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D4.11 Final evaluation of the newly developed characterisation in an LCA case study - car manufacturing and operation

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Summary

The following report is presenting the results of the Life Cycle Inventory analysis (LCI) performed to apply the newly developed spatially differentiated characterization factors (CFs) and it gives an overview on the methodology used and points out the difficulties in the process of the application of the new CFs.

Not all the CFs have a spatial differentiation. Some simply distinguish between 3 concepts of evaluation (e.g. abiotic resource consumption). Those containing an area specification have different resolution types. Additionally, the number of areas differs inside one resolution type. This makes the new system very time intensive to apply. In the calculation phase the two LCA softwares GaBi and SimaPro were used to find out in which tool framework integration of regionalised specific CFs might be easier.

For the case study on car production and operation the relevant impact categories are shown in Table 1. Especially, the emissions due to operation are causing the major share of impacts, i.e. the actual combustion of fuel. For the spatial allocation of the emission good assumptions can be made.

In both LC assessment softwares there is the possibility to integrate adjusted elementary flows. However, this multiplies the amount of flows inside the databases by a factor up to 1000 or more (depending on the resolution). Alternatively, cut-off criteria can be defined or simplifying assumptions made. The focus of this case study is to discuss the new CFs, to point out the different procedures of using them as well as to calculate the first results. For most of the CFs one or more resolutions needed to assess the life cycles (LC) are missing.. For some impact categories site specific CFs have been applied to show the overall impact of a detailed allocation of emission to the category results compared to those resulting from the usage of globally averaged CFs only.

LC-IMPACT

SEVENTH FRAMEWORK PROGRAMME

1 Introduction

Starting the assessment

For the case study on car production and operation the relevant impact categories are shown in Table 1.

Table 1: Case study Transport: Car production and operation and relevant impact categories based on {LC-IMPACT_DoW, 2012 #2134}.

Impact category	
Mineral resource use	+[1]
Fossil resource use	+[2]
Water use	+[3]
Land use	+[3]
Ecotoxicity	+[4]
Acidification	+[2]
Photoch. ozone formation	+[2]
Fine part. matter formation	+[2]
Noise	+[2]
Human toxicity	+[4]

[1] metals used in car production
[2] car use
[3] water and land use cause by biodiesel production
[4] metal emissions

Goal and scope definition

The complete life cycle of a light passenger car will be assessed using different data sources for the production and operation phase in order to calculate the environmental impact. To include and validate newly spatially differentiated CFs the inventory data are allocated and characterized by those specific CFs and afterwards compared to the result without specifications.

Functional unit

The functional unit will be 1pkm (person km) of road transport service in a light passenger vehicle.

System boundaries

The system will include all relevant processes from cradle to grave including production, operation, maintenance and disposal of the car, fuel production and consumption, as well as production, maintenance and disposal of the road.

2 Inventory analysis

For the following case study three different sources of inventory data were needed to perform the assessment:

- local car manufacturer Daimler,
- the Ecoinvent database and
- a model concerning biodiesel use designed by the Technical University of Denmark (DTU).

Especially the difference between primary and secondary data will be important for the following steps.

2.1 Data from Daimler Rastatt

As one of the partners of LC-IMPACT the car manufacturer Daimler provided primary inventory data from its production plant in Rastatt Germany. The LCI data contain natural gas and water use, land-occupation and emissions to air and water. All these data can directly be assigned to the production-plant site and therefore no assumptions have to be made concerning the use of the new spatially differentiated CFs in chapter 6.

The Rastatt plant is the newest production plant of the company in Germany and will therefore have a better environmental performance than an average production plant for cars in Europe. It produces the Mercedes A and B-class models in series production. About 6,000 people work onsite for Daimler and about 1,000 for ancillary companies.[3]

All the data provided by Daimler are primary data. The quality is therefore very good because state of the art measures have been performed. The problem concerning these data is that no complete inventory of all inputs and outputs was provided by the project partner but only 33 emission and resource figures have been provided directly. These data can be seen in Table 1. The table shows the inventory data for one year and for one car produced in 2010. In this year 238,351 cars left the factory. All heavy metal emissions to air that have been considered are emitted inside the paint shop or during the body shell production. The emissions differ between night and day periods and between working days and weekends. The concentration and volume of exhaust air was measured and the overall emission during the year 2010 was calculated.

[3] Cf. Daimler (2011) page 4

Table 2: Inventory data provided by Daimler Rastatt

Flow name	category	sub-category	unit	/a	/piece
Antimony	air	unspecified	kg	2.19E+00	9.20E-06
AOX, Adsorbable Organic Halogen as Cl	water	unspecified	kg	6.60E+01	2.77E-04
Arsenic	air	unspecified	kg	4.13E-01	1.73E-06
Cadmium	air	unspecified	kg	1.12E-02	4.70E-08
Carbon dioxide, fossil	air	unspecified	kg	3.23E+07	1.36E+02
Carbon monoxide, fossil	air	unspecified	kg	7.30E+03	3.06E-02
Chromium	air	unspecified	kg	5.39E-01	2.26E-06
Cobalt	air	unspecified	kg	1.62E-02	6.80E-08
Copper	air	unspecified	kg	6.61E+00	2.77E-05
Gas, natural, in ground	resource	in ground	Nm^3	1.56E+07	6.55E+01
Hydrocarbons, unspecified	water	unspecified	kg	4.70E+01	1.97E-04
Iron	air	unspecified	kg	2.93E+02	1.23E-03
Iron, ion	water	unspecified	kg	1.50E+01	6.31E-05
Lead	water	unspecified	kg	8.57E-01	3.60E-06
Lead	air	unspecified	kg	1.75E-01	7.33E-07
Manganese	air	unspecified	kg	5.83E+00	2.45E-05
Nickel	air	unspecified	kg	4.52E-01	1.89E-06
Nickel, ion	water	unspecified	kg	1.50E+01	6.29E-05
Nitrite	water	river	kg	1.19E+02	4.99E-04
Nitrogen oxides	air	unspecified	kg	1.99E+04	8.36E-02
NMVOC, non-methane volatile organic compounds, unspecified origin	air	unspecified	kg	1.40E+05	5.85E-01
Occupation, arable, non-irrigated	resource	land	m^2a	1.47E+06	6.19E+00
Occupation, industrial area, built up	resource	land	m^2a	5.35E+05	2.24E+00
Occupation, industrial area, vegetation	resource	land	m^2a	4.81E+05	2.02E+00
Particulates, > 2.5 um, and < 10um	air	high population density	kg	9.00E+02	3.78E-03
Strontium	air	unspecified	kg	1.28E-01	5.37E-07
Sulfur dioxide	air	unspecified	kg	6.37E+02	2.67E-03
Thallium	air	unspecified	kg	8.02E-04	3.36E-09
Tin	air	unspecified	kg	5.22E+00	2.19E-05
Titanium	air	unspecified	kg	6.00E+00	2.52E-05
Water, unspecified natural origin	resource	in water	m^3	1.76E+05	7.40E-01
Zinc	air	unspecified	kg	1.22E+02	5.11E-04
Zinc, ion	water	unspecified	kg	3.51E+00	1.47E-05

The other emissions e.g. carbon monoxide or carbon dioxide emissions refer to the whole production site. They were provided in kg emission per year. Additionally, measurements concerning the wastewater provided data for emissions to water and a land use plan of the area provided numbers for land occupation. All the figures provided refer to flows from or to nature and no in- or outputs from technosphere have been delivered directly. As Daimler is seeking to use the measured data for marketing reasons, most of the inventory data are output orientated and refer to those chemicals being important for this purpose.

Additionally, some data have been taken from the sustainability report published by the company annually. The numbers sought refer to the year of 2010 as the other data from Daimler refer to the same year. These additional data can be seen in Table 2. In some cases the figures have been the same in the report as in the sheets provided by Daimler directly only differing in accuracy. Therefore, only data concerning new in - or outputs have been taken from the sustainability report.

Table 3: Additional inventory data taken from the annual environmental report

Flow name	category	unit	/a	/piece
Diesel	resource	l	4.74E+05	1.99E+00
Electricity, from German energy mix	resource	MWh	1.19E+05	5.00E-01
Electricity, own production	resource	MWh	2.06E+04	8.66E-02
Gasoline	resource	l	4.04E+05	1.70E+00
Light fuel oil	resource	l	7.90E+03	3.31E-02
	resource	MWh	8.00E+01	3.36E-04
Liquified Natural Gas (LNG)	resource	l	2.27E+05	9.51E-01
Natural gas	resource	m³	2.08E+07	8.71E+01
	resource	MWh	2.31E+05	9.68E-01
Occupation, traffic area	resource	m²a	4.58E+05	1.92E+00
Rainwater	resource	m³	6.23E+02	2.61E-03
Tab water	resource	m³	3.92E+04	1.64E-01
Waste for recovery	waste	t	8.77E+03	3.68E-02
Waste for treatment	waste	t	1.85E+04	7.76E-02
Waste water	waste	m³	2.51E+05	1.06E+00
Water (ground water)	resource	m³	3.00E+05	1.26E+00

2.2 Data from DTU

The LC-IMPACT partner DTU has modelled the use phase of a car consuming 100% biodiesel. It takes into account not only the burning of the fuel in the engine but also the complete production phase of the biodiesel. The production chain consists of the following processes:

- rapeseed production
- rapeseed oil production
- esterification process [4]
- the transport service in vehicle kilometre

The biodiesel used is an ester and is assumed to be burned in a conventional engine for which no specifications are necessary. Additionally, it was taken into account that the rapeseed straws are burned to provide heat and therefore avoid the use of coal in other processes. This process is beneficial for the production of biodiesel and is common practice in Germany.

The data from DTU are a mixture of primary and secondary data. The model was built on the base of Ecoinvent data and some data have been collected as primary data. The goal in modelling the 100%-biodiesel use-phase has not been to allocate the emissions spatially but to have a first estimation on the impact of biodiesel production. Therefore no data of the production sites containing area specific data are available yet. However, it is assumed that most of the inventory data refer to Danish conditions. As there are no information about which of the data inside the DTU model are primary and which are secondary LCI-data the procedure of the Ecoinvent processes is followed (cf. next section).

[4] In this process alcohol is necessary which has been produced from methanol.

2.3 Data from Ecoinvent

The last and most important source of inventory data is the Ecoinvent database. The database was founded in Switzerland in 2003 with version 1.1. In this deliverable Version 2.2 (2010) has been used. It is not designed to make comparative assessments at the product stage[5] because most of the data it uses are averaged for a specific area e.g. Germany or Europe. Consequently the error which is made by using the default data might be higher than the error caused by using the wrong CFs in chapter 6. The data have not been collected focusing on the area sites of the production chains. Consequently they have to be looked-up in the Ecoinvent reports individually for every single process. These are depending on the life cycle of about 2,000 processes for each one. As these locations represent just the data-sources for the default process and not the real site where the process takes place in our models it is preferred in this case study to make assumptions on the locations of the processes in the production chain. Also if all locations of the processes are available the amount of work necessary for inserting all these data into an excel sheet or one of the LCIA software would be very high. Therefore steps for simplifying this integration had to be made.

