,40E-006	4,41E-006	6,17E-007	2,89E-007	1,78E-006
Radiation	DALY	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000
Ozone layer	DALY	1,28E-009	3,78E-010	5,49E-010	3,85E-011	2,43E-012	3,15E-010
Ecotoxicity	PAF*m2yr	**3,97E+000**	8,65E-001	1,46E+000	7,92E-001	2,60E-001	5,88E-001
Acidification/ Eutrop	PDF*m2yr	7,72E-001	1,81E-001	3,49E-001	8,98E-002	3,77E-002	1,14E-001
Land use	PDF*m2yr	1,51E+000	4,07E-001	6,32E-001	1,69E-001	4,75E-002	2,51E-001
Minerals	MJ surplus	6,18E+000	1,82E+000	2,68E+000	3,69E-001	4,85E-002	1,26E+000
Fossil fuels	MJ surplus	**3,83E+001**	9,69E+000	1,71E+001	2,36E+000	1,15E+000	7,98E+000

Table 7: Characterisation values of impact categories of each subsystem of Steering System

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause the most impact of the sixth sub-system are: steering wheel (with a 4,24E-06 DALY of respiratory effects inorganics), steering gear box (with a 1,46 PDF*m2yr of ecotoxicity and with a

1,71E+01 MJ surplus of fossil fuels).

7. Suspension

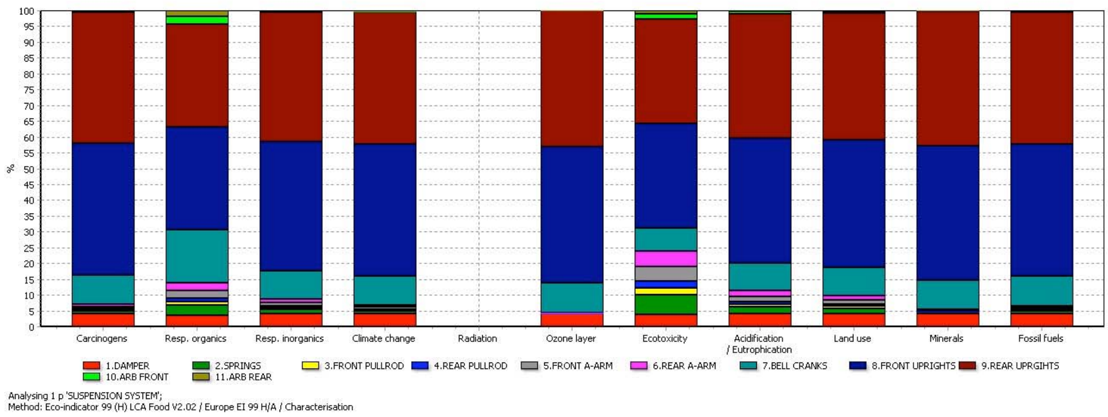


Image 27: Graphic of characterisation results of the Suspension System

This graphic shows that there is no impact on radiation. It also shows that the “Front uprights” and “Rear uprights” have a big impact in all the categories.

Impact category	Unit	Total	1.Damper	2.Springs	3.Front pullrod	4.Rear pullrod	5.Front a-arm
Carcinogens	DALY	8,15E-006	3,29E-007	7,60E-008	2,68E-008	2,64E-008	5,96E-008
Resp. organics	DALY	6,35E-008	2,21E-009	2,02E-009	7,05E-010	7,02E-010	1,58E-009
Resp. inorganics	DALY	**9,22E-005**	3,75E-006	1,27E-006	4,43E-007	4,40E-007	9,91E-007
Climate change	DALY	3,59E-005	1,46E-006	3,03E-007	1,07E-007	1,05E-007	2,38E-007
Radiation	DALY	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000
Ozone layer	DALY	6,12E-009	2,47E-010	5,03E-012	2,13E-012	1,75E-012	3,99E-012
Ecotoxicity	PAF*m2yr	**8,75E+000**	3,43E-001	5,33E-001	1,86E-001	1,85E-001	4,17E-001
Acidification/ Eutrop	PDF*m2yr	2,41E+000	9,68E-002	5,38E-002	1,88E-002	1,87E-002	4,21E-002
Land use	PDF*m2yr	5,59E+000	2,27E-001	9,84E-002	3,44E-002	3,42E-002	7,71E-002
Minerals	MJ surplus	2,83E+001	1,17E+000	1,00E-001	3,49E-002	3,49E-002	7,86E-002
Fossil fuels	MJ surplus	**1,47E+002**	5,93E+000	1,12E+000	3,95E-001	3,89E-001	8,77E-001

6.Rear a-arm	7.Bell cranks	8.Front uprights	9.Rear uprights	10.Arb front	11.Arb rear
5,96E-008	7,47E-007	3,39E-006	3,39E-006	2,18E-008	1,25E-008
1,58E-009	1,06E-008	2,06E-008	2,06E-008	1,51E-009	1,26E-009
9,91E-007	8,39E-006	3,77E-005	3,77E-005	3,72E-007	2,16E-007
2,38E-007	3,32E-006	1,50E-005	1,50E-005	8,80E-008	5,07E-008
0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000	0,00E+000
3,99E-012	5,77E-010	2,64E-009	2,64E-009	1,44E-012	8,20E-013
4,17E-001	6,45E-001	2,89E+000	2,89E+000	1,52E-001	8,69E-002
4,21E-002	2,12E-001	9,51E-001	9,51E-001	1,58E-002	9,18E-003
7,71E-002	4,99E-001	2,25E+000	2,25E+000	2,83E-002	1,62E-002
7,86E-002	2,67E+000	1,20E+001	1,20E+001	2,87E-002	1,64E-002
8,77E-001	1,38E+001	6,15E+001	6,15E+001	3,70E-001	2,32E-001

Table 8: Characterisation values of impact categories of each subsystem of Suspension System

In this table it can be seen that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause the most impact of the seventh sub-system are: Front uprights and Rear uprights.

8. Wheels&Tires

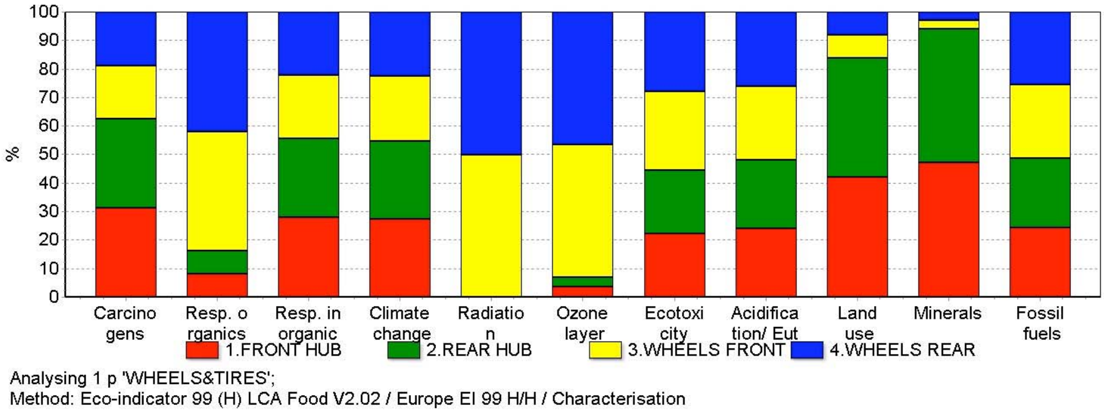


Image 28: Graphic of characterisation results of the Wheels&Tires System

This graphic shows on one hand that radiation, ozone layer and respiratory effects organic are mainly caused by “Wheels front” and “Wheels rear” (which incorporate the material EPDM rubber ETH S). On the other hand it shows that Land use and minerals are mainly affected by the components of the “Front hub” and the “Rear hub”. All the categories have a proportionate and constant impact of all the parts that compose the wheel&tires system.

Impact category	Unit	Total	1.FRONT HUB	2.REAR HUB	3.WHEELS FRONT	4.WHEELS REAR
Carcinogens	DALY	1,12E-005	3,52E-006	3,50E-006	2,11E-006	2,11E-006
Resp. organics	DALY	2,82E-007	2,29E-008	2,28E-008	1,18E-007	1,18E-007
Resp. inorganics	DALY	**1,42E-004**	3,96E-005	3,94E-005	3,17E-005	3,17E-005
Climate change	DALY	5,67E-005	1,56E-005	1,55E-005	1,28E-005	1,28E-005
Radiation	DALY	2,89E-007	0,00E+000	0,00E+000	1,45E-007	1,45E-007
Ozone layer	DALY	7,62E-008	2,67E-009	2,66E-009	3,54E-008	3,54E-008
Ecotoxicity	PAF*m2yr	**1,55E+001**	3,44E+000	3,43E+000	4,32E+000	4,32E+000
Acidification/ Eutrop	PDF*m2yr	4,24E+000	1,02E+000	1,01E+000	1,10E+000	1,10E+000
Land use	PDF*m2yr	5,70E+000	2,39E+000	2,38E+000	4,65E-001	4,65E-001
Minerals	MJ surplus	2,63E+001	1,24E+001	1,24E+001	7,77E-001	7,77E-001
Fossil fuels	MJ surplus	**2,60E+002**	6,33E+001	6,31E+001	6,67E+001	6,67E+001

Table 9: Characterisation values of impact categories of each subsystem of Wheels&Tires

This table shows that in the first group of Human Health, respiratory effects inorganics have also the highest value of DALY. About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr. And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus.

Taking together the conclusions of these last two graphics, the focus points that cause more impact in the eight sub-system are not that clear. This is because the third category detected in table 9 with more impact (resp. Inorganic, ecotoxicity and fossil fuels) are generated by the four parts of the system with the same contribution. There are two options: to focus on wheels (who impact in radiation and ozone layer with a total of 3,60E-07 DALY) or to focus on hub (that impacts on land use with a 4,77 PDF*m2yr and minerals with a 2,48E+01 MJ surplus).

Total:

Impact category	Unit	Total	Frame&Body	Brakes	Engine	Electrical	Miscel.	Steering	Suspension	Wheels
Carcinogens	DALY	1,65E-004	2,81E-006	8,04E-007	1,34E-004	1,37E-006	5,19E-006	1,98E-006	8,15E-006	1,12E-005
Resp. organics	DALY	2,64E-006	1,19E-007	1,14E-008	1,33E-006	3,50E-007	4,08E-007	7,49E-008	6,35E-008	2,82E-007
Resp. inorganics	DALY	**2,05E-003**	6,78E-005	1,65E-005	**1,60E-003**	5,70E-005	4,58E-005	2,57E-005	9,22E-005	1,42E-004
Climate change	DALY	7,62E-004	1,90E-005	7,10E-006	6,10E-004	1,37E-005	1,07E-005	9,50E-006	3,59E-005	5,67E-005
Radiation	DALY	8,85E-007	4,17E-009	1,18E-009	5,90E-007	0,00E+000	0,00E+000	0,00E+000	0,00E+000	2,89E-007
Ozone layer	DALY	1,14E-006	1,38E-007	9,85E-010	2,05E-007	1,41E-008	6,98E-007	1,28E-009	6,12E-009	7,62E-008
Ecotoxicity	PAF*m2yr	**2,31E+002**	**1,78E+001**	1,63E+000	**1,79E+002**	2,83E+000	1,34E+000	3,97E+000	8,75E+000	1,55E+001
Acidif./ Eutroph.	PDF*m2yr	6,21E+001	4,36E+000	5,53E-001	4,42E+001	2,23E+000	3,32E+000	7,72E-001	2,41E+000	4,24E+000
Land use	PDF*m2yr	1,11E+002	3,26E+000	7,80E-001	9,30E+001	1,32E+000	3,51E-001	1,51E+000	5,59E+000	5,70E+000
Minerals	MJ surplus	5,61E+002	4,41E+000	2,72E+000	4,71E+002	2,14E+001	9,31E-001	6,18E+000	2,83E+001	2,63E+001
Fossil fuels	MJ surplus	**3,85E+003**	1,61E+002	3,41E+001	**2,59E+003**	1,87E+002	**4,30E+002**	3,83E+001	1,47E+002	2,60E+002

Table 10: Characterisation values of impact categories of the total car

After analysing all the characterisation results of each sub-system of the car, a table has been made of all sub-systems together and the most impact results as logic are: for the group of Human Health, respiratory effects inorganics have the highest value of DALY (the sub-system with a highest contribution is the engine&drivetrain). About the second group, Ecosystem Quality, ecotoxicity has the highest value of PDF*m2yr (the sub-system with a highest contribution is the engine&drivetrain). And regarding the third group, resources, fossil fuels has the highest impact of MJ surplus (the sub-system with a highest contribution is the engine&drivetrain). These results are logic because the system Engine & Drivetrain is the one with most components and materials.