In the Life Cycle Inventory for the production phase in the Ecoinvent database data from a study by Schweimer (2002) have been used. They assessed a production plant for Golf A4 vehicles in northern Germany. According to this paper the plant infrastructure is not included[6]. The work of Spielmann et al. (2007) is based on the LCI data collected by those authors. For the disposal phase it has been assumed that copper, steel, and aluminum are fully recycled and therefore the impact of the recycling processes for these materials are not allocated to the car life cycle as they are used as raw materials in other processes. Half of the tyres used will be recycled in cement works which is common practice in Switzerland and the same cut off criteria is assumed. These information and additional reading to the model is provided in Spielmann et al. (2007) page 63ff. The vehicle operation phase is an European average and consequently contains petroleum and diesel use. It is therefore an average pkm transport service that is assessed by this process.

All the processes used from the database are available as two different types: an aggregated version (agg.) which is a balance or overview of all the LCI data that occurred in the production chain until this process and a unit process consisting of raw data (u-so) which contains only information about one specific process.

The numbers within the agg. and u-so - data have different values. The result is an error of up to over 10% in the mass balance of a single flow (base: agg. - data per pkm in Ecoinvent) which has different influence on the calculation of the different mid- and endpoint categories. But as it is necessary to rebuild the model from u-so processes to be able to allocate the impacts to processes and later to specific areas, this step has to be made. The error caused by that will not be considered in the following calculations.

[5] Cf. Frischknecht et al. (2007). page 7
[6] Cf. Schweimer,Levin (2002) page 1

3 Scenarios used for the assessment

Three life cycles including different processes have been assessed in the following case study. All of the following life cycles have been subdivided into the four phases: car production, car operation, road (including production, operation, maintenance and disposal), car maintenance, and car disposal as shown in Figure 1. The life cycle stages road, maintenance and disposal are the same in each life cycle and will therefore not cause any difference in the results of the assessment. But as the scope of the LCA is the complete car life cycle they have to be considered in the calculations. Diagrams showing the 2nd level of the operation and production phases can be found in Appendix A.1.

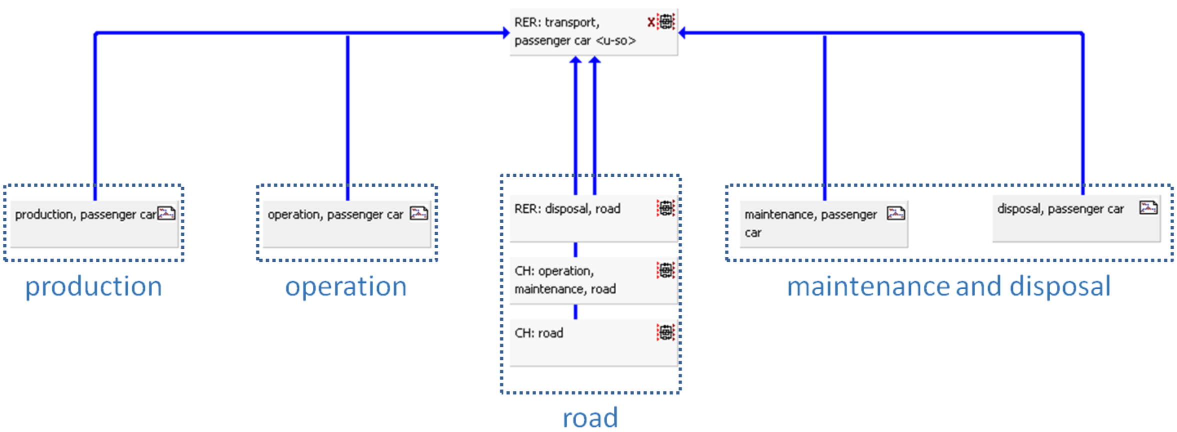

Figure 1: 1st level of the life cycle model

Life cycle 1 (LC1) represents the baseline scenario. This scenario has already been modelled inside the Ecoinvent database and was only rebuilt into the 2nd level to be able to find the hot spots for the different impact categories. The system contains a production phase which is supposed to be an average for car manufacturing in Europe. The LCI was made in a VW production plant in Germany producing 1.4l Otto, Golf A4 vehicles. But not for all processes (almost 2,000) LCI data have been available[7].

		data sources			
local name	**abr.**	**production**	**operation**	**road**	**maintenance disposal**
Life Cycle 1	LC1	Ecoinvent v2.2	Ecoinvent v2.2	Ecoinvent v2.2	Ecoinvent v2.2
Life Cycle 2	LC2	Ecoinvent v2.2 & Daimler Rastatt	Ecoinvent v2.2	Ecoinvent v2.2	Ecoinvent v2.2
Life Cycle 3	LC3	Ecoinvent v2.2 & Daimler Rastatt	DTU	Ecoinvent v2.2	Ecoinvent v2.2

Table 4: Data sources of the life cycles

Life Cycle 2 (LC2) has the same structure as LC1. The only difference is that in LC2 the primary data provided by Daimler for the production site have been added or respectively replaced as explained later.

Life cycle 3 (LC3) uses the same production phase as LC2 and replaces the operation phase. The burning of conventional diesel and petroleum in LC1 and 2 is now replaced by the burning of 100% biodiesel. The data sources for the different phases are summarized for all life cycles in Table 3.

[7] Cf. Spielmann et al. (2007) page 63

Especially during the step of converting the production phase of LC1 into the production phase of LC2 simplifying assumptions had to be made which will be displayed in the following.

Assumptions concerning the transfer in the existing production model

Several assumptions had to be made concerning the data given by the environmental report as they show that the two factories have not just different amounts of in- and outputs but also different flow types. The following section summarizes the assumptions that were made to fit the new primary data into the model used in the Ecoinvent database. Originally it was attempted to generate a new model using only the new primary data but the error introduced by disregarding e.g. the steel use in the factory with some orders of magnitude higher than that caused by the assumptions.

Land occupation was considered in LC1 in the process 'RER: road vehicle plant'. This process was deleted in LC2 because new data for land use have been available which could not be adjusted into this model. The resource 'Occupation, arable, non-irrigated' is divided into the three other occupation types: 'industrial area, built up', 'industrial area, vegetation', and 'traffic area, road network'. Therefore it is not an own resource and will be disregarded in the model[8].

The resource 'water, unspecified natural origin' only refers to the water used at the production line of the car (process water) and excludes all other water uses inside the Rastatt factory. In the following analysis all the water used inside the production plant will be assessed excluding only the use of sanitary water and the water used in the canteen as they are not caused directly by the production of a car. It is therefore assumed that workers use the same amount of water for eating and sanitary services at work as they would use at home. The rest of the water is assumed to be used in the energy conversion and heat supply processes inside the plant and are consequently inside the scope of the LCA. The calculated amount of water[9] is supposed to have the same share of rain, tap- and groundwater as the complete production site. Ground- and rainwater[10] are inputs from ecosphere and therefore do not contain any upstream processes. In contrast tap water is an input from technosphere and several technical procedures are needed to provide it for the consumer.

Natural gas is used in Rastatt for heat and electricity generation. It is burned in a decentral combined heat and power station for which no further data have been available. Although it is mentioned in the environmental report that their power is 4MW, the data is not sufficient to model the actual type of power generation technology. Therefore a 1MW cogeneration system from the Ecoinvent database was used. As for the use of natural gas different figures with different units were provided it was decided to use the net caloric value given in Table 3.[11]

Solar panels inside the area are exclusively used for heating the sanitary water and are therefore not a part of the assessment[12].

Diesel and gasoline consumption have been taken into account as material flows that enter the plant only as there are no data about how the fuels are used inside the area. Liquefied natural gas (LNG) was just taken into account as a material flow too. Upstream processes for delivering those raw materials have been taken into account.

The light fuel oil is assumed to be burned in an industrial furnace of 1MW power.

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[8] Cf. Daimler (2011) page 40

[9] About 270,000 m³/a, which is about 80% of the overall water use (calculated water use plus the use for sanitary and canteen services.

[10] The density of tap and rain water is 1,000 kg/m³

[11] Consequently the entry natural gas, in ground in Table 2was disregarded.

[12] Cf. Daimler (2011) page 27

The wastewater, waste for recovery, and waste for disposal were taken into account as waste flows but further treatment was not considered as no appropriate process was found in the Ecoinvent database and no details about the treatment actually taking place was provided.

The electricity supplied by third parties was assumed to be delivered in medium voltage from the German energy mix.

Input flows for which no data have been provided have been assumed to be the same as in the Ecoinvent process production of a VW Golf A4 model.

The primary particulate matter (PPM) data given as PPM>2.5 and <10µm have been modelled as PPM2.5.[13]

All the other flows in Tables 1 and 2 are flows to or from nature and therefore no assumptions had to be made.

Tables 5 and 6 show the comparison between the production in LC1 and LC2.

[13] This is caused by the type of measurement.

Table 5: Comparison of the production phase in LC1 and LC2 (input flows)

	Input flows	Quantity	LC1	LC2	Unit
1	DE: electricity, medium voltage, at grid [supply mix]	Energy (net calorific value)	0.00E+00	1.80E+03	MJ
2	GLO: natural gas liquids, from natural gas, helium extraction [inorganics]	Mass	0.00E+00	4.28E-01	kg
3	GLO: nickel, 99.5%, at plant [Benefication]	Mass	1.40E+00	1.40E+00	kg
4	Occupation, industrial area, built up [Hemerobie ecoinvent]	Areatime	0.00E+00	2.24E+00	m2*yr
5	Occupation, industrial area, vegetation [Hemerobie ecoinvent]	Areatime	0.00E+00	2.02E+00	m2*yr
6	Occupation, traffic area, road network [Hemerobie ecoinvent]	Areatime	0.00E+00	1.92E+00	m2*yr
7	RER: alkyd paint, white, 60% in H2O, at plant [Manufacturing]	Mass	4.16E+00	4.16E+00	kg
8	RER: aluminium, production mix, at plant [Benefication]	Mass	5.18E+01	5.18E+01	kg
9	RER: chromium, at regional storage [Benefication]	Mass	2.40E+00	2.40E+00	kg
10	RER: copper, at regional storage [Benefication]	Mass	1.01E+01	1.01E+01	kg
11	RER: diesel, at regional storage [fuels]	Mass	0.00E+00	1.67E+00	kg
12	RER: ethylene glycol, at plant [organics]	Mass	4.80E+00	4.80E+00	kg
13	RER: ethylene, average, at plant [monomers]	Mass	1.85E+01	1.85E+01	kg
14	RER: flat glass, uncoated, at plant [construction]	Mass	3.01E+01	3.01E+01	kg
15	RER: heat, natural gas, at industrial furnace >100kW [heating systems]	Energy (net calorific value)	0.00E+00	2.22E+03	MJ
16	RER: lead, at regional storage [Benefication]	Mass	1.30E+01	1.30E+01	kg
17	RER: light fuel oil, burned in industrial furnace 1MW, non-modulating [heating systems]	Energy (net calorific value)	6.30E+01	1.21E+00	MJ
18	RER: natural gas, burned in cogen 1MWe lean burn [cogeneration]	Energy (net calorific value)	0.00E+00	3.48E+03	MJ
19	RER: palladium, at regional storage [Benefication]	Mass	3.00E-04	3.00E-04	kg
20	RER: petrol, low-sulphur, at regional storage [fuels]	Mass	0.00E+00	1.28E+00	kg
21	RER: platinum, at regional storage [Benefication]	Mass	1.60E-03	1.60E-03	kg
22	RER: polyethylene, HDPE, granulate, at plant [polymers]	Mass	1.02E+02	1.02E+02	kg
23	RER: polypropylene, granulate, at plant [polymers]	Mass	4.90E+01	4.90E+01	kg
24	RER: polyvinylchloride, at regional storage [polymers]	Mass	1.60E+01	1.60E+01	kg
25	RER: reinforcing steel, at plant [Benefication]	Mass	8.91E+02	8.91E+02	kg
26	RER: road vehicle plant [Street]	Number of pieces	2.91E-07	0.00E+00	pcs.
27	RER: section bar rolling, steel [processing]	Mass	2.03E+02	2.03E+02	kg
28	RER: sheet rolling, steel [processing]	Mass	5.41E+02	5.41E+02	kg
29	RER: steel, low-alloyed, at plant [Benefication]	Mass	9.90E+01	9.90E+01	kg
30	RER: sulphuric acid, liquid, at plant [inorganics]	Mass	8.00E-01	8.00E-01	kg
31	RER: synthetic rubber, at plant [polymers]	Mass	4.41E+01	4.41E+01	kg
32	RER: tap water, at user [Appropriation]	Mass	3.22E+03	2.05E+02	kg
33	RER: transport, freight, rail [Railway]	Ecoinvent quantity ton kilometer (tkm)	5.30E+02	5.30E+02	tkm
34	RER: transport, lorry >16t, fleet average [Street]	Ecoinvent quantity ton kilometer (tkm)	5.30E+01	5.30E+01	tkm
35	RER: wire drawing, copper [processing]	Mass	1.01E+01	1.01E+01	kg
36	RER: zinc, primary, at regional storage [Benefication]	Mass	5.89E+00	5.89E+00	kg
37	UCTE: electricity, medium voltage, production UCTE, at grid [production mix]	Energy (net calorific value)	7.70E+03	0.00E+00	MJ
38	Water (rain water) [Water]	Mass	0.00E+00	1.45E+01	kg
39	Water, well, in ground [Resources]	Volume	0.00E+00	9.13E-01	m3

Table 6: Comparison of the production phase in LC1 and LC2 (output flows)

	Output Flows	Quantity	LC1	LC2	Unit
40	Adsorbable organic halogen compounds (AOX) [Analytical measures to fresh water]	Mass	0.00E+00	2.77E-04	kg
41	Antimony [Heavy metals to air]	Mass	0.00E+00	9.20E-06	kg
42	Arsenic (+V) [Heavy metals to air]	Mass	0.00E+00	1.73E-06	kg
43	water]	Mass	2.60E-02	0.00E+00	kg
44	Cadmium (+II) [Heavy metals to air]	Mass	0.00E+00	4.70E-08	kg
45	Carbon dioxide [Inorganic emissions to air]	Mass	0.00E+00	1.36E+02	kg
46	Carbon monoxide [Inorganic emissions to air]	Mass	0.00E+00	3.06E-02	kg
47	water]	Mass	1.93E-01	0.00E+00	kg
48	Chromium (+VI) [Heavy metals to air]	Mass	0.00E+00	2.26E-06	kg
49	Cobalt [Heavy metals to air]	Mass	0.00E+00	6.80E-08	kg
50	Copper (+II) [Heavy metals to air]	Mass	0.00E+00	2.77E-05	kg
51	Dust (PM2.5) [Particles to air]	Mass	0.00E+00	3.78E-03	kg
52	Hydrocarbons (unspecified) [Hydrocarbons to fresh water]	Mass	0.00E+00	1.97E-04	kg
53	Iron [Heavy metals to air]	Mass	0.00E+00	1.23E-03	kg
54	Iron ion (+II/+III) [Inorganic emissions to fresh water]	Mass	0.00E+00	6.31E-05	kg
55	Lead (+II) [Heavy metals to air]	Mass	0.00E+00	7.33E-07	kg
56	Lead (+II) [Heavy metals to fresh water]	Mass	0.00E+00	3.60E-06	kg
57	Manganese (+II) [Heavy metals to air]	Mass	0.00E+00	2.45E-05	kg
58	Nickel (+II) [Heavy metals to air]	Mass	0.00E+00	1.89E-06	kg
59	Nickel (+II) [Heavy metals to fresh water]	Mass	0.00E+00	6.29E-05	kg
60	Nitrite [Inorganic emissions to sea water]	Mass	0.00E+00	4.99E-04	kg
61	Nitrogen oxides [Inorganic emissions to air]	Mass	0.00E+00	8.36E-02	kg
62	NMVOC (unspecified) [Group NMVOC to air]	Mass	4.80E+00	5.85E-01	kg
63	Phosphate [Inorganic emissions to fresh water]	Mass	1.00E-03	0.00E+00	kg
64	RER: passenger car [Street]	Number of pieces	1.00E+00	1.00E+00	pcs.
65	Strontium [Inorganic emissions to air]	Mass	0.00E+00	5.37E-07	kg
66	Sulphur dioxide [Inorganic emissions to air]	Mass	0.00E+00	2.67E-03	kg
67	Thallium [Heavy metals to air]	Mass	0.00E+00	3.36E-09	kg
68	Tin (+IV) [Heavy metals to air]	Mass	0.00E+00	2.19E-05	kg
69	Titanium [Heavy metals to air]	Mass	0.00E+00	2.52E-05	kg
70	Waste heat [Other emissions to air]	Energy (net calorific value)	7.70E+03	0.00E+00	MJ
71	Waste for disposal (unspecified) [Waste for disposal]	Mass	0.00E+00	7.76E+01	kg
72	Waste for recovery (unspecific) [Waste for recovery]	Mass	0.00E+00	3.68E+01	kg
73	Waste water [Other emissions to fresh water]	Mass	0.00E+00	1.06E+03	kg
74	Zinc (+II) [Heavy metals to air]	Mass	0.00E+00	5.11E-04	kg
75	Zinc (+II) [Heavy metals to fresh water]	Mass	0.00E+00	1.47E-05	kg

25 of the 75 in- and output flows are the same in both production stages.

The main difference between the two production stages in LC1 and 2 are the differences in power supply and the additional emissions measured in Rastatt from the paint shop and the body shell production.

As a next step the LCIA method which was used to better understand car the car life cycles will be introduced shortly.

4 Assessment with CML2001

The CML2001 LCIA method assesses environmental impacts at the midpoint level. It also provides normalization factors for different locations. In this study normalization was performed using the factor for the 25 European Union countries[14].

The method is based on the guidance book published by Guinée et al. (2001). This publication includes several case study specific midpoint categories which can be used to assess life cycles. 11 baseline impact categories are defined and CFs are provided for most of these.

The CML version used here (version Nov. 2009) consists of 11 midpoint impact categories. Two of them, the 'abiotic depletion elements' and 'abiotic depletion, fossil' are input orientated categories. All the other 9 categories are output orientated midpoints as they assess emission flows to nature. Concerning the debate about climate change taking place at the moment, the most important indicator is the Global Warming Potential (GWP) expressed in CO_2-Equivalent.This is the case because the transport sector, and within that, the individual motor car traffic, is responsible for a high share of the emissions in this sector in Germany.

The CML2001 model is continuously updated. As the changing characterization and normalization factors are disregarded in the Monte Carlo Analysis performed in chapter 5.4 this uncertainty is not taken into account. In Appendix C the complete assessment of this chapter was executed by using the first version of CML2001. It is also possible to assess how the results based on the same inventory data change in time.

In the complete case study, the assessment was executed using the LCIA software GaBi.

4.1 Impact assessment result of Life Cycle 1

Table 6 shows the impact assessment results for LC1 including all of the life cycle stages as absolute values (characterised scores) and as a normalized score for each impact category. As mentioned before the absolute values of different midpoints cannot be compared. The table does not answer the question about how strongly this flow influences the environment.

Table 7: absolute and normalized values of theCML2001 impact categories of LC1

CML2001 - Nov. 2009	LC1			
	absolut value	unit	normalized Europe	unit
Abiotic Depletion (ADP elements)	4.6E-07	[kg Sb-Equiv.]	5.64E-15	[yr]
Abiotic Depletion (ADP fossil)	2.5E+00	[MJ]	8.07E-14	[yr]
Acidification Potential (AP)	6.5E-04	[kg SO2-Equiv.]	2.39E-14	[yr]
Eutrophication Potential (EP)	2.2E-04	[kg Phosphate-Equ	1.68E-14	[yr]
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	2.3E-02	[kg DCB-Equiv.]	4.58E-14	[yr]
Global Warming Potential (GWP 100 years)	1.8E-01	[kg CO2-Equiv.]	3.65E-14	[yr]
Human Toxicity Potential (HTP inf.)	7.2E-02	[kg DCB-Equiv.]	9.50E-15	[yr]
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	5.9E+01	[kg DCB-Equiv.]	5.24E-13	[yr]
Ozone Layer Depletion Potential (ODP, steady state)	2.1E-08	[kg R11-Equiv.]	2.44E-16	[yr]
Photochem. Ozone Creation Potential (POCP)	1.7E-04	[kg Ethene-Equiv.]	2.12E-14	[yr]
Terrestric Ecotoxicity Potential (TETP inf.)	6.9E-04	[kg DCB-Equiv.]	1.46E-14	[yr]

[14] Excluding Romania and Bulgaria which join EU in 2007 but are not part of the EU25.

To better deal with the result, the normalized value for each category has been calculated. As LC1 is a European average the NF used was the one for the European Union. It tells which share of the overall impact of an average European inhabitant is caused by this process. Again it is important to remember the functional unit: the share of e.g. GWP100 of 3.65E-14 do not refer to the share of a car lifetime but to 1pkm of transport service. The normalized value does not tell anything about the importance of an impact category either. Looking at the numbers it would seem that marine ecotoxicity should be the first one to be handled if trying to reduce environmental impacts in a car life cycle. However it just tells the reader that it has the highest share in the environmental impact of an average European citizen in this category.