In spite of having some conclusions after this first methodology of the analysis, as it has been said before, the results in the characterisation are not normalised. For this reason, if the analysis stops here and the projector starts to think in possible improvements, it can be a mistake because the focus points with the most impact can be changed after a normalisation procedure.

5.3.3. Normalisation

As it has been said in the part 3.4.3, normalisation is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is done by dividing the impact category indicators by a “Normal” value. There are different ways to determine the “Normal” value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result the number of inhabitants in that area. In this case, the normal value is calculated by the SimaPro program.

1. Frame&Body System:

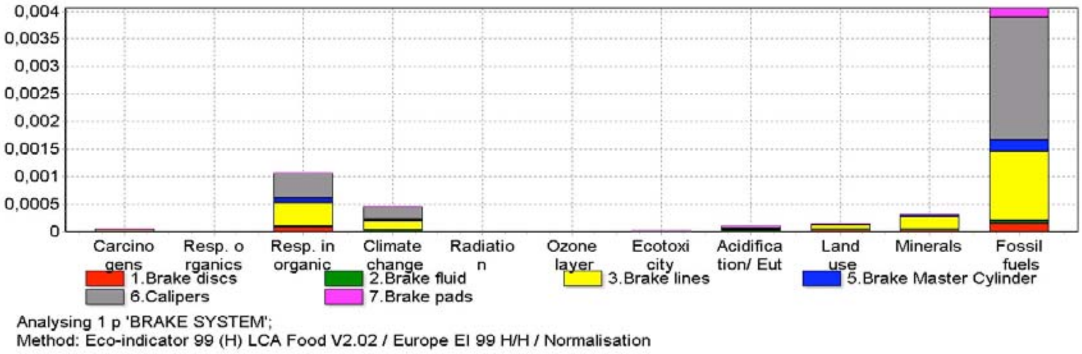


Image 29: Graphic of normalisation results of the Frame&Body System

When the normalisation is done the real importance of the impact can be evaluated and compared. In this case, the figure shows that the highest impact of the Frame&Body System is on “Fossil Fuels”, the second one is on “Respiratory effects (organic)” and the third one on “Climate change”.

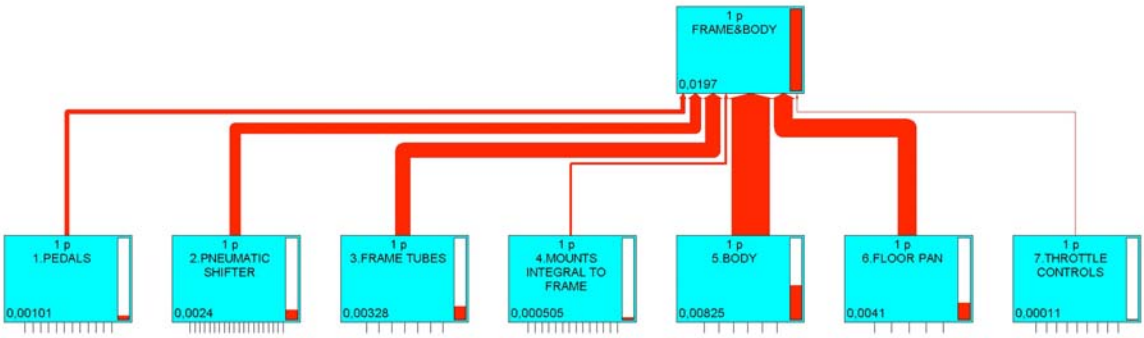


Image 30: Process contribution tree of the Frame&Body system

The process contribution tree is representing the normalised contribution in Resources (Minerals and Fossil Fuels).

No	Process	Unit	Total	5.Body
	Total of all processes	-	1,97E-002	8,25E-003
1	Carbon fibre I	-	1,38E-002	8,13E-003
2	Crude oil I	-	2,42E-003	1,93E-005
3	Steel I	-	8,52E-004	6,80E-006
4	Polycarbonate E	-	5,00E-004	x
5	Electricity UCPTE gas I	-	4,59E-004	1,88E-006
6	Diesel I	-	3,69E-004	2,99E-006
7	Aluminium ingots I	-	3,67E-004	x
8	Energy Africa I	-	2,69E-004	2,16E-006
9	Polyurethane rigid foam E	-	1,77E-004	8,06E-005
10	Energy Australia I	-	1,00E-004	8,01E-007
11	Energy US I	-	7,05E-005	6,99E-007
12	Electricity UCPTE oil I	-	6,67E-005	1,91E-007
13	Electricity UCPTE coal I	-	5,84E-005	1,54E-007
14	Copper I	-	3,96E-005	x
15	Paint ETH S	-	3,43E-005	x
16	Scrap (iron) I	-	2,64E-005	2,11E-007
17	Scrap (alum.) I	-	1,58E-005	x
18	Lead I	-	1,53E-005	7,27E-007
19	Manganese I	-	1,27E-005	1,02E-007
20	Aluminium rec. I	-	1,24E-005	x

Table 11: Top 20 process contribution in resources of Frame&Body System

This figure shows the 20 first processes/materials that have a highest impact on Frame&Body system and also on the subsystem Body, because according to the figure X, Body is the subsystem with most contribution in Fossil Fuels and in Minerals, with a 42% of the total impact of Frame&Body.

2. Brakes system:

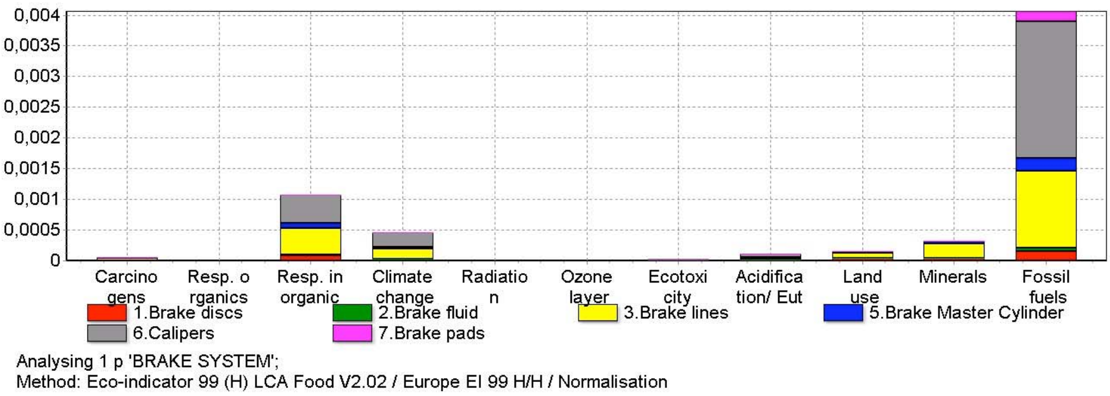


Image 31: Graphic of normalisation results of the Brakes System

In this case, the figure shows that the highest impact of the Brakes System is on "Fossil Fuels", the second one is on "Respiratory effects (organic)" and the third one is on "Climate change".

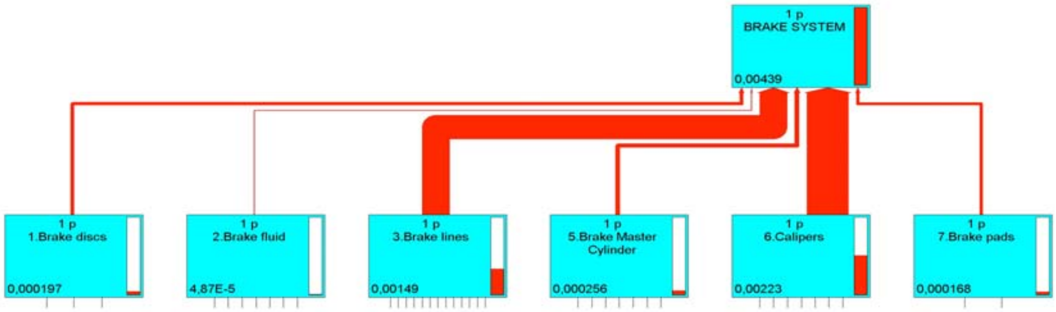


Image 32: Process contribution tree of the Brakes system

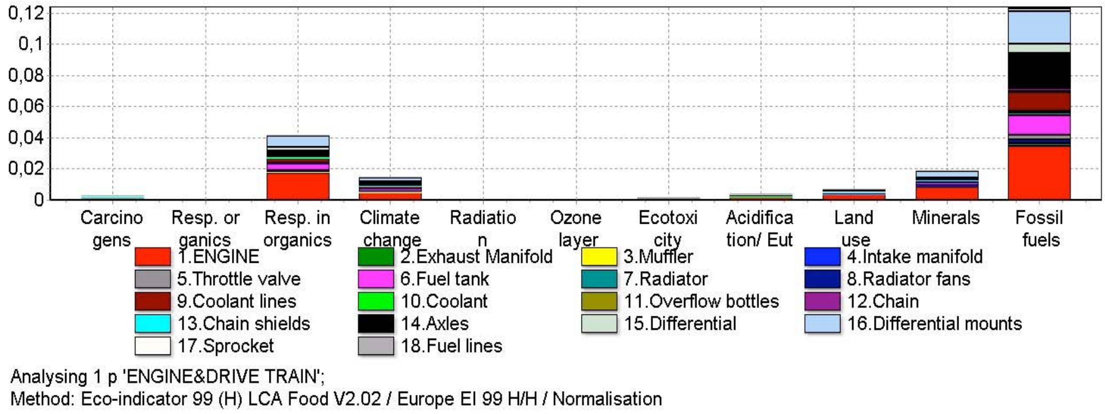
The process contribution tree is representing the normalised contribution of Resources (Minerals and Fossil Fuels).

No	Process	Unit	Total	6.Calipers
	Total of all processes	-	4,39E-003	2,23E-003
1	Energy US I	-	2,17E-003	**2,13E-003**
2	Aluminium ingots I	-	1,20E-003	4,77E-005
3	Natural gas I	-	2,04E-004	1,69E-006
4	Electricity UCPTE gas I	-	1,97E-004	7,20E-006
5	Crude oil I	-	1,57E-004	2,64E-005
6	Electricity UCPTE oil I	-	8,65E-005	3,37E-006
7	Electricity UCPTE coal I	-	8,49E-005	3,31E-006
8	Scrap (alum.) I	-	5,06E-005	8,50E-007
9	Steel I	-	4,69E-005	1,01E-006
10	Aluminium rec. I	-	3,97E-005	6,67E-007
11	Diesel I	-	3,65E-005	7,51E-006
12	Chemicals inorganic	-	3,65E-005	x
13	Molybdenum I	-	3,20E-005	x
14	Energy Africa I	-	1,60E-005	3,18E-007
15	ABS I	-	1,37E-005	x
16	Energy Australia I	-	5,52E-006	1,19E-007
17	Electricity UCPTE nuclear I	-	4,20E-006	1,66E-007
18	Electricity UCPTE hydro I	-	2,25E-006	8,92E-008
19	Carbon fibre I	-	1,51E-006	x
20	Scrap (iron) I	-	1,45E-006	3,15E-008

Table 12: Top 20 process contribution in resources of Brakes System

This figure shows the 20 first processes/materials that have a highest impact on Brakes system and also on the subsystem Calipers, because according to the figure 32 Calipers is the subsystem with the most contribution in Fossil Fuels and in Minerals. They also contribute 51% of the total impact caused by the Brakes system.

Image 33: Graphic of normalisation results of the Engine&Drivetrain System



3. Engine&Drivetrain system:

In the case of Engine&Drivetrain system, the figure shows that the highest impact is also on “Fossil Fuels”, the second one is on “Respiratory effects (organics)” and the third one on “Minerals”.