However, this has to be further analysed and it has to be tested which effort is needed to reduce certain impacts in order to make a judgement about where are sensible measured which have a good return in reducing impacts.

To look deeper inside the car life cycle it has been investigated which life cycle stage is the most important one in each category.

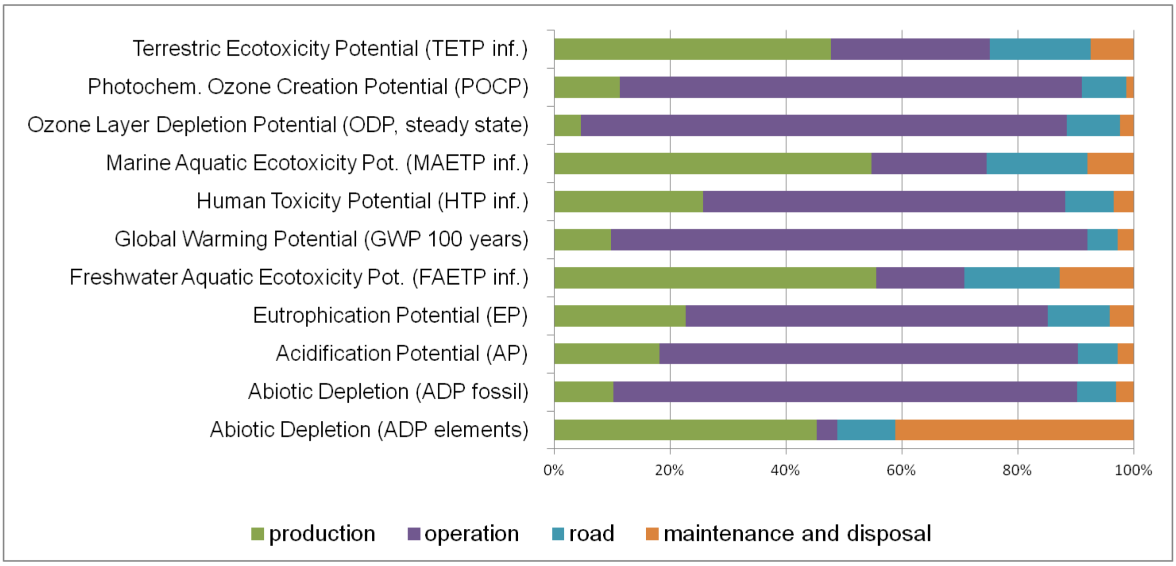

Figure 2: Contribution of the 4 life cycle stages to the CML2001 midpoint categories scores for LC1.

As shown in Figure 3 the production stage is most important in 4 of the 11 impact categories, the car operation phase has the highest impact in 7 midpoints, the road can be disregarded and the maintenance and disposal phase only has a significant impact in one impact category. Maintenance and disposal of a car does not have any significant impact anywhere but in the FAETP and ADP elements. This is the result of the baseline scenario. In LC 2 the production phase has been updated with newly measured data from the Daimler Rastatt production plant.

4.2 Impact assessment result of Life cycle 2

As the comparison takes place in chapter 5.4 this section will just analyse the result of LC2 on its own. As shown in Table 7, the highest normalized value is again the MAETP inf. and the others all have the same order of magnitude.

Table 8: Absolute and normalized scores of the CML2001 impact categories for LC2.

CML2001 - Nov. 2009	LC2			
	absolut value	unit	normalized Europe	unit
Abiotic Depletion (ADP elements)	4.6E-07	[kg Sb-Equiv.]	5.57E-15	[yr]
Abiotic Depletion (ADP fossil)	2.4E+00	[MJ]	7.95E-14	[yr]
Acidification Potential (AP)	6.3E-04	[kg SO2-Equiv.]	2.31E-14	[yr]
Eutrophication Potential (EP)	2.0E-04	[kg Phosphate-Equ	1.59E-14	[yr]
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	2.1E-02	[kg DCB-Equiv.]	4.19E-14	[yr]
Global Warming Potential (GWP 100 years)	1.8E-01	[kg CO2-Equiv.]	3.60E-14	[yr]
Human Toxicity Potential (HTP inf.)	7.0E-02	[kg DCB-Equiv.]	9.20E-15	[yr]
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	5.3E+01	[kg DCB-Equiv.]	4.67E-13	[yr]
Ozone Layer Depletion Potential (ODP, steady state)	2.1E-08	[kg R11-Equiv.]	2.42E-16	[yr]
Photochem. Ozone Creation Potential (POCP)	1.7E-04	[kg Ethene-Equiv.]	2.03E-14	[yr]
Terrestric Ecotoxicity Potential (TETP inf.)	6.7E-04	[kg DCB-Equiv.]	1.41E-14	[yr]

Figure 4 shows again the shares of each stage for the impact category score. The operation stage is still the most important in 7 categories and the production stage in 4 impact categories. The change of the production stage does not have any significant impact on the share of the life cycle stages for each category score.

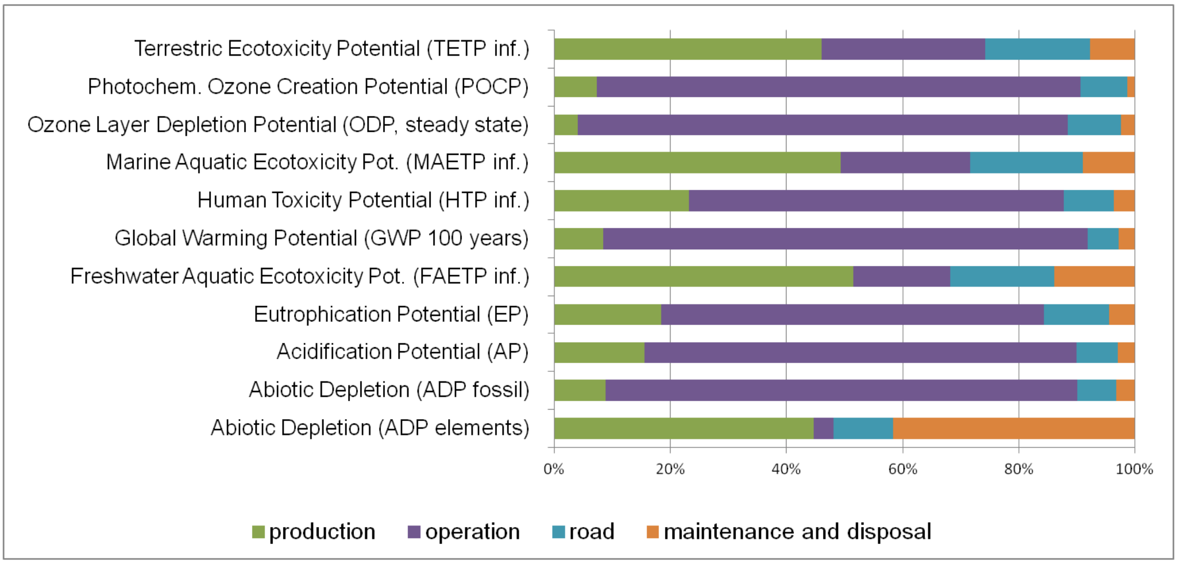

Figure 3: Contribution of the 4 life cycle stages to the CML2001 midpoint categories' scores for LC2.

4.3 Impact assessment result of Life Cycle 3

In LC3 additionally to the changes between LC 1and 2, the operation stage has been changed from conventional fuel use into 100% biodiesel use. Looking into Table 8 one might recognize that MAETP inf. still has the highest share in normalized values but ODP and ADP fossil fell by one or two orders of magnitude.

Table 9: Absolute and normalized scores of theCML2001 impact categories for LC3

CML2001 - Nov. 2009	LC3			
	absolut value	unit	normalized Europe	unit
Abiotic Depletion (ADP elements)	5.2E-07	[kg Sb-Equiv.]	6.37E-15	[yr]
Abiotic Depletion (ADP fossil)	7.9E-01	[MJ]	2.59E-14	[yr]
Acidification Potential (AP)	5.7E-04	[kg SO2-Equiv.]	2.09E-14	[yr]
Eutrophication Potential (EP)	4.2E-04	[kg Phosphate-Equ	3.27E-14	[yr]
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	1.9E-02	[kg DCB-Equiv.]	3.86E-14	[yr]
Global Warming Potential (GWP 100 years)	1.9E-01	[kg CO2-Equiv.]	3.91E-14	[yr]
Human Toxicity Potential (HTP inf.)	3.0E-02	[kg DCB-Equiv.]	3.95E-15	[yr]
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	4.6E+01	[kg DCB-Equiv.]	4.06E-13	[yr]
Ozone Layer Depletion Potential (ODP, steady state)	5.8E-09	[kg R11-Equiv.]	6.70E-17	[yr]
Photochem. Ozone Creation Potential (POCP)	6.5E-05	[kg Ethene-Equiv.]	7.89E-15	[yr]
Terrestric Ecotoxicity Potential (TETP inf.)	7.9E-04	[kg DCB-Equiv.]	1.66E-14	[yr]

Figure 5 shows that now in terrestrial ecotoxicity the share of the production and the operation stages are almost identical. In 6 of the other impact categories the operation stage remains the most important one and in the other 4 the production stage is still most important. It seems that in some categories the share of the operation stage has even increased instead of decreasing. This is especially the case of the GWP100 where it was expected to fall.

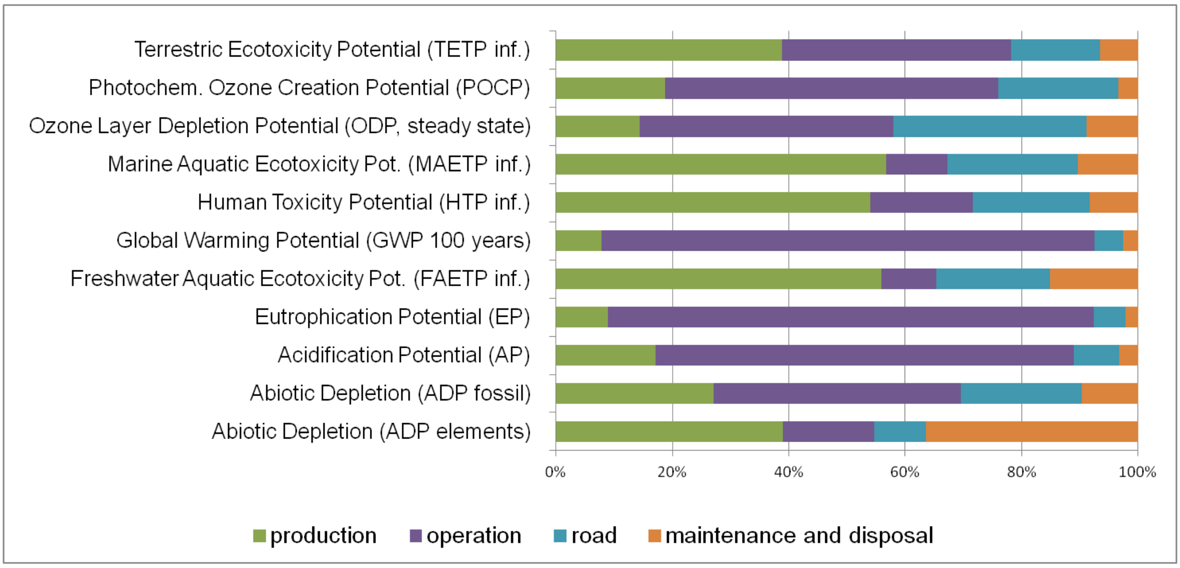

Figure 4: Contribution of the 4 life cycle stages to the CML2001 midpoint categories scores for LC3

4.4 Summary and critical review of the results

After each scenario has been analyzed shortly on its own, they will now be compared on an aggregated level.