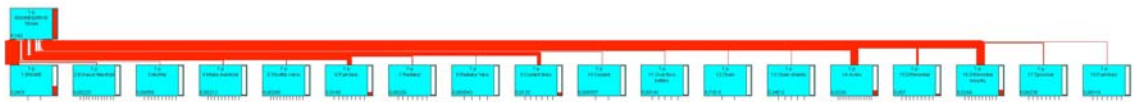


Image 34: Process contribution tree of the Engine system

The process contribution tree is representing the normalised contribution of Resources (Minerals and Fossil Fuels).

When normalisation procedure is done, the block of “Resources” is the one with the highest impact. Making a list of process contribution is important to know which processes and materials impact the most.

No	Process	Unit	Total Engine&Drivetrain	1.ENGINE
	Total of all processes	norm	1,43E-001	4,31E-002
1	Aluminium ingots I	norm	5,75E-002	1,68E-002
2	Energy US I	norm	2,20E-002	3,43E-004
3	Electricity UCPTE gas I	norm	1,32E-002	3,03E-003
4	Crude oil I	norm	9,65E-003	7,85E-003
5	EPDM rubber ETH S	norm	8,87E-003	x
6	Electricity UCPTE oil I	norm	4,51E-003	1,23E-003
7	Electricity UCPTE coal I	norm	4,36E-003	1,21E-003
8	Copper I	norm	4,14E-003	3,79E-003
9	Steel I	norm	3,03E-003	2,75E-003
10	Scrap (alum.) I	norm	2,52E-003	7,74E-004
11	Diesel I	norm	2,08E-003	1,37E-003
12	Aluminium rec. I	norm	1,98E-003	6,08E-004
13	Natural gas I	norm	1,63E-003	4,75E-004
14	Energy Africa I	norm	1,09E-003	9,95E-004
15	Chemicals organic	norm	1,06E-003	x
16	HDPE ETH S	norm	8,42E-004	x
17	Carbon fibre I	norm	5,74E-004	x
18	Electricity (natural gas)	norm	5,46E-004	x
19	Scrap (copper) I	norm	4,53E-004	4,14E-004
20	Lead I	norm	3,72E-004	2,94E-004

Table 13: Top 20 process contribution in resources of Engine&Drivetrain System

This figure shows the 20 first processes/materials that have the highest impact on Engine&Drivetrain system and also on the subsystem Engine, because according to the figure 34 the engine is the subsystem with most contribution in Fossil Fuels and in Minerals.

4. Instruments&Wiring

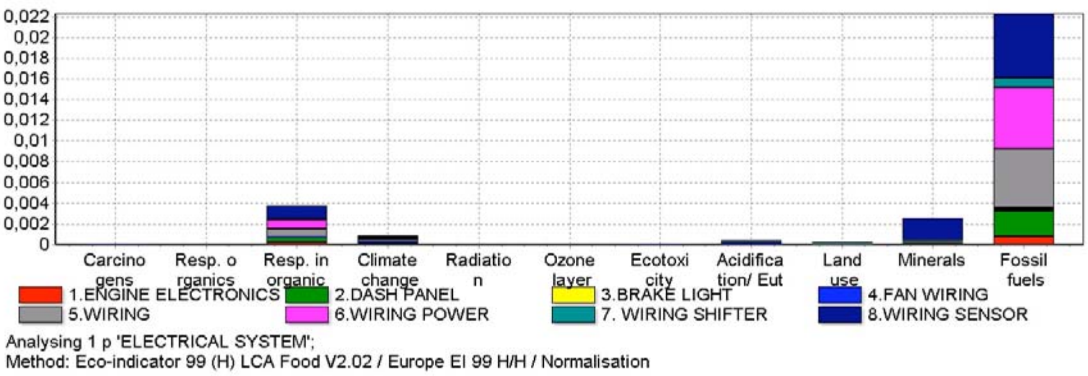


Image 35: Graphic of normalisation results of the Electrical System

In the case of Instruments&Wiring system (also known as Electrical system), the figure shows that the highest impact is also on “Fossil Fuels”, the second one is on “Respiratory effects organics” and the third one on “Minerals”.

Process contribution tree of the Electrical system. Representing the normalised contribution of Resources (Minerals and Fossil Fuels).

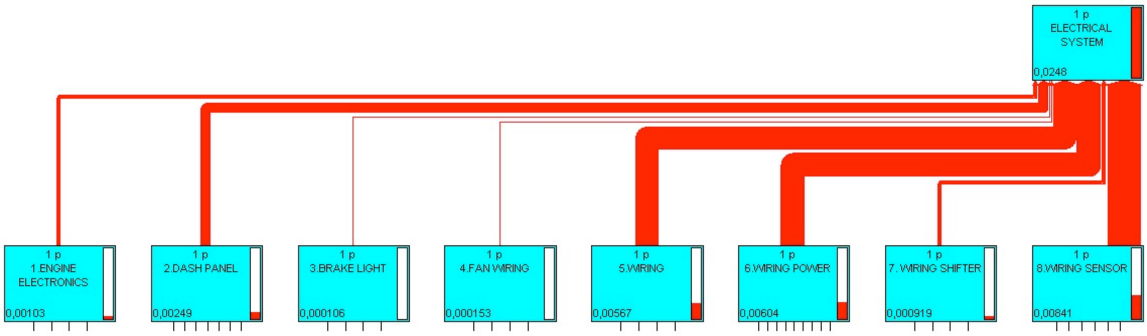


Image 36: Process contribution tree of the Electrical System

When normalisation procedure is done, the block of “Resources” is the one with the highest impact. Making a list of process contribution is important to know which processes and materials impact the most.

No	Process	Unit	Total	8.Wiring sensor
	Total of all processes	-	2,48E-002	8,41E-003
1	PS (EPS) I	-	7,63E-003	2,85E-003
2	PC I	-	5,44E-003	8,87E-004
3	PE (LLDPE) I	-	4,07E-003	5,95E-004
4	Carbon fibre I	-	1,30E-003	x
5	Copper I	-	1,29E-003	1,11E-003
6	Tin I	-	1,12E-003	1,12E-003
7	PB I	-	1,08E-003	1,05E-003
8	PE (LDPE) I	-	9,62E-004	4,34E-004
9	Aluminium ingots I	-	7,66E-004	7,36E-006
10	Crude oil I	-	1,91E-004	4,29E-005
11	Scrap (copper) I	-	1,41E-004	1,22E-004
12	Electricity UCPTE gas I	-	1,22E-004	4,18E-006
13	PS (GPPS) I	-	1,06E-004	x
14	Scrap (Sn) I	-	9,90E-005	9,90E-005
15	Steel I	-	6,26E-005	1,10E-005
16	PE expanded I	-	6,13E-005	2,76E-005
17	Electricity UCPTE oil I	-	5,47E-005	8,30E-007
18	Electricity UCPTE coal I	-	5,37E-005	7,62E-007
19	Crude oil N-sea(a) I	-	5,00E-005	x
20	Diesel I	-	4,21E-005	1,23E-005

Table 14: Top 20 process contribution in resources of Instruments&wiring System

This figure shows the 20 first processes/materials that have a highest impact on Electrical system and also on the subsystem Wiring sensor, because according to the figure X wiring sensor is the subsystem with more contribution in Fossil Fuels and in Minerals, with a 34% of the total impact of the system.

5. Miscellaneous

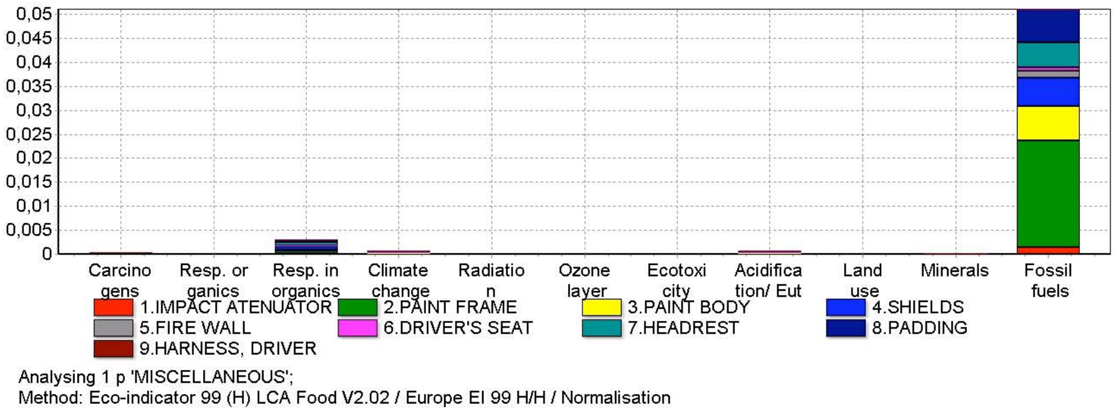


Image 37: Graphic of normalisation results of the Miscellaneous System

In this case, the figure shows that the highest impact of the Miscellaneous System is on "Fossil Fuels", the second one is on "Respiratory effects organics" and the third one on "Climate change".

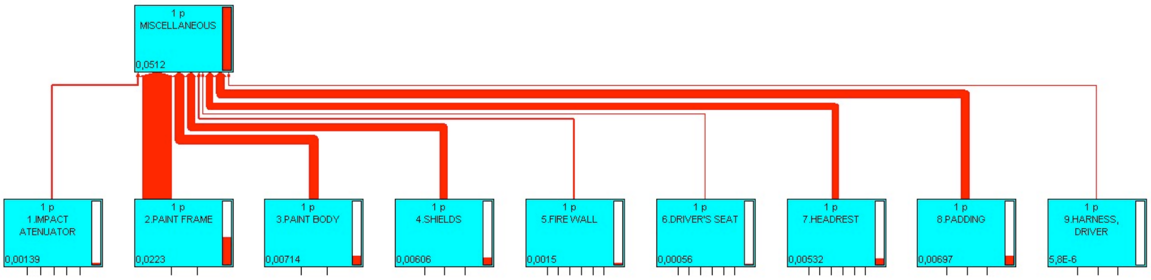


Image 38: Process contribution tree of the Miscellaneous System

Process contribution tree of the Miscellaneous system. Representing the normalised contribution of Resources (Minerals and Fossil Fuels).

No	Process	Unit	Total	2.Paint frame
	Total of all processes	-	5,12E-002	2,23E-002
1	Crude oil N-sea(a) I	-	3,69E-002	2,23E-002
2	Carbon fibre I	-	9,83E-003	x
3	Natural gas I	-	1,31E-003	x
4	Crude oil I	-	9,44E-004	x
5	Crude oil N-sea(b) I	-	7,85E-004	x
6	PB I	-	4,07E-004	x
7	PMMA I	-	3,71E-004	x
8	Epichlorohydrin I	-	1,72E-004	x
9	PVC I	-	1,42E-004	x
10	Electricity UCPTE gas I	-	9,91E-005	x
11	Pentane blowing agent I	-	8,73E-005	x
12	Bisphenol A I	-	5,83E-005	x
13	Steel I	-	2,92E-005	x
14	Crude coal I	-	2,21E-005	x
15	Diesel I	-	2,00E-005	x
16	Glass fibre I	-	1,44E-005	x
17	Electricity UCPTE oil I	-	1,00E-005	x
18	Energy Africa I	-	9,27E-006	x
19	Electricity UCPTE coal I	-	8,08E-006	x
20	Energy Australia I	-	3,49E-006	x

Table 15: Top 20 process contribution in resources of Miscellaneous System

This figure shows the 20 first processes/materials that have a highest impact on Miscellaneous system and also on the subsystem Paint frame, because according to the figure 38 paint frame is the subsystem with most contribution in Fossil Fuels and in Minerals and has a contribution of 44% of the total impact of system.

6. Steering system

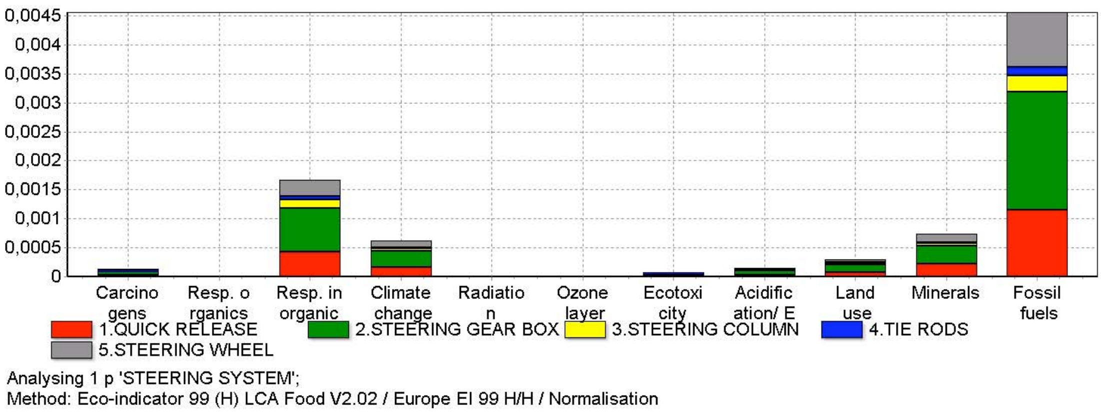


Image 39: Graphic of normalisation results of the Steering System

In this case, the figure shows that the highest impact of the Steering System is on “Fossil

Fuels", the second one is on "Respiratory effects (organic)" and the third one on "Minerals".

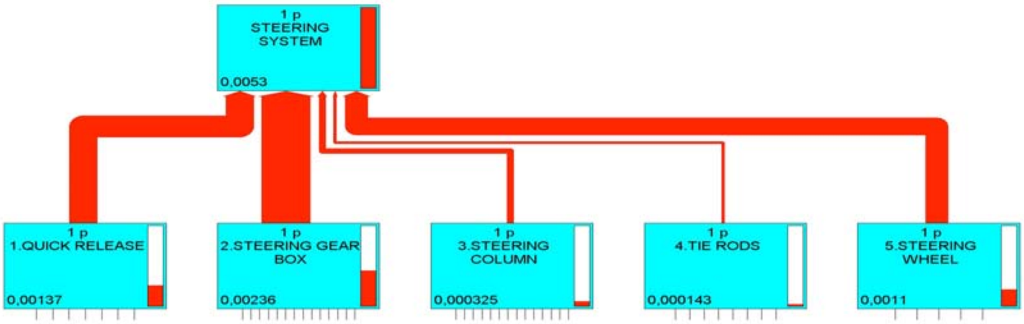


Image 40: Process contribution tree of the Steering system

It represents the normalised contribution of Resources (Minerals and Fossil Fuels).

No	Process	Unit	Total	2.Steering gear box
	Total of all processes	-	2,42E-003	1,10E-003
1	Aluminium ingots I	-	9,88E-004	4,40E-004
2	Electricity UCPTE coal I	-	5,49E-004	2,37E-004
3	Bulk carrier I	-	2,44E-004	8,66E-005
4	Steel I	-	1,78E-004	6,35E-005
5	Magnesium I	-	1,69E-004	1,68E-004
6	Electricity UCPTE gas I	-	7,12E-005	2,71E-005
7	Electricity UCPTE oil I	-	6,13E-005	2,63E-005
8	Aluminium rec. I	-	4,88E-005	2,16E-005
9	PA 6 GF30 I	-	3,60E-005	5,71E-006
10	Leather I	-	1,01E-005	x
11	Energy Australia I	-	8,75E-006	3,11E-006
12	Energy Africa I	-	7,87E-006	2,83E-006
13	Crude oil I	-	7,74E-006	2,73E-006
14	Trailer I	-	5,81E-006	3,02E-006
15	Copper I	-	5,49E-006	x
16	Electricity UCPTE hydro I	-	3,94E-006	1,75E-006
17	Polyether-polyols I	-	3,93E-006	x
18	Energy US I	-	3,78E-006	1,37E-006
19	Electricity UCPTE nuclear I	-	3,72E-006	1,64E-006
20	Diesel I	-	3,34E-006	1,66E-006

Table 16: Top 20 process contribution in resources of Steering System

This figure shows the 20 first processes/materials that have a highest impact on Steering system and also on the subsystem steering gear box, because according to the figure 40 steering gear box is the subsystem with most contribution in Fossil Fuels and in Minerals. It also has a contribution 54% of the total impact of system.

7. Suspension

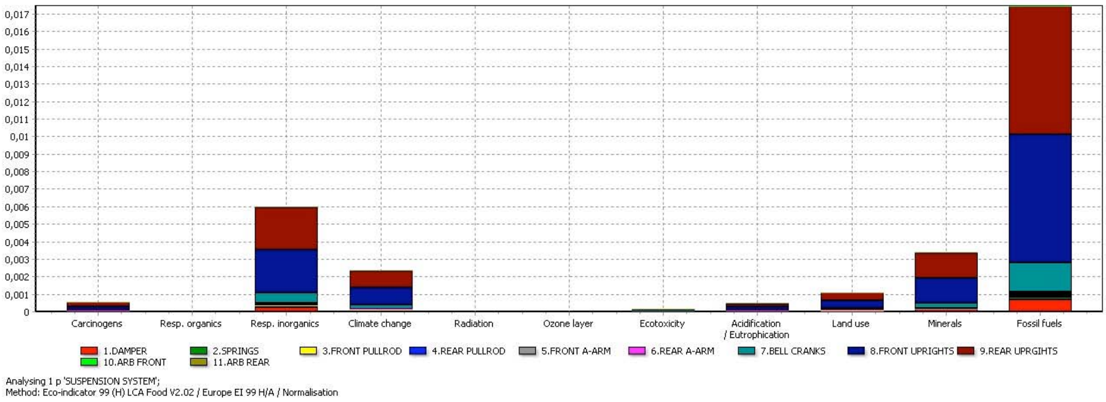


Image 41: Graphic of normalisation results of the Suspension System

In this case, the figure shows that the highest impact of the Suspension System is on “Fossil Fuels”, the second one is on “Respiratory effects (organic)” and the third one on “Minerals”.

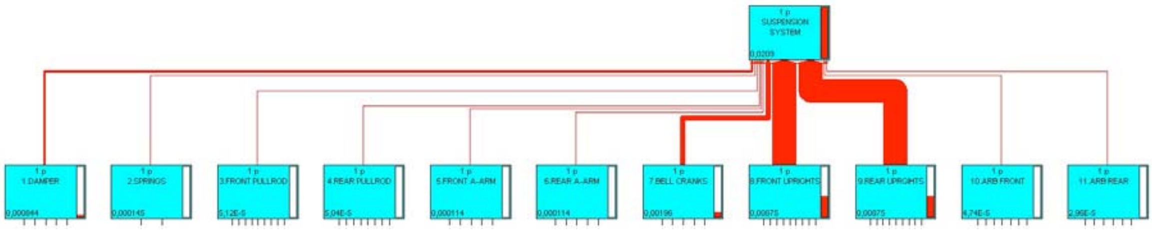


Image 42: Process contribution tree of the Suspension system

It represents the normalised contribution of Resources (Minerals and Fossil Fuels).

The following figure shows the 20 first processes/materials that have a highest impact on Suspension system and also on the subsystem front/rear uprights , because according to the figure 42 front/rear uprights are the subsystem with the most contribution in Fossil Fuels and in Minerals and each one has with a 42% an impact on the system.

No	Process	Unit	Total	8.Front uprights/ 9.Rear uprights
	Total of all processes	-	2,09E-002	8,75E-003
1	Aluminium ingots I	-	1,43E-002	6,18E-003
2	Electricity UCPTE gas I	-	2,20E-003	9,47E-004
3	Electricity UCPTE oil I	-	1,01E-003	4,38E-004
4	Electricity UCPTE coal I	-	9,98E-004	4,30E-004
5	Scrap (alum.) I	-	6,15E-004	2,66E-004
6	Aluminium rec. I	-	4,83E-004	2,09E-004
7	Natural gas I	-	4,05E-004	1,75E-004
8	Crude oil I	-	3,11E-004	6,00E-006
9	Diesel I	-	1,42E-004	4,16E-005
10	Steel I	-	1,10E-004	2,04E-006
11	Electricity UCPTE nuclear I	-	4,98E-005	2,15E-005
12	PE (LDPE) I	-	4,72E-005	x
13	Energy Africa I	-	3,43E-005	4,31E-007
14	Crude oil N-sea(b) I	-	3,14E-005	1,57E-005
15	Electricity UCPTE hydro I	-	2,68E-005	1,16E-005
16	Energy Australia I	-	1,29E-005	2,40E-007
17	Lead I	-	1,15E-005	1,45E-007
18	Energy US I	-	1,11E-005	1,39E-007
19	Epichlorohydrin I	-	6,89E-006	3,44E-006
20	Scrap (Pb) I	-	5,66E-006	7,11E-008

Table 17: Top 20 process contribution in resources of Suspension System

8. Wheels&Tires

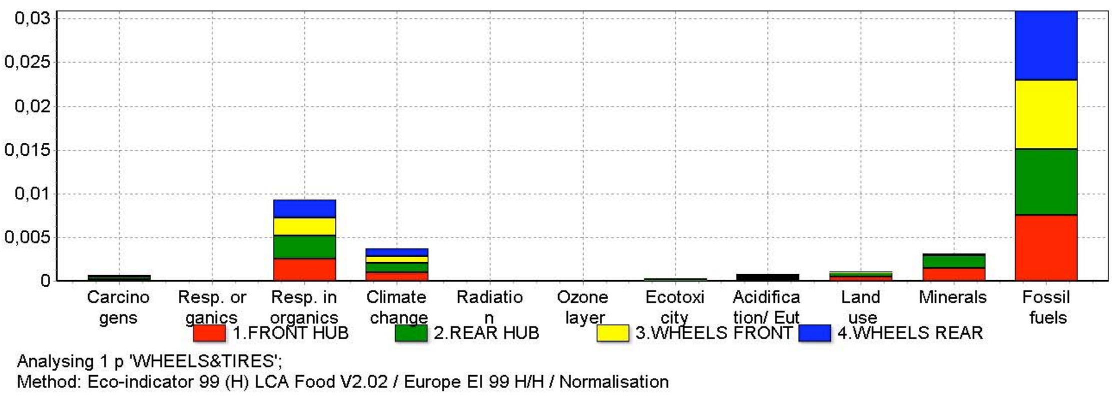


Image 43: Graphic of normalisation results of the Wheels&Tires System

In this case, the figure shows that the highest impact of the Wheels&Tires System is on “Fossil Fuels”, the second one is on “Respiratory effects organics” and the third one on “Climate change”.

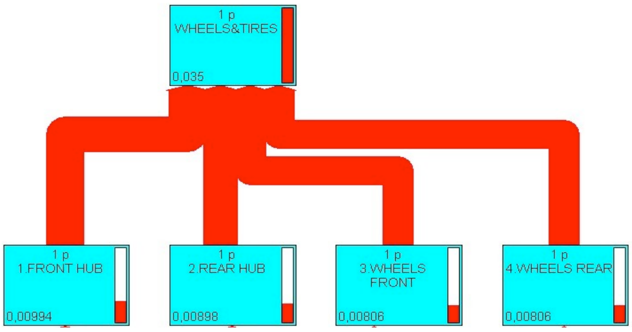


Image 44: Process contribution tree of the Wheels&Tires System

No	Process	Unit	Total	1.FRONT HUB
	Total of all processes	-	3,50E-002	9,94E-003
1	Aluminium ingots I	-	1,24E-002	5,94E-003
2	Magnesium I	-	7,93E-003	5,26E-005
3	EPDM rubber ETH S	-	7,31E-003	x
4	Electricity UCPTE gas I	-	1,86E-003	8,80E-004
5	Copper I	-	1,17E-003	1,17E-003
6	Electricity UCPTE oil I	-	8,76E-004	4,17E-004
7	Electricity UCPTE coal I	-	8,63E-004	4,11E-004
8	Diesel I	-	5,77E-004	6,60E-005
9	Scrap (alum.) I	-	5,42E-004	2,72E-004
10	Aluminium rec. I	-	4,26E-004	2,13E-004
11	Natural gas I	-	3,52E-004	1,68E-004
12	Crude oil I	-	2,36E-004	9,24E-005
13	Scrap (copper) I	-	1,27E-004	1,27E-004
14	Steel I	-	7,72E-005	2,81E-005
15	Energy Africa I	-	7,21E-005	4,59E-005
16	Electricity UCPTE nuclear I	-	4,32E-005	2,06E-005
17	Energy US I	-	3,22E-005	2,13E-005
18	Zinc I	-	2,91E-005	x
19	Electricity UCPTE hydro I	-	2,33E-005	1,11E-005
20	Crude oil production onshore U	-	1,92E-005	x

Table 18: Top 20 process contribution in resources of Wheels&tires System

This figure shows the 20 first processes/materials that have a highest impact on Wheels&tires system and also on the subsystem front hub , because according to the figure 44 front/rear hub is the subsystem with the most contribution in Fossil Fuels and in Minerals and has 28% of the total impact of the system.