Table 10 shows the variation of the 11 regarded CML2001 categories on the base of LC1 and consequently on the base of an European average car. LC2 has a slightly lower impact in all categories. Consequently the production inside the Daimler Rastatt plant has lower impact than the one used in LC1. The reader might remember that the production stage in LC1 taken completely from the Ecoinvent database had gaps in the inventory which were partly filled by the new data used in LC2. The different types of power generation have therefore higher impact than the additional airborne emissions measured in Rastatt.

Table 10: Impact of LC2 and LC3 compared to the impact of LC1 (CML2001 - all categories)

CML2001 - Nov. 2010	LC1	LC2	LC3
Abiotic Depletion (ADP elements)	100%	99%	113%
Abiotic Depletion (ADP fossil)	100%	99%	32%
Acidification Potential (AP)	100%	97%	88%
Eutrophication Potential (EP)	100%	95%	195%
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	100%	92%	84%
Global Warming Potential (GWP 100 years)	100%	99%	107%
Human Toxicity Potential (HTP inf.)	100%	97%	42%
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	100%	89%	78%
Ozone Layer Depletion Potential (ODP, steady state)	100%	99%	27%
Photochem. Ozone Creation Potential (POCP)	100%	96%	37%
Terrestric Ecotoxicity Potential (TETP inf.)	100%	97%	114%

Critical review

The first thing being recognized by those interested in climate change is that the GWP is higher when driving a car with biofuel than driving it with conventional fuel. This is a result of the fact that CML does not distinguish between biogenic CO_2 and fossil CO_2. In the use stage of LC3 the sequestering of the carbon dioxide during growth phase of the plant was not considered. Without the effect of this biogenic compound the GWP100a of LC3 would decrease by over 80%. Here to mention is also that the LCIA methods named CML2001 in both programs differ between GaBi and SimaPro[15]. A list of the characterization factors for GWP100a from both sources can be seen in Appendix E.

The significant decrease of ADP fossil in LC3 is apparently a result of the substitution of the fossil resource crude oil by the renewable resource rapeseed in the operation stage. The benefits in acidification potential come from processes which avoid the use of fossil resources. The use of these resources would cause acid emissions and the benefit caused by replacing those fossil raw materials is giving a credit in the model by DTU. Eutrophication in LC1 and 2 is caused by the compounds in the exhaust fumes on the streets only. In biodiesel production the crop growing on fields has additional EP in the same order of magnitude as the emissions from the biodiesel or conventional fuel engines. The additional fertilizers also account in the terrestric ecotoxicity. Human toxicity of burning conventional fuels is ten times higher than burning biofuel as the emission of NMVOCs are very low

[15] SimaPro is the second LCIA software to be used to assess the life cycles and was used to perform the Monte Carlo Analysis as GaBi does not take the standard deviation of single elementary flows into account.

during ester combustion. This fact also causes the lower ozone layer depletion potential and photochemical ozone creation potential.

In Appendix E a Monte Carlo Analysis[16] of LC1 and the operation stage of LC3 were performed to know about the magnitude of the error in the results. As LC1 and 2 vary only in the few primary data provided by Daimler and taking into account the fact that those data have the least uncertainty possible, it can be taken as granted that the production of the Daimler plant in Rastatt has less environmental impact than the European average used in LC1. The result of LC3 is highly dependent on the uncertainty of biofuel production and burning. The variation in some categories is as high as 6000% and would consequently allow no comparison between biodiesel and conventional fuel use.

Koffler et al. (2012) provide evidence that the standard deviation of in- and outputs from respectively to ecosphere have less impact on the uncertainty of a process than the variation of flows in technosphere like the increase of car production in the Rastatt plant. Following Koffler et al. (2012) and assessing only the year 2010 in the case study, one may compare the numbers given in Table 9 not taking the uncertainty into account as the production for this year is known and uncertainty in fuel consumption was never addressed.

[16] Performed using 10,000 runs and a confidence interval of 95%.

5 Hot spot analysis

In the following the newly developed spatially differentiated CFs will be tested for applicability. Before the LCIA can be conducted, the processes have to be allocated.

If the location of the processes is unknown because the data used in the LCI are secondary data, it is not seen to be practicable to locate every single environmental impact where it happened in reality as for example LC1 includes 1,958 different processes. Instead, only the most important processes can be located. This decreases the amount of work significantly. Consequently a hot spot analysis is needed to find out which processes have to be allocated.

For the analysis, the two programs GaBi[17] and SimaPro[18] were available to do the impact assessment and both have been used to conduct the best assessment possible.

Neither GaBi nor SimaPro has the function to allocate emissions directly to an area. But in GaBi the grouping function can be used to find out which amount of emission/resource use takes place in which region (region has to be inserted manually). In both softwares there is the possibility to create new flows like e.g. "Carbon dioxide, to air, in DE"[19] and then for each of these flows CFs can be inserted. This will greatly increase the amount of flows that have to be handled and consequently make the assessment more costly. In the following case study the processes will be located and not the flows.

In the following the most important processes which will be allocated spatially have been found through two different approaches:

1. Within GaBi by manually finding the most important processes in the 2nd level. The exact procedure is shown in the section below. As only the 2nd level has been remodelled the impacts are completely allocated to that 2nd level process which means that all the impacts which occur in processes earlier in the production chain are characterized at the location of the plant where the 2nd level process is located. For that reason it is highly dependent on the way the system is modelled.

2. Within SimaPro by calculating the network/tree and using a cut-off criteria to find the most important processes in each level of the life cycle.

5.1 Hot spots through GaBi

To ease the application of the spatially specific CFs the hot spots of this system have been localized. They were found by manually analyzing the data at first of the 1st level. Only those of the 4 LC phases having more than 10% of the impact were taken into account with the additional criteria that 90% of each midpoint impact had to be covered. Then the two or three most important processes in each of those life cycle phases have been found. A table showing the results of this operation is shown in Appendix B.

The most important processes found in LC1 through this criterion are:

[17] Product of PE International
[18] Product of Pré
[19] The population density can be taken into, too.

Table 11: Hot spots of level 1 and 2 processes in LC1

The result of this kind of analysis includes of course a lot of assumptions and consequently mistakes. One is that the impacts do not take place in the first and second stage of the LC only but also further upstream in the production chains. GaBi was designed to implement averaged processes in the LC if no primary data are readily available. Therefore aggregated processes have been created that consist of all the LCI data of all processes upstream in the production chain. Like that the process of reinforcing steel involves the impacts of e.g. the crude ore extraction in Russia as well as the steel production in China. If the hot spots of all the ca. 2,000 processes have to be found, each of these processes has to be looked up in a database and be inserted manually.

5.2 Hot spots through SimaPro

SimaPro provides a different and easier function to find the hot spots in the system which can be shown directly in a tree or system chart. By calculating the balance of an existing system from the Ecoinvent database like LC1, it automatically creates a system containing all the processes in all stages of the production chain. The hot spots can be and have to be displayed for each impact category on its own. Figure 6 shows the calculated system for LC1 and the relative contribution of the Acidification potential (AP) with a 20% cut-off criterion[20].

[20] Meaning no process containing less than 20% of the acidification potential of the life cycle is displayed in the system.

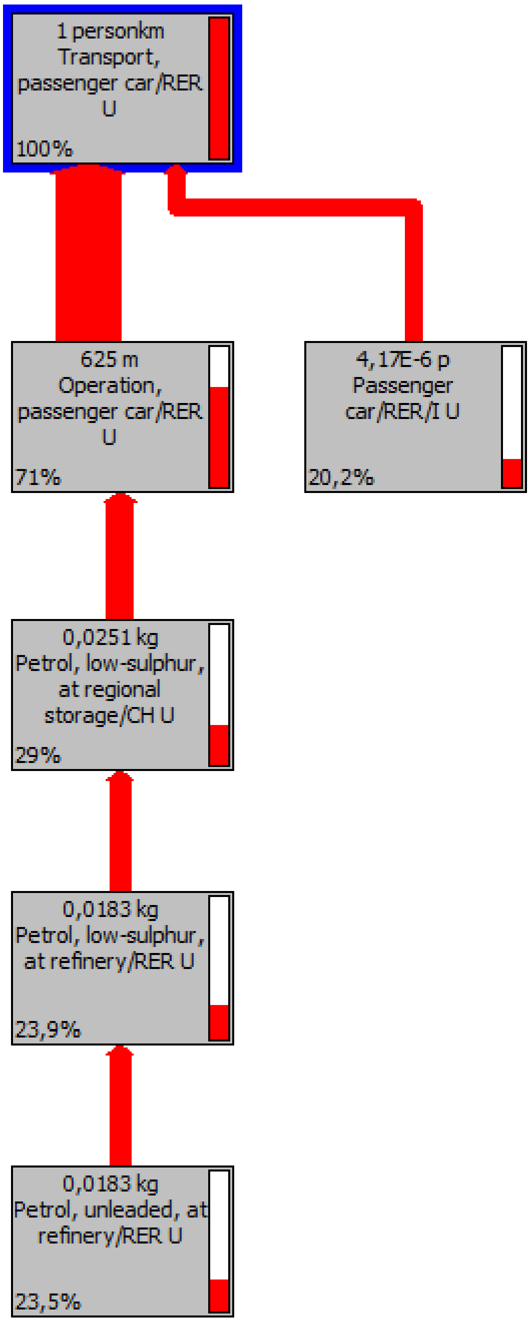

Figure 5: Hot spots of the Acidification Potential (AP) through SimaPro in LC1.

The chart shows that all the processes that are worth being allocated in LC1 concerning AP are inside the life cycle production stage (right) and the operation stage (left). Using a 10% cut-off criterion 13 processes have to be allocated. Using a 1% cutoff criterion 73 processes of all life cycle phases will be included. The requirements concerning the accuracy of the allocation has therefore a big influence on the amount of work that is necessary.

As there were no data about the location of all the processes in the production chain available, assumptions were made in the following to be able to test the applicability of the spatial differentiation.