Total:

When the normalisation procedure is finished, it is seen that the group "Fossil fuels" has a bigger magnitude than all the others categories. This is an important tool if the project has to focus only in one category depends on the block (Human Health, Ecosystem Quality, Resources).

The list bellow shows the 20 first processes that have a bigger contribution in resources impact of all the car. It is a summary of all the tables that where shown before. The first material on the list of impact is aluminium and the second is carbon fibre.

No	**Process**	**Total Car**
1	Aluminium ingots I	8,76E-002
2	Carbon fibre I	2,55E-002
3	Energy US I	2,43E-002
4	Electricity UCPTE gas I	1,82E-002
5	Crude oil I	1,39E-002
6	EPDM rubber ETH S	8,87E-003
7	Magnesium I	8,10E-003
8	PS (EPS) I	7,63E-003
9	PS (EPS) I	7,63E-003
10	Electricity UCPTE coal I	6,98E-003
11	Electricity UCPTE oil I	6,68E-003
12	Copper I	6,64E-003
13	PC I	5,44E-003
14	Steel I	4,39E-003
15	PE (LLDPE) I	4,07E-003
16	Natural gas I	3,90E-003
17	Scrap (alum.) I	3,75E-003
18	Diesel I	3,27E-003
19	Aluminium rec. I	2,99E-003
20	Energy Africa I	1,50E-003

Table 19: Top 20 process contribution in resources of the car

The Life Cycle Impact Assessment shows that the first material with the highest impact of the hole car is aluminium and the second one is carbon fiber. In the following paragraphs of the part 5.3.4. these processes are exhaustive described considering the inputs from nature (resources), technosphere (materials, electricity), emissions to air, water and soil.

Part of the car	**Process**	**Value**
Frame&Body	Carbon fibre	1,38E-002
Brakes	Energy US I	2,17E-003
Engine&Drivetrain	Aluminium lingots I	5,75E-002
Electrical	PS (EPS) I	7,63E-003
Miscellaneous	Crude oil N-sea(a) I	3,69E-002
Steering	Aluminium ingots I	9,88E-004
Suspension	Aluminium ingots I	1,43E-002
Wheels	Aluminium ingots I	1,24E-002

Table 20: Normalised values of each system of the car with the respective first impact in Resources

In the following table it is shown the weights of steel and aluminium in the eight systems of the car. It is shown that the total weight of steel is the double of the weight of aluminium. In the previous table 20 it has been shown that aluminum has a higher impact than steel. These two results show that the unitary impact of the aluminium is very high because although the presence of aluminium is the half than the presence of steel, it causes a higher impact. In the annex X it is described the impact assessment of one kilo of steel and one kilo of Aluminium.

System	**Steel (Kg)**	**Aluminium (Kg)**
Frame&Body	35	0,3
Brakes	2	1
Engine&Drivetrain	120	59
Electrical	3	0,7
Miscellaneous	1	0
Steering	5	3
Suspension	5	14
Wheels&Tires	3	12
Total	174	90

Table 21: list of the using of steel and aluminium in the eight systems

5.3.4. Processes description

In this part of the Life Cycle Impact Assessment are described the processes that impact the most on each system of the car.

Aluminium lingots

The use of Aluminium in the car is causing the highest impact on the environment. Engine, Steering, Suspension and wheels&tires are the subsystems in which aluminium is mostly present in the process contribution study.

Thanks to the available data in the extensive databases used for doing this thesis the information of extraction, production and impact can be shown.

Category type	material
Process identifier	IDEMAT0106626600043
Process name	**aluminium 0% recycling**
Time period	1990-1994
Geography	Europe, Western
Date	09/01/1992
Record	Delft University of Technology
Literature references	EAA report 1996
	Environmental Issues of Aluminium Industry
Comment	LCA for production of primairy aluminium in Europe, transport included. Average data

PRODUCTS	Amount	Unit	Quantity	Allocation %	Waste type	Category
Aluminium ingots I	1000	kg	mass	100	Aluminium	Metals\Non Ferro

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
Bauxite, in ground	in ground	3675	kg
Coal, 29.3 MJ per kg, in ground	in ground	103,1	kg
Gas, natural, 30.3 MJ per kg, in ground	in ground	154,8	kg
Oil, crude, 41 MJ per kg, in ground	in ground	1221,4	kg
Limestone, in ground	in ground	170	kg
Water, unspecified natural origin/kg	in water	8615	kg
Sodium chloride, in ground	in ground	54	kg
Transformation, to urban, continuously built	land	0,00064	m2
Occupation, industrial area	land	0,01	m2a

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Diesel I	8,1	kg
Sulphuric acid I	29,4	kg
Stoneware I	8,6	kg
Steel I	6,1	kg
Carbon black I	30,7	kg

Known inputs from technosphere (Electricity/heat)

Name	Amount	Unit
Electricity UCPTE hydro I	7779,4	kWh
Electricity UCPTE nuclear I	2505,6	kWh
Electricity UCPTE oil I	405	kWh
Electricity UCPTE coal I	4032,1	kWh
Electricity UCPTE gas I	1016,8	kWh

Emissions to air

Name	Amount	Unit
Carbon dioxide	4567,8	kg
Carbon monoxide	60,3	kg
Particulates	16,6	kg
Fluoride	0,5	kg
PAH, polycyclic aromatic hydrocarbons	0,05	kg
VOC, volatile organic compounds	0,62	kg
Methane, tetrafluoro-, CFC-14	0,36	kg
Ethane, hexafluoro-, HFC-116	0,04	kg
Nitrogen oxides	5,8	kg
Sulfur dioxide	38,9	kg

Emissions to water

Name	Amount	Unit
COD, Chemical Oxygen Demand	0,019	kg
Chloride	2,7	kg
Fluoride	0,001	kg
PAH, polycyclic aromatic hydrocarbons	0,02	kg
Sulfuric acid	0,8	kg
Suspended solids, unspecified	0,7	kg

Emissions to soil

Name	Amount	Unit
-	-	-

Final waste flows

Name	Amount	Unit
Slags and ashes	1054	kg
Dross	2,1	kg
Process waste	135,8	kg

Non material emissions

Name	Amount	Unit
-	-	-

Social issues

Name	Amount	Unit
-	-	-

Economic issues

Name	Amount	Unit
-	-	-

Known ouputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit
-	-	-

Carbon fibre

The use of Carbon fibre in the car is causing the second highest impact on environment of the car. Frame&body is the subsystem in which carbon fibre is mostly present in the process contribution study.

Thanks to the extensive databases used the information of extraction, production and impact of emissions can be shown.

Category type	material
Process identifier	IDEMAT0106626600410
Type	Unit process
Process name	**Carbon fibre**
Time period	1995-1999
Geography	Europe, Western
Technology	Average technology
Representativeness	Average from a specific process
Cut off rules	Less than 5% (physical criteria)
Capital goods	Second order (material/energy flows including operations)
Date	12/02/2001
Generator	Delft University of Technology
Comment	Peebles, L.H., Carbon fibers:formation,structure and properties. Boca Rotan: CRC Press Inc., 1995. energy data from: Lee, S.M. et al., 'The beneficial energy and environmental impact of composite materials-un unexpected bonus' SAMPE Journal vol.27, 1991

PRODUCTS	Amount	Unit	Quantity	Allocation %	Waste type	Category
Carbon fibre I	1	kg	mass	100	Fibres	Fibers

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
Bauxite, in ground	in ground	0,777145	kg
Clay, unspecified, in ground	in ground	0,000111	kg
Coal, 29.3 MJ per kg, in ground	in ground	2,18684	kg
Gas, natural, 30.3 MJ per kg, in ground	in ground	2,06226	kg
Oil, crude, 41 MJ per kg, in ground	in ground	0,44934	kg
Energy, unspecified		0,179452	MJ
Energy, from coal	in ground	0,555	MJ
Energy, from hydro power	in water	0,290698	MJ
Energy, from gas, natural	in ground	12,358	MJ
Energy, from oil	in ground	171,717	MJ
Energy, from uranium	in ground	0,039411	MJ
Iron ore, in ground	in ground	0,00057	kg
Limestone, in ground	in ground	5,2E-005	kg
Sodium chloride, in ground	in ground	0,000518	kg
Uranium ore, 1.11 GJ per kg, in ground	in ground	0,007973	kg
Water, unspecified natural origin/kg	in water	0,078648	kg

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
-	-	-

Known inputs from technosphere (Electricity/heat)

Name	Amount	Unit
-	-	-

Emissions to air

Name	Amount	Unit
Acrylonitrile	0,00034	kg
Arsenic	2,00541E-008	kg
Benzene	0,000064173	kg
Cadmium	2,00541E-008	kg
Methane, trichlorofluoro-, CFC-11	0,000025	kg
Methane, dichlorodifluoro-, CFC-12	0,000024	kg
Carbon monoxide	0,0507666	kg
Carbon dioxide	11,8664	kg
Coal dust	0,000410469	kg
Chromium	8,02162E-008	kg
Copper	2,00541E-008	kg
Hydrocarbons, unspecified	0,0120036	kg
Cyanide	0,089	kg
Particulates, SPM	0,0014001	kg
Ethane	0,00076	kg
Ethene	0,00035	kg
Hydrogen	0,009	kg
Hydrogen chloride	2,10196E-005	kg
Heavy metals, unspecified	0,0000037	kg
Metals, unspecified	0,000000369	kg
Methane	0,0120169	kg
Ammonia	0,042	kg
Nickel	2,00541E-008	kg
Nitrogen dioxide	0,00345042	kg
Nitrogen oxides	0,0312679	kg
Propane	0,000165	kg
Propene	0,000229	kg
Sulfur dioxide	0,00166432	kg
Soot	0,000463392	kg
Sulfur oxides	0,0186957	kg
Toluene	0,000156422	kg
water	0,084	kg

Emissions to water

Name	Amount	Unit
Acidity, unspecified	0,000111	kg
BOD5, Biological Oxygen Demand	0,000020345	kg
Chlorine	4,55963E-005	kg
COD, Chemical Oxygen Demand	4,06899E-005	kg
Crude oil	2,36121E-006	kg
Hydrocarbons, unspecified	8,13799E-005	kg
Fluorine	2,33054E-005	kg
Iron	4,2931E-008	kg
Hydrogen	1,31612E-005	kg
Metallic ions, unspecified	2,06823E-005	kg
Ammonia	1,47394E-005	kg
Ammonium, ion	0,0000037	kg
Nitrate	0,0000037	kg
Nitrogen, total	5,88869E-006	kg
Phenol	6,7463E-008	kg
Suspended substances, unspecified	0,000222	kg

Emissions to soil

Name	Amount	Unit
-	-	-

Final waste flows

Name	Amount	Unit
-	-	-

Non material emissions

Name	Amount	Unit
-	-	-

Social issues

Name	Amount	Unit
-	-	-

Economic issues

Name	Amount	Unit
-	-	-

Known ouputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit
-	-	-

Crude oil N-sea

The using of Crude oil N-sea in the car is causing the impact on environment in the subsystem miscellaneous.

Thanks to the available data in the extensive databases used for doing this thesis the information of extraction, production and impact can be shown.

Category type	material
Process identifier	IDEMAT0106626600025
Process name	**Northsea oil I**
Time period	1990-1994
Geography	Europe, Western
Technology	Mixed data
Representativeness	Average of all suppliers
Capital goods	Second order (material/energy flows including operations)
Infrastructure	No
Date	12/12/1994
Record	Delft University of Technology
Literature references	PWMI report 2 Olefins
Comment	Oil from various North sea production sites. Includes production and transportation to the shore mostly by pipeline. HHV=45MJ/kg, LHV = 42.7 MJ/kg.