6 Assessment with CFs developed within LC-IMPACT

The goal of this part of the case study will be to test the applicability of newly developed and spatially differentiated CFs with the three scenarios shown in the previous chapters. If possible the LCA will be performed.

For the case study the following impact categories have been assessed:

- land use
- water use
- mineral and fossil resource use
- terrestrial ecotoxicity
- higher predator toxicity
- human toxicity of pesticides
- aquatic eutrophication
- acidification
- photochemical ozone and fine particulate matter formation
- noise

As the location of the processes is needed and most of the data are secondary data for which no exact location is available assumptions concerning the spatial allocation have to be made. As these assumptions have to be made in a high share of all processes the representativeness of the results is questionable.

6.1 Assumptions

<u>Production phase:</u>

As the primary data from the Daimler Rastatt plant can directly be located at its real origin, a CF referring to the production site is therefore needed. All the processes which cannot be allocated directly at the Daimler Rastatt plant are modelled as European average conditions and will therefore be assessed by default CFs for Europe. The only process pointed out as a global average is the nickel production. This one will consequently be characterized by a global default factor.

<u>Operation phase:</u>

The fuel consumption in the use stage will take place in Germany only. Consequently a German default CF is needed for this process.

The biodiesel production as a part of the car operation stage was modelled by DTU. The project partner refers that the production is based on data collected in Denmark but was adapted to German conditions. Consequently it will be assumed that the production will take place in Europe as it cannot be attached to a specific country.

Therefore again European averaged CFs are needed.

Road

As road construction, manufacturing, and disposal take place in Germany too, it is assumed that all the environmental impacts in this life cycle stage take place in Germany. Although some impacts take place in other countries it is seen more feasible to characterize the process, the overall impact of this life cycle stage is not important enough to justify the amount of work the exact allocation of each process would cost.

Maintenance and disposal

As the impact of maintenance and disposal of the car is even less important than the one of the road, again CFs for averaged German conditions are needed.

Considering the assumptions made for the allocation the following area specific CFs are needed for each impact category.

- Site specific CF for the Rastatt plant
- German default
- European default
- Global default

The following table will show for each set of CFs if the factors needed for the case study are provided.

Rastatt	Global	European	German
YES/NO	YES/NO	YES/NO	YES/NO

To get a rough estimation of how the share of the different impacts will be concerning the different areas LC1-3 have been assessed once again.

Figure 7 shows the results of all life cycles and midpoint categories. This time using the differentiation of the areas as explained before. Caused by the assumptions, the most important areas in all categories are Germany and Europe as most of the processes have been allocated there. To facilitate the comparison the same processes have been given the same spatial allocation in each category. Consequently the production stage in LC1 was located in Rastatt.

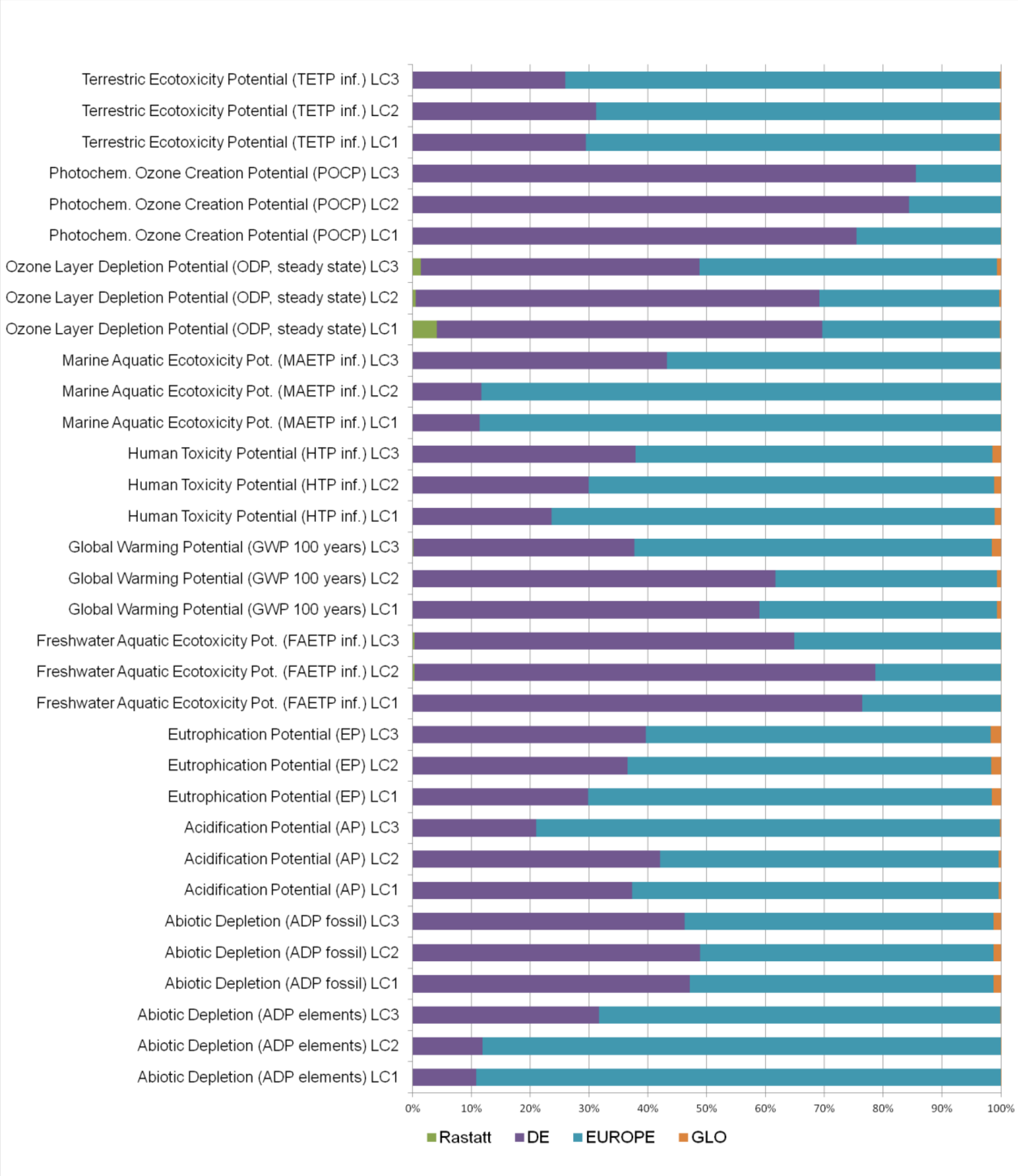

Figure 6: Result of LC1-3 according to the different locations (CML2001 - all categories).

Another important differentiation in addition to the country-specific resolution of the CFs is the population density in which the emissions of the output oriented factors take place. The Ecoinvent database uses the three types: high population density, low population density, and unspecified. Another nomenclature could be urban, rural, and unspecified. This allocation is only said to be important for emissions to nature.

In the following pages the CFs that have been developed in WP1-3 of the LC-IMPACT project will be displayed as a diagram to facilitate the understanding of the impact assessment pathway. The diagrams contain the task number in which the CFs have been developed, the type of the LCI data, the type of spatial differentiation which was made as well as the name of the impact category the inventory data are converted to and the units of all these numbers.

The focus will be on practicability and if all characterization factors that are needed in the case study are available in the tables given by the developers. Additional data are provided if the nomenclature in the LCI is different from the one in the excel sheets provided by the method developers. Not all the problems concerning the application can be displayed as not all of the CFs are provided. Additionally, spreadsheets containing new CFs have been updated and new ones have been added during the time this report was written. Consequently some of the CFs are only regarded very quickly and superficially while others are displayed in more detail.

6.2 Land use

The land use CFs were given in 8 excel-spreadsheets by the project partner IIASA. All of them are input oriented and therefore do not refer to an output to nature but to raw material extraction and land use. Consequently no differentiation in population density has to be considered.

A major problem in the CFs given by the project partner is that the structure and resolution is different in almost every single sheet. Especially the resolution differs from country (partly in ISO 3166 country codes), WWF ecoregions and biomes. The CFs will be needed in all the spatial resolutions shown before as there are impacts caused by land use in the production as well as in the operation phase. As the guidance document (cookbook)[21] are only given for 2 of the 8 spreadsheet it might be possible that units or assessment paths are wrong as they had to be devised.

Figure 8 shows the path of assessing the production of four different kinds of crops per kg of its production in sheets 1 and 2[22] (Sheet 1: Agricultural erosion: rangeland base; Sheet 2: Agricultural erosion: tree base). The midpoint category is an impact measured monetarily in $. The resolution of the CFs is on a country scale containing about 200 different nations worldwide.

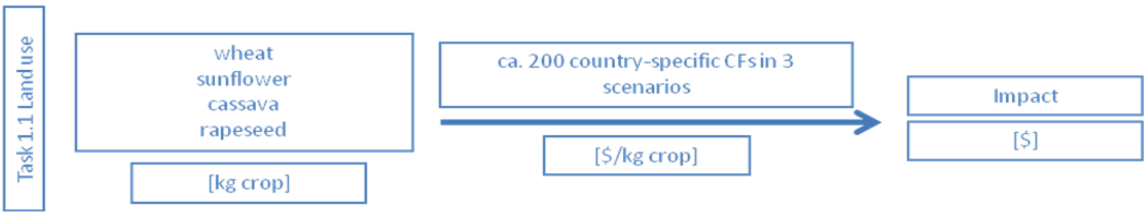

Figure 7: Characterization factor: Task 1.1: land use (1)[23]

[21] These should clearly explain how to use the CFs.

[22] As 8 excel sheets are part of this impact category they are enumerated by the order given in the summary table of the LC-IMPACT online wiki.

[23] During the time this deliverable report was written three more crops were added to the list: sugar cane, corn, and soybean. None of the new ones is needed to provide transport service with a passenger car.

As said before population density has not to be considered here. The following table shows if the resolutions needed for the case study are covered in the spreadsheets 1 and 2.

Rastatt	Global	European	German
NO	NO	NO	YES

The agricultural erosion CFs refer to land used indirectly as they assess the impact of growing a specific mass of crops. The only agricultural product that will be used in this case study will be the rapeseed used for producing the biodiesel in LC2 and LC3. The amount needed for one pkm of transport service can be displayed by both programs GaBi and SimaPro. Rapeseed is a flow in the technosphere and will therefore not appear looking at the overall balance sheet because it is just an intermediate product. About 109g of rapeseed are necessary for one pkm of transport service. As said before the production of the biofuel is assumed to take place in Europe and no average European CF was provided yet. The biggest producers of biofuels are countries like the USA, Canada, Mexico, and Australia. For all these countries CFs are given in sheets 1 and 2 if imported fuel has to be assessed.

To give a first estimation on how severe the difference between the different countries in the world is, some examples will be given:

Table 12: Impact of rapeseed use in LC2 and LC3

country	country	impact[$]
Niger	NER	2.78E-07
Germany	DEU	2.36E-06
United States	USA	2.42E-06
Italy	ITA	1.72E-05
Canada	CAN	3.06E-05
Norway	NOR	3.99E-04
Iceland	ISL	1.29E-01

Additionally to the impact category expressed in $ in sheets 1 and 2 a midpoint category concerning the species loss was provided by the project partner in sheets 3 and 5 (Sheet 3: BDP CF Occupation, Sheet 5: deBaan Local CF Occupation final). Figure 9 shows the assessment path. The LCI data have to be specified in the categories given in the big box on the left side of the table. For the primary data from the Daimler Rastatt production plant these data have been collected but have to be specified in detail by the project partner Daimler. For the secondary data taken from Ecoinvent an assessment without default CFs will not be possible.

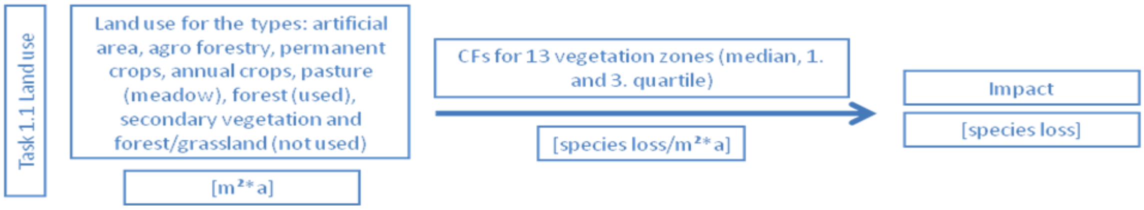

Figure 8: Characterization factor: Task 1.1: land use (2)

The CFs are given for 13 vegetation zones and therefore contain no default factor for a specific country. The factors are given for specific types of vegetation. As the operation of a car takes place in all kinds of vegetation covers an overall default factor is needed for Germany. To assess the other processes containing land use a default factor for Europe is needed as well as one global default factor to have an comparative value. The following table shows that none of the resolutions needed for assessing the life cycle is given in spreadsheets 3 and 5. The inventory data that are needed for this category are given in a table in Appendix D1.[24]

Sheet 4[25] (sheet 4: CF database BDP) displays again the impact of land use on biodiversity but this time the input data type is divided in more subcategories (e.g. land use for agricultural purpose (Level 1), with a permanent crop (Level 2), non-irrigated (Level 3), extensive (Level 4) in a tropical and subtropical dry broad-leafed forest (vegetation zone - spatial differentiation)). There is a subcategory named traffic area in the sheet which can be used to assess the operation phase of the car.

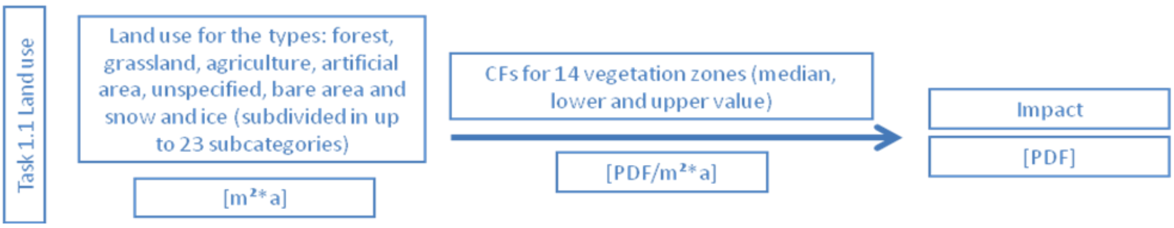

Figure 9: Characterization factor: Task 1.1 land use (3)

[24] The data are already divided into the different locations.

[25] this sheet contains an empty table that shows which CFs will be provided in the future but not one of them was calculated yet (last update: 19.06.2012)

Table 13: CFs used for assessing the species loss

	CFs		
[species loss]	World	DE	RER
Occupation, arable	6.00E-01	7.60E-01	7.36E-01
Occupation, arable, non-irrigated	6.00E-01	7.60E-01	7.36E-01
Occupation, construction site	4.40E-01	4.00E-01	4.06E-01
Occupation, dump site	4.40E-01	4.00E-01	4.06E-01
Occupation, dump site, benthos	4.40E-01	4.00E-01	4.06E-01
Occupation, forest, intensive	1.80E-01	2.20E-01	2.14E-01
Occupation, forest, intensive, normal	1.80E-01	2.20E-01	2.14E-01
Occupation, forest, intensive, short-cycle	1.80E-01	2.20E-01	2.14E-01
Occupation, industrial area	4.40E-01	4.00E-01	4.06E-01
Occupation, industrial area, benthos	4.40E-01	4.00E-01	4.06E-01
Occupation, industrial area, built up	4.40E-01	4.00E-01	4.06E-01
Occupation, industrial area, vegetation	4.40E-01	4.00E-01	4.06E-01
Occupation, mineral extraction site	4.40E-01	4.00E-01	4.06E-01
Occupation, permanent crop, fruit, intensive	4.20E-01	2.00E-02	8.00E-02
Occupation, shrub land, sclerophyllous	4.40E-01	4.00E-01	4.06E-01
Occupation, traffic area, rail embankment	4.40E-01	4.00E-01	4.06E-01
Occupation, traffic area, rail network	4.40E-01	4.00E-01	4.06E-01
Occupation, traffic area, road embankment	4.40E-01	4.00E-01	4.06E-01
Occupation, traffic area, road network	4.40E-01	4.00E-01	4.06E-01
Occupation, urban, discontinuously built	4.40E-01	4.00E-01	4.06E-01
Occupation, water bodies, artificial	4.40E-01	4.00E-01	4.06E-01
Occupation, water courses, artificial	4.40E-01	4.00E-01	4.06E-01

It was assumed that Germany is a part of the ecoregion ‘Temperate broadleaf and mixed forest’ only and that Europe is a mixture of 85% ‘Temperate broadleaf and mixed forest’ and 15% of ‘Mediterranean forests, woodlands and scrubs’.

Table 14: Result of assessing the species loss

[species loss]	LC1	LC2	LC3
specified as said in Chapter 6.1	2.72E-03	2.66E-03	4.18E-02
Global averaged CF only	2.94E-03	2.88E-03	3.48E-02
relative change caused by specification	-7%	-8%	+20%

The result of the characterization shows different changes in the 3 scenarios. While the impact of LC1 and LC2 decreases by specifying the locations of the impact, in LC3 the figure increases significantly as shown in Table 14.

The next sheet (Sheet 6: deBaan Regional CF Mammals) covers three types of midpoint impact categories. As shown in Figure 10 the LCI data have to be subdivided into 4 land use types and the assessment covers endemic and non-endemic species in different paths. The impact of occupation and transformation on regional biodiversity is covered as well as the permanent species loss on a global scale.

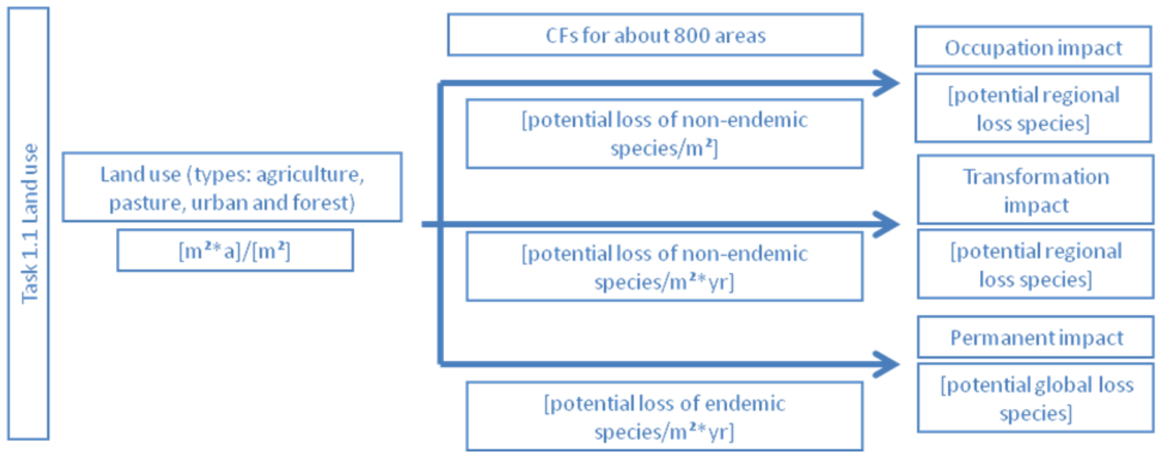

Figure 10: Characterization factor: Task 1.1 land use (4)

The problem that occurs here is that no averaged CFs for Global and European impacts are given to compare the specified results with a default factor.

Rastatt	Global	European	German
NO	NO	NO	NO

A singularity of this excel sheet compared to the other tasks is that the areas are given in the official code of the WWF ecoregions[26]. This resolution differs from the ones used by any of the other CF providers. If the location of the impacts inside the life cycles is known, they are known to happen in a country which differs from the resolution used by the WWF as it considers the changing of natural vegetation and not the human country borders.

The next sheet (Sheet 7: Characterisation factors for forestry) deals with the extraction of wood from forests and considers two different endpoints and one midpoint category as shown in Figure 11.

[26] Cf. Olson et al. (2001)

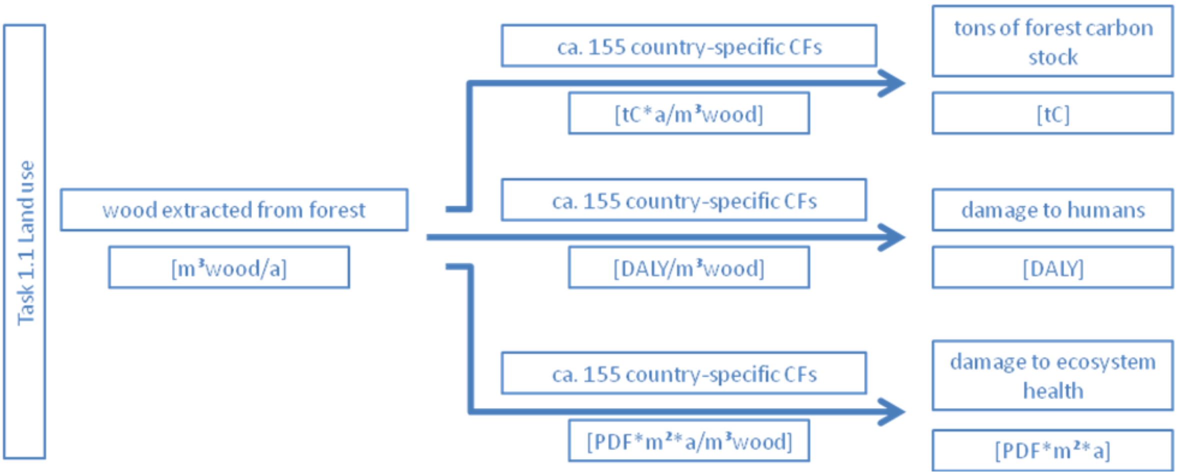

Figure 11: Characterization factor: Task 1.1: Land use (5)

The resolution here is country specific. This makes it easy to apply in the operation phase of the life cycle.