PRODUCTS	Amount	Unit	Quantity	Allocation %	Waste type	Category
Crude oil N-sea(a) I	1	kg	mass	100	not defined	Fuels\Oil\Crude oil

Known inputs from nature (resources)

Name	Sub-compartr	Amount	Unit
Oil, crude, 42.7 MJ per	in ground	1,014	kg
Gas, natural, 30.3 MJ	in ground	0,055	kg
Bauxite, in ground	in ground	400	mg
Water, unspecified nat	in water	9,5	g
Energy, unspecified		2,66	MJ
Transformation, to indu	land	0,0000206	m2

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
-	-	-

Known inputs from technosphere (Electricity/heat)

Name	Amount	Unit
-	-	-

Emissions to air

Name	Amount	Unit
Carbon dioxide	0,152	kg
Carbon monoxide	0,00007	kg
Hydrocarbons, unspec	0,0018	kg
Nitrogen oxides	0,0022	kg
Particulates, SPM	0,00023	kg
Sulfur oxides	0,00006	kg
Hydrogen chloride	0,00001	kg

Emissions to water

Name	Amount	Unit
Hydrogen	0,000031	kg
Metallic ions, unspecifi	0,000005	kg
Crude oil	0,000035	kg
Phenol	1	mg

Emissions to soil

Name	Amount	Unit
-	-	-

Final waste flows

Name	Amount	Unit
Mineral waste	0,0011	kg
Slags	0,00001	kg

Non material emissions

Name	Amount	Unit
-	-	-

Social issues

Name	Amount	Unit
-	-	-

Economic issues

Name	Amount	Unit
-	-	-

Known ouputs to technosphere. Waste and

Name	Amount	Unit
-	-	-

PS (EPS) I

The using of PS (EPS)I in the car is causing the impact on environment in the subsystem electrical system.

Thanks to the available data in the extensive databases used for doing this thesis the information of extraction, production and impact can be shown.

Category type	material
Process identifier	IDEMAT0106626600031
Process name	**PS (EPS) I**
Time period	1990-1994
Geography	Europe, Western
Technology	Average technology
Representativeness	Average of all suppliers
Capital goods	Second order (material/energy flows including operations)
Infrastructure	No
Date	05/10/1999
Record	Delft University of Technology
Generator	F. Groenland
Literature references	APME report 4 PS
Comment	Expandable Polystyrene. Blowing agent included. Average data for 1994

PRODUCTS	Amount	Unit	Quantity	Allocation %	Waste type	Category
PS (EPS) I	1	kg	masss	100	PS	Plastics\Thermoplasts

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
-	-	-

Known inputs from technosphere (Electricity/heat)

Name	Amount	Unit
-	-	-

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
Coal, 29.3 MJ per kg, in ground	in ground	0,089	kg
Oil, crude, 42.7 MJ per kg, in ground	in ground	1,15	kg
Gas, natural, 30.3 MJ per kg, in ground	in ground	0,83	kg
Energy, unspecified		14,263	MJ
Water, barrage	in water	10	kg
Uranium ore, 1.11 GJ per kg, in ground	in ground	0,0009	kg
Coal, brown, 10 MJ per kg, in ground	in ground	0,043	kg
Iron ore, in ground	in ground	0,00073	kg
Limestone, in ground	in ground	0,0017	kg
Water, cooling, unspecified natural origin/kg	in water	170	kg
Water, process, unspecified natural origin/kg	in water	5,5	kg
Bauxite, in ground	in ground	0,0011	kg
Sulfur dioxide	in air	3E-005	kg
Sulfur, in ground	in ground	6E-005	kg
Sodium chloride, in ground	in ground	0,0019	kg
Sand, unspecified, in ground	in ground	0,00012	kg
Gypsum, in ground	in ground	1E-005	kg
Occupation, industrial area	land	400	cm2a

Emissions to air

Name	Amount	Unit
Particulates	0,002	kg
Carbon monoxide	0,00096	kg
Carbon dioxide	2,4	kg
Sulfur oxides	0,011	kg
Nitrogen oxides	0,012	kg
Hydrogen chloride	0,000025	kg
Hydrocarbons, unspecified	0,0047	kg
Methane	0,011	kg
Organic substances, unspecified	0,000003	kg
Metals, unspecified	0,000066	kg
Hydrocarbons, aromatic	0,00022	kg

Emissions to water

Name	Amount	Unit
COD, Chemical Oxygen Demand	0,00071	kg
BOD5, Biological Oxygen Demand	0,00015	kg
Acidity, unspecified	0,00004	kg
Solved solids	0,00011	kg
Ammonium, ion	0,000014	kg
Hydrocarbons, unspecified	0,00009	kg
Suspended solids, unspecified	0,00069	kg
Sodium, ion	0,00061	kg
Phenol	0,000005	kg
Metallic ions, unspecified	0,00033	kg
Nitrogen	0,000004	kg
Chloride	0,0035	kg
Sulfate	0,00012	kg
Oils, unspecified	0,000061	kg
Solved organics	0,00005	kg
Organic substances, unspecified	0,000004	kg

Emissions to soil

Name	Amount	Unit
-	-	-

Final waste flows

Name	Amount	Unit
Mineral waste	0,026	kg
Waste, industrial	0,0021	kg
Slags and ashes	0,0043	kg
Chemical waste, inert	0,008	kg
Chemical waste, regulated	0,001	kg
Waste, unspecified	0,000017	kg
Construction waste	0,000028	kg
Metal waste	0,000016	kg
Waste, from incinerator	0,00036	kg
Packaging waste, unspecified	0,000002	kg

Non material emissions

Name	Amount	Unit
-	-	-

Social issues

Name	Amount	Unit
-	-	-

Economic issues

Name	Amount	Unit
-	-	-

Known ouputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit
-	-	-

Energy Us

The using of Carbon fibre in the car is causing the impact on environment in the subsystem of brakes.

Thanks to the available data in the extensive databases used for doing this thesis the information of extraction, production and impact can be shown.

Category type	energy
Process identifier	IDEMAT0106626600419
Process name	**Energy US**
Time period	1995-1999
Geography	North America
Technology	Average technology
Date	02/01/1901
Record	Delft University of Technology
Literature references	World Resources 95-97
Comment	Average fuel requirement and emissions for energy generation per MJ for the US

PRODUCTS	Amount	Unit	Quantity	Allocation %	Waste type	Category
Energy US I	1	MJ	100	not defined	Electricity	country mix\Production

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit
Coal, 29.3 MJ per kg, in ground	in ground	0,011	kg
Oil, crude, 41 MJ per kg, in ground	in ground	0,0055	kg
Gas, natural, 30.3 MJ per kg, in ground	in ground	0,0087	kg
Energy, from hydro power	in water	0,17	MJ
Energy, from uranium	in ground	0,103	MJ

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
-	-	-

Known inputs from technosphere (Electricity/heat)

Name	Amount	Unit
-	-	-

Emissions to air

Name	Amount	Unit
Sulfur oxides	0,000227	kg
Nitrogen dioxide	0,000141	kg
Carbon monoxide	0,000009	kg
Carbon dioxide	0,0695	kg
Hydrocarbons, unspecified	0,000008	kg
Soot	0,000099	kg
Particulates, SPM	0,000013	kg

Emissions to water

Name	Amount	Unit
-	-	-

Emissions to soil

Name	Amount	Unit
-	-	-

Final waste flows

Name	Amount	Unit
-	-	-

Non material emissions

Name	Amount	Unit
-	-	-

Social issues

Name	Amount	Unit
-	-	-

Economic issues

Name	Amount	Unit
-	-	-

Known ouputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit
-	-	-

5.4. Life cycle interpretation

The existence of uncertainties is often mentioned as a crucial limitation for a clear interpretation of LCA results. Due to this problem, the uncertainty analysis is slowly gaining importance in the realisation of LCA's, but it still isn't a common practise.

In this study, the major part of the data is well defined because the materials and its weights that compose the car are well defined in the Race Up Team documents (Cost final [9]). But like as it has been said before, every model represents as similar as possible the reality, and between these two both there are always differences. Some simplifications could develop some kind of uncertainties.

1. Data uncertainties: ecoinvent dataset always provides a value plus uncertainty information. The value they specify can be interpreted as the “best guess” value is determined by sampling many different measurements.

2. Model uncertainties: in order to represent some manual processes that are not founded in the data base available, some simplifications have been introduced. In the case of the processes like wrench, screw driving, brush applying, manual lamination, aerosol applying a simplification has been done. The supposition of this kind of activities consume a personal energy of 9,03MJ (energia persona).

3. Data uncertainties: incompleteness. There is some data not available. The document *Cost final* doesn't contain all the information related on the inventory of all processes and materials involved in the production of the car.

5.4.1. Sensitivity analysis

In order to see the influence of the most important assumptions, it is recommended to perform a sensitivity analysis at the end of the LCA. Finding the most important assumptions is typically something you do in the goal and scope phase and later in the data collection phase.

The Monte Carlo analysis is a numerical way to process uncertainty data and establish an uncertainty range in the calculation results.

1. Frame&Body System

When the uncertainty analysis of frame&body system is done, the statistics of the program show that only a 0,0868% of the values contain uncertain data.

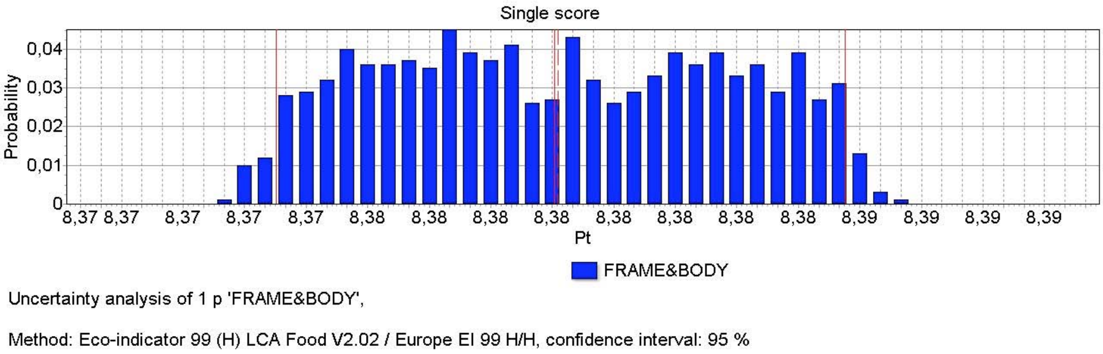


Image 45: Monte Carlo results of Frame&Body System

2. Brakes System

When the uncertainty analysis of brakes system is done, the statistics of the program show that only a 0,124% of the values contain uncertain data.

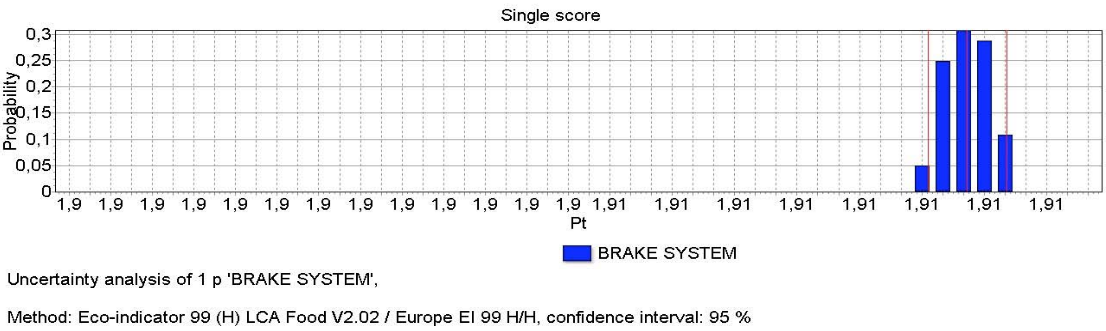


Image 46: Monte Carlo results of Brakes System

3. Engine&Drivetrain system

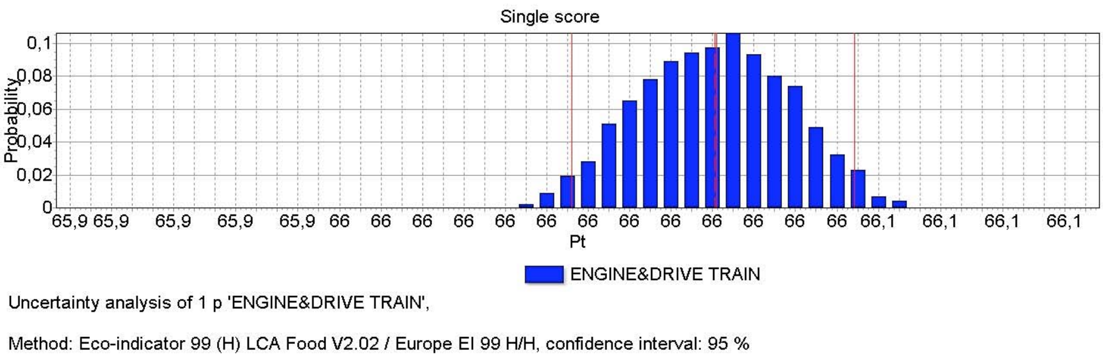


Image 47: Monte Carlo results of Engine&DrivetrainSystem

When the uncertainty analysis of engine&drivetrain system is done, the statistics of the program show that only a 0,0684% of the values contain uncertain data.

4. Instruments&Wiring

When the uncertainty analysis of electrical system is done, the statistics of the program show that only a 0,149% of the values contain uncertain data.

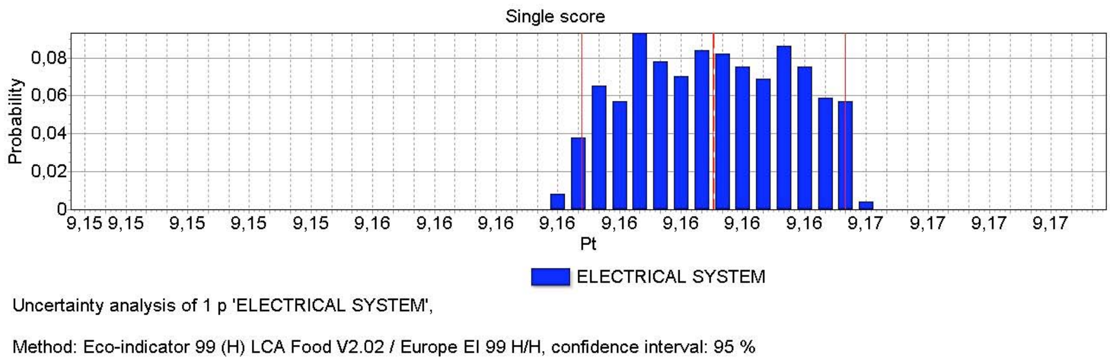


Image 48: Monte Carlo results of Electrical system

5. Miscellaneous

When the uncertainty analysis of miscellaneous system is done, the statistics of the program show that only a 0,212% of the values contain uncertain data.

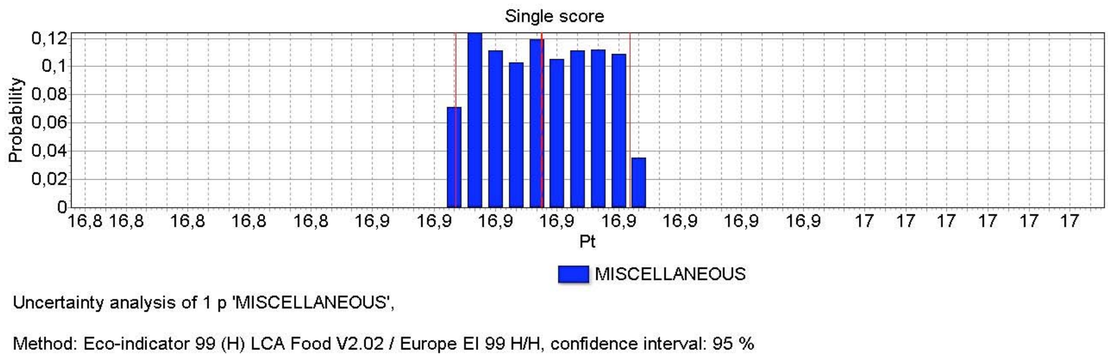


Image 49: Monte Carlo results of Miscellaneous System

6. Steering system

When the uncertainty analysis of steering system is done, the statistics of the program show that only a 0,167% of the values contain uncertain data.

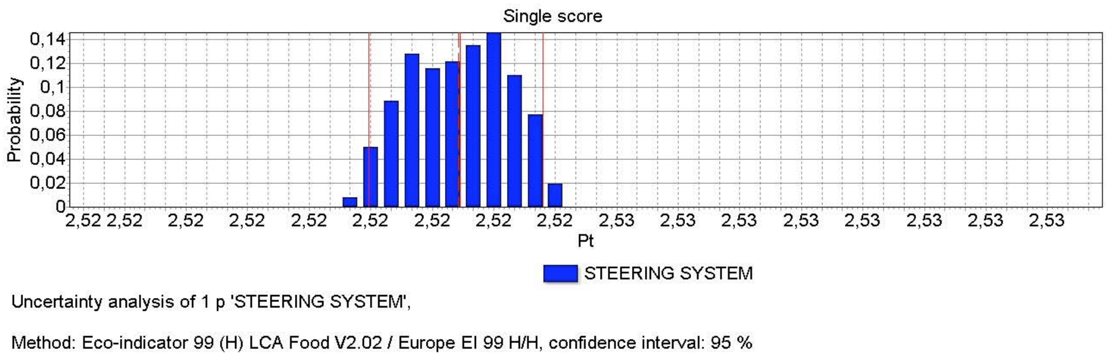


Image 50: Monte Carlo results of Steering System

7. Suspension

When the uncertainty analysis of suspension system is done, the statistics of the program show that a 0,186% of the values contain uncertain data.

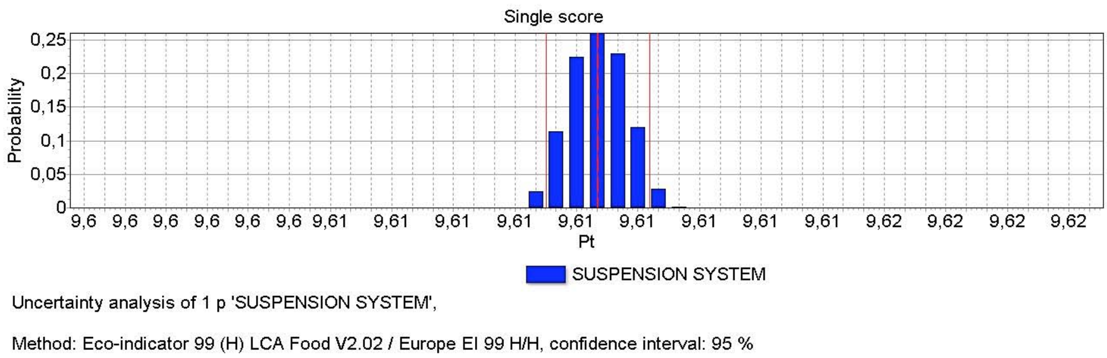


Image 51: Monte Carlo results of Suspension System

8. Wheels&Tires

When the uncertainty analysis of wheels&tires system is done, the statistics of the program show that only a 0,022% of the values contain uncertain data.

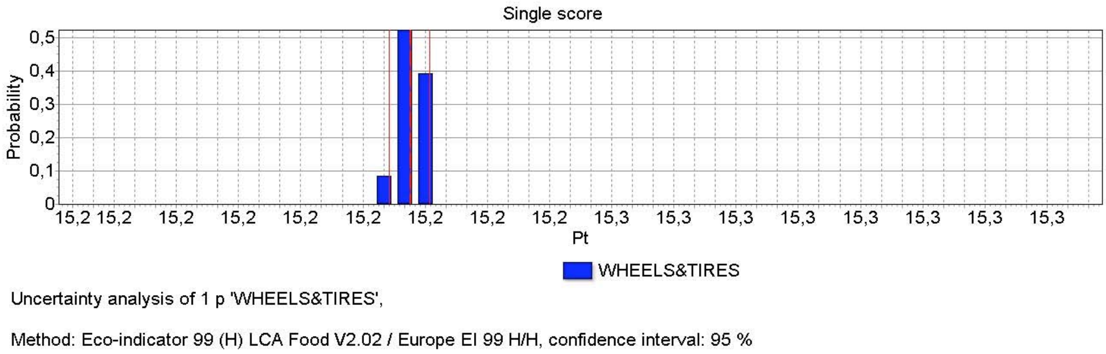


Image 52: Monte Carlo results of Wheels&Tires System

Total

In the end, all graphics of each 8 systems of the car show that the uncertain data is really low. The main reason is that the data introduced in the program were figures well accurate. There are no inputs in the system with range of values or functions.

6. Confidentiality of the project

Since the subject principally discussed in this thesis is a car, participating in a European competition with other universities, this is to state that all materials and products used to build the car are to be treated confidentially and are property of the Race Up Team. All the information needed for the LCA has been given to the projector of the thesis with the promise not to use any of this information given for purposes not related to the thesis.

Moreover, as normative says, Life Cycle Assessment serves as a tool to explore the impact of a product, thus improving it. It's not a way of showing that one product is better than the other in publicity or marketing.

This is an academic project that works with and for the Race Up Team of the University of Padova.

Conclusions

The purpose of the Life Cycle Assessment is to see which materials and processes have which impact. The results can be found in table 19. The result like there are shown in this table point out that aluminium has the highest impact. Now, it would be wrong to interpret or distract the conclusion that a possible improvement would be to just change a big part of that aluminium and replace it with another material. First of all an new analysis should be made of the replacing material. In the case this part has a lower impact, also some other characteristics should be studied and be taken into an account. In this case of a vehicle, choosing lighter materials like aluminium or carbon fiber decreases the vehicle's weight. A lower weight will also impact on the environment because a decrease in fuel consumption. Some studies show that a modern car with components that are made of aluminium can be 24% lighter than one with components made of steel, which also allows fuel consumption to be reduced by 2 litres per 100Km. [10]

Also has been conclude that in spite of using a material that is weighting less the impact of using aluminium is higher of using steel (table 19 and 21).

This Life Cycle Assessment gives also as a result of environmental impact of each subsystem that composes the car. Discovering that aluminium is the material with highest impact on the subsystems engine&drivetrain, steering, suspension and wheels; carbon fibre has the highest impact on the frame&body subsystem; PS (EPS) has the highest impact on electrical subsystem; energy US I is the process with highest impact in the brakes subsystem impact assessment and crude oil N-sea is the process with highest impact when analysing the miscellaneous subsystem. This divided results in each subsystem of the vehicle will help for taking future decisions of changing or improving some materials. Because the car is composed by a lot of pieces and dividing the total system makes easy to focus in some parts of the car.

The first approach to possible improvements it is changing some characteristics of materials, for example using the AlMgSi0.7(6005) instead of the AlCuMg1(2017). The little difference between both in the environmental impact context can make the difference in the big car. Deciding to make a substitution of steel in the place of aluminium is not that easy to make. Such a decision is difficult because the mechanicals aspects like resistance or fatigue have to be considered.

At last I can note that it is important to explain that some different categories have been studied when analysing the environmental impact of each of the eight subsystems. After the normalisation of that impact results it always occurred that the highest impact is on fossil fuels is substantial more than on the other categories. Like shown in the graphics from 31 to 43 the highest category with most impact is fossil fuels and followed by respiratory effects inorganics, minerals and climate change. Also these conclusions are important to limited where the impact of the car occurs because the concept of environment is too big for being treated just as one single system.

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[http://www.ecoinvent.org, 04/06/2013]

ANNEX A: Impact categories [4]

Each damage category comprises a number of impact categories. The Eco-indicator 99 method considers eleven impact categories each describing different aspect of the environmental impact. [4]

Carcinogenic substances

Many chemicals can cause cancer in humans or animals after prolonged exposure. A carcinogen may act in different ways, such as causing dangerous changes to DNA or increasing rate of cell division. Some commonly known carcinogens include asbestos, radon, arsenic, benzene etc. Units: DALY

Respiratory inorganics

The goal of the respiratory system is bringing oxygen to all organs of our body and exchanging it for carbon-dioxide produced by the cells. Exposure to high levels of gases such as Nitrogen oxides (NOx) or Sulfur dioxide (SO2) can damage the respiratory airways. Nitrogen oxides form during fuel combustion at high temperatures, thus the primary sources for the NOX are motor vehicle and industrial technologies that burn fuel. NOX is one of the main ingredients in creating ground-level ozone (smog), which is formed when NOX and volatile organic compounds react at high heat or sunlight. The ground-level ozone can cause serious health effects, among them damage to lung tissue and reduction in lung function. In addition, nitrogen oxides react with different compounds and liquid droplets in the air to form particulates – tiny particles with diameter less then 10μm that can penetrate deeply into the lungs and cause severe respiratory diseases. Sulfur dioxide is formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil. Similar to NOx, SiO2 contributes to respiratory illness and to formation of atmospheric particles. SiO2 pollution is considered more harmful when particle and other pollution concentrations are high. Units: DALY.

Respiratory organics

Another group of air pollutants is toxic organic materials also called Toxic Organic Micro-Pollutants (TOMPs). TOMPs are produced during incomplete combustion of fuels and consist of a wide range of highly toxic chemicals. They include: PAHs (PolyAromatic Hydrocarbons), PCBs (PolyChlorinated Biphenyls), Dioxins and Furans. Units: DALY.

Climate change

During the 20th century global surface temperature of the Earth increased 0.74 ±0.18oC (4) and it is anticipated to increase 1.4–5.6 °C between 1990 and 2100. The increasing concentration of the greenhouse gases in the troposphere (a region in the atmosphere from the ground level up to 16km above Earth’s surface) is believed to be the major source of the climate change. The greenhouse gases, such as carbon dioxide (CO2), methane (CH4) and water vapor, are transparent to short-wave solar radiation, but opaque to the longer waves radiated back from the Earth as a heat. CO2 is the most important greenhouse gas with radiative forcing of 60% from all of the greenhouse gases (5)(radiative forcing is defined as a change in the balance between incoming solar radiation and outgoing infrared radiation in a given climate system and it is measured in W/m2). The global increase in CO2 concentration is mainly due to human activity such as combustion of fossil fuels and deforestation. Methane is another important greenhouse gas with radiative forcing of 20%. The major sources of the CH4 emission derived from human activities are energy production, landfills, waste treatment and biomass burning. Although water vapor is an extremely potent greenhouse gas, it is not possible to directly influence atmospheric water vapor concentration, as its concentration in the atmosphere mainly depends on air temperature. Units: DALY

Radiation

Frequent exposures to radiation can cause cancer and other severe health effects. The major source of radiation is a power production by nuclear and coal-fired power plants. Radioactive materials, such as Uranium-235 or Plutonium-239, are used to generate electricity by nuclear power plants. The spent fuel is highly radioactive and stored with a great care in temporally storage sites while methods for final disposal are still discussed. However, radioactive wastes from nuclear power plants comprise less than 1% of total industrial toxic wastes (6). The major source of radioactive materials released to the environment is coal-fired power plants, which naturally release radioactive materials, mainly uranium and thorium, as part of coal combustion (7). Units: DALY.

Ozone layer

Ozone (O_3) gas is primarily found in the stratosphere, the region between 16km and 50km above the Earth's surface. Ozone forms a layer that protects life on earth by greatly reducing the amount of UV-B radiation. Human exposure to UV-B increases the risk of skin cancer, cataracts, and suppression of the immune system. In the stratosphere, the ozone is created when oxygen molecules (O_2) are broken apart by ultraviolet radiation into two atoms (O), which combine with another oxygen molecule (O_2) to form ozone (O_3). When ozone reacts with natural and human produced chemicals the ozone molecule is lost and another chemical is produced. The Reactive gases containing chlorine and bromine, such as ethane and methane, are known as being responsible for stratospheric ozone depletion. Units: DALY Ecotoxicity Chemicals emitted to water, air and soil affect the environment and the organisms living in it. Since all organisms are connected in the web of life, the effect on one organism can lead to injury in many other organisms. Units: PAF·m2yr

Acidification/Eutrophication

Both, SO_2 and NO_x react with water vapor in the atmosphere to form Sulfuric acid (H_2SO_4) and Nitric acid (HNO_3). Acid rain is harmful in water and on land (rain water is considered acid rain when pH level goes below 5.6). Sea life dies if the water becomes too acidic. Plants will be damaged and eventually die when the acid seeps into the leaves disrupting the process of photosynthesis. Acid rain also damages buildings and marble statues. Eutrophication is a response of the ecosystem to the human activities that artificially enrich water bodies with nitrogen and phosphorus. Eutrophication can lead to changes in animal and plant population and degradation of water. Units: PDF·m2yr

Land use

Every human activity affects land use leading to modification of the natural ecosystem. This modification includes land degradation, reduction of local biodiversity, suppression of the natural resources, etc. In addition, it may raise demographical, economical and political problems. The Eco-indicator 99 method used in these calculations considers the following land use aspects: occupation of forests, construction sites, industrial areas, mineral extraction sites and traffic areas. Units: PDF * m2 * yr

Minerals depletion

There is a finite amount of minerals in the Earth's crust. Mineral extraction itself has an environmental impact due to use of much energy, waste and greenhouse emissions. Units: MJ Surplus energy Depletion of fossil fuels Fossil fuels are currently a primary source of energy for our civilization. There are three types of fossil fuels: coal, mainly used to produce electricity, oil, used as a transportation fuel, and natural gas used primarily for heating. In addition, oil is used to manufacture products such as plastics, asphalts, medications, paints, etc. The world's total amount of resources is limited and fossil fuels are reaching a shortage. According to experts, crude oil may remain plentiful for less than 30 years (8). This fact may eventually lead to energy crisis and to radical increase in oil prices. Units: MJ Surplus energy

ANNEX B: COMPARISON OF THE IMPACT OF TWO TYPES OF ALUMINIUM

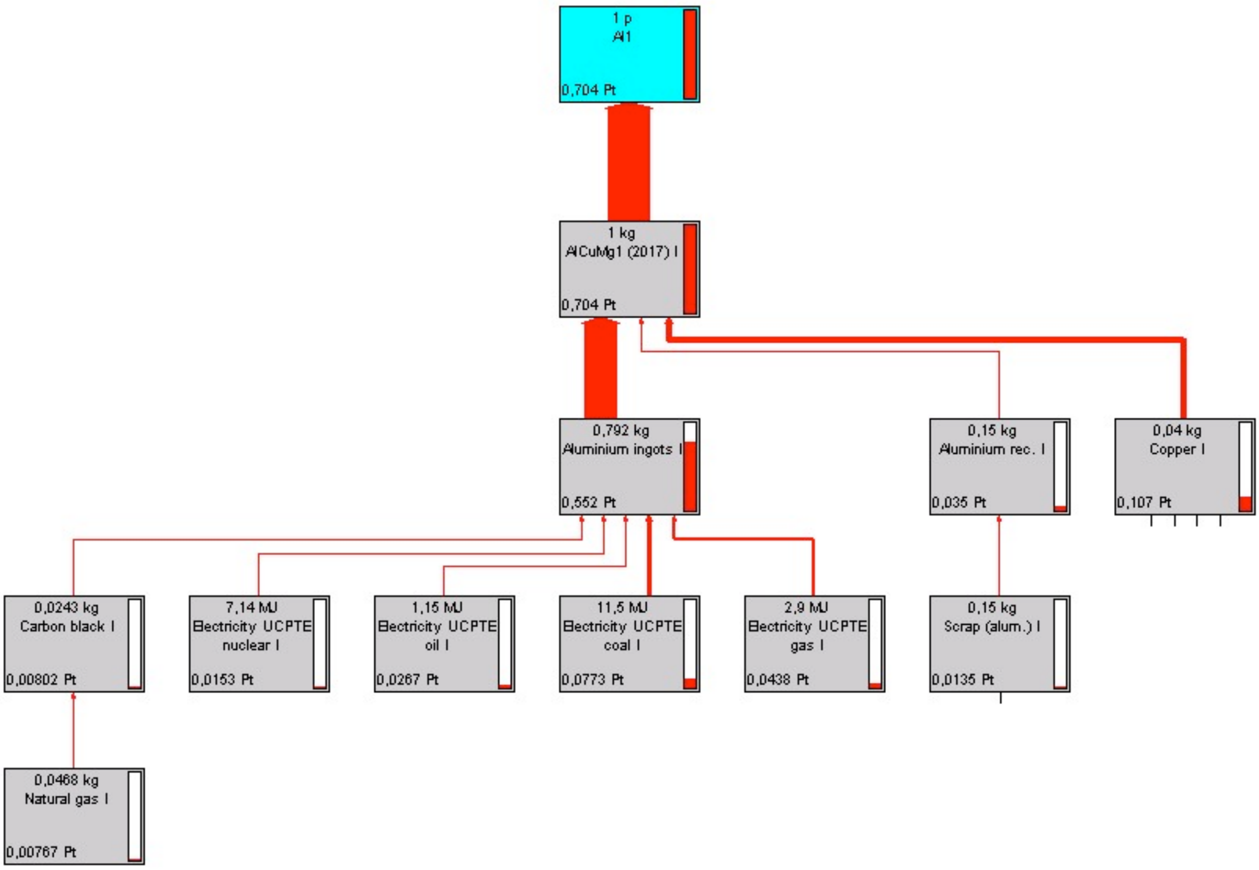

Figure 1: Single score process contribution tree AlCuMg1 (2017)

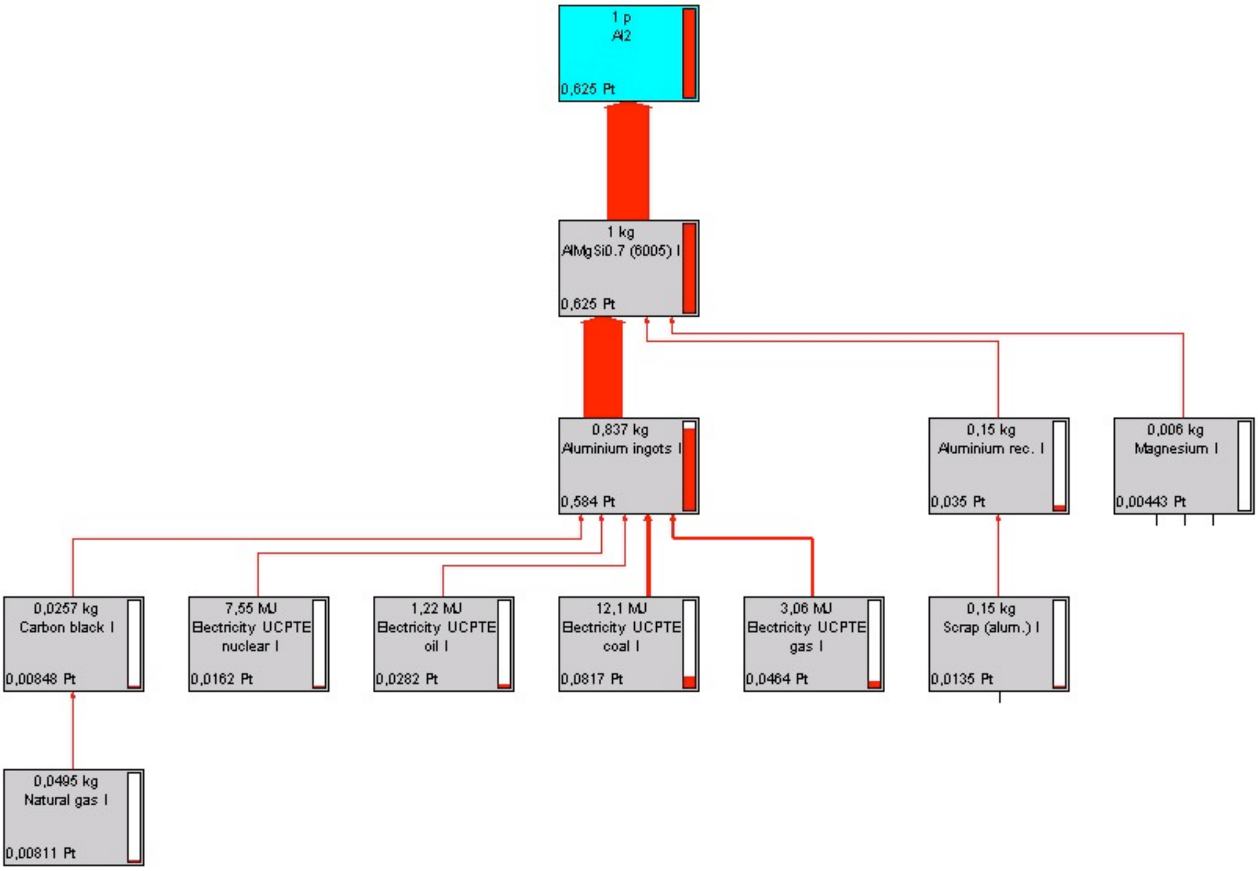

Figure 2: Single score process contribution tree AlMgSi0.7 (6005)