Rastatt	Global	European	German
NO	NO	NO	YES

To be mentioned here additionally is that the LCIA programs and the Ecoinvent database distinguish between different types of wood. This is not done by the CF developer.

Table 15 shows the inventory data needed to calculate the midpoint impacts shown before.

Table 15: Wood used in LC1-3 [unit/pkm]

wood [m^3]	LC1	LC2	LC3
Rastatt	0.00E+00	0.00E+00	0.00E+00
DE	3.43E-07	3.75E-07	3.75E-07
EUROPE	4.22E-07	2.43E-07	3.16E-07
GLO	1.39E-09	1.39E-09	1.39E-09
Sum	7.67E-07	6.20E-07	6.93E-07

Wood is used in the production and use phase in processes that are assumed to take place especially in Europe for which no CF was provided yet.

The last sheet (Sheet 8: CFs soil erosion Núñez et al.) contains the impact of soil erosion caused by land occupation only as transformation was not addressed. Two endpoint indicators were developed: one for damage to resources (unit: MJ solar energy) the other for damage to ecosystems (unit: decimal percentage of net primary production depletion, NPPD).[27]

The method was developed to be able to assess the secondary data of the Ecoinvent database as well as primary data from any other process. Like that the assessment of the complete life cycles is possible without errors through assumptions or the application of cut-off criteria.

[27] Cf. Cookbook_soil erosion_Nunez et al.; page 1

Rastatt	Global	European	German
NO[28]	YES	YES	YES

As the table above shows, this sheet is covering most of the resolution types necessary to assess the complete life cycle of a car and according to the CF provider the site specific factor for Rastatt can be displayed on a grid cell level easily.[29]

In this case another problem occurs: The LCI data of land use have to be converted into soil erosion figures. Consequently averaged soil erosion rates for Germany, Europe and the world are necessary as well as a site specific rate for Rastatt to assess the impact of soil erosion to resources and damage to ecosystems. Cerdan et al. 2010 provides erosion data for Germany and Europe and additionally concludes that recent estimations of global erosion rates overestimate the true average global erosion.[30] As these figure is necessary to validate the calculations, the characterization phase has not been performed yet.

[28] Is not included in the excel sheet but according to the text given by the author in the guidance document it can be calculated.

[29] cf. guidance document (cookbook) task 1.1: Cookbook_soil erosion Núñez et al

[30] cf. Cerdan et al. 2010 page 174

6.3 Water Use

Inside this resource oriented impact category two excel sheets have been developed by the project partner ETH.

The first one (CFs wetland for review) contains water use CFs that refer just to impact caused by using surface or groundwater inside wetlands of international importance. It does not assess impacts caused by water use outside these wetlands. The way the characterization is made is shown in Figure 12.

All CFs necessary to assess the life cycles as said in chapter 6.1 have been provided by the project partner.

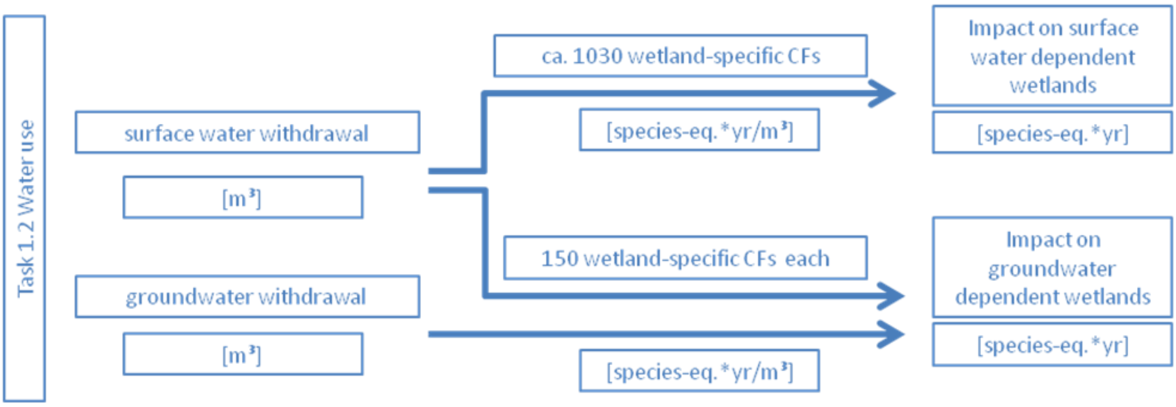

Figure 12: Characterization factor: Task 1.2: water use (1)

Rastatt	Global	European	German
YES	YES	YES	YES

The Ecoinvent database and consequently the LCIA programs do not distinguish water in ground and surface water only.

Table 16: Water use in LC1-3 [unit/pkm]

	surface water			groundwater		
[m³]	LC1	LC2	LC3	LC1	LC2	LC3
Rastatt	0.00E+00	6.05E-08	6.05E-08	0.00E+00	3.80E-06	3.80E-06
DE	3.10E-01	3.15E-01	3.15E-01	1.36E-05	1.62E-05	1.62E-05
EUROPE	1.56E-01	1.20E-01	1.19E-01	3.06E-05	1.82E-05	2.21E-05
GLO	2.50E-03	2.50E-03	2.50E-03	9.66E-07	9.66E-07	9.66E-07
Sum	4.69E-01	4.37E-01	4.36E-01	4.52E-05	3.92E-05	4.31E-05

Table 16 shows the inventory data needed to calculate the midpoint impact as shown before. The LCI data are classified in more categories than ground- and surface water, but over 75% of the water used in the production chain is not even allocated to ground or surface water (includes lake, river, and sea water). If only 24% of the overall water use can theoretically be assessed by the CFs and the practicability is questionable, it seems that in the case of this life cycle this allocation is not beneficial without calculating a CF for the resource water (unspecified). In Table 16 it was assumed that this kind of water is surface water as most of it is for turbine use.

Table 17 shows the result of the characterization summing up the loss of waterbirds, non-residential birds, water dependant mammals, reptiles and amphibians caused by the ground and surface water extraction.

It shows that the species loss declines significantly in all three scenarios if the characterization is performed by using the specifications of chapter 6.1 compared to using global averaged CFs only.

Table 17: Combined species loss caused by water extraction

[species loss]	LC1	LC2	LC3
specified as said in Chapter 6.1	2.75E-07	2.67E-07	2.67E-07
Global averaged CF only	4.11E-07	3.83E-07	3.82E-07
relative change caused by specefication	-33%	-30%	-30%

The second sheet contains CFs for water extraction from river basins worldwide as shown in Figure 13.

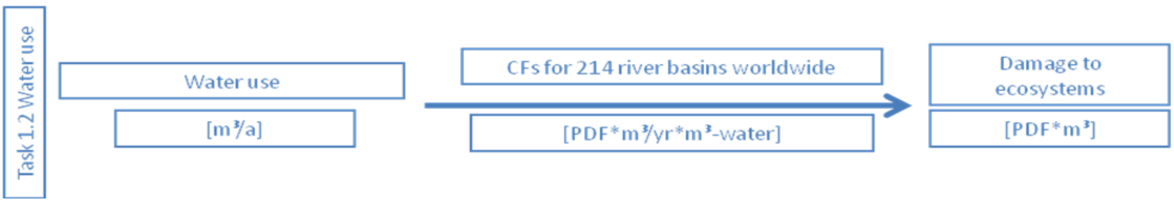

Figure 13: Characterization factor: Task 1.2: water use (2)

The water used in the Daimler production plant is ‘unspecified natural origin’ but a part of it is likely to be extracted from the Rhine as it runs nearby. But as it is not part of the list provided by ETH (neither is any other German river) a CF specific for this river has to be developed first. Additionally default CFs for water extraction from river will be needed for the countries and resolutions (except Rastatt) in the table below.

6.4 Mineral and fossil resource use

The mineral and fossil resource CFs are provided in one excel sheet by the project partner Pré.

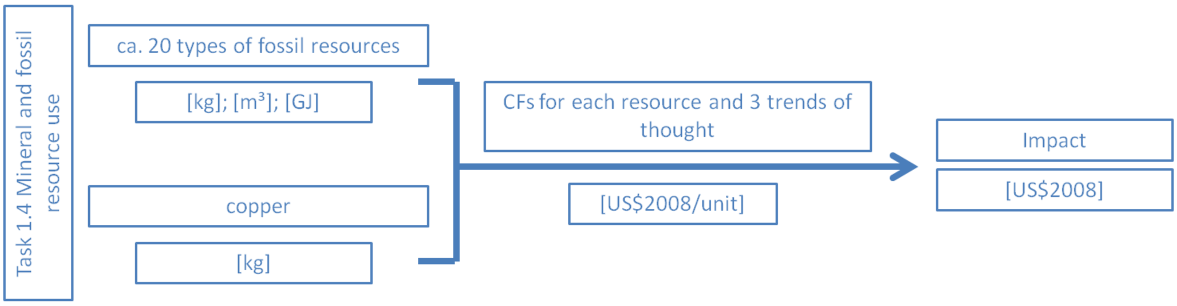

Figure 14: Characterization factor: Task 1.4: Mineral and fossil resource use

The impact category does not contain any spatial differentiation but factors for 3 cultural perspectives (i.e. individualist, hierarchist, and egalitarian) are given for characterising the use of copper and fossil resources.

The amount of resources used in all the processes of the production combined can easily be displayed using GaBi's resource filter or SimaPro's inventory function. In a case like this where spatial allocation of the different production sites is not necessary the characterisation can be made using a generic integration of an impact assessment method in both programs as they assess all the copper used in all phases combined making it impossible to distinguish between the product stages. The inventory data for copper and nickel are displayed in Table 18.
This case study and the CF-provider do not use the same classification in categories of fossil resources as it is used in the Ecoinvent database and the LCIA programs. The inventory data do not differ in the categories shown in Table 20 but into the categories crude oil, hard coal, lignite and natural gas only.

Here to be mentioned again is that the impact of resource use is allocated to its point of use and not to its origin.

Table 18: Inventory data for copper and nickel use

	copper			nickel		
kg	LC1	LC2	LC3	LC1	LC2	LC3
Rastatt	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DE	6.11E-06	6.24E-06	6.24E-06	1.49E-05	1.50E-05	1.50E-05
EUROPE	3.76E-05	3.45E-05	4.33E-05	5.85E-05	5.77E-05	7.19E-05
GLO	4.45E-08	4.45E-08	4.45E-08	7.37E-06	7.37E-06	7.37E-06
Sum	4.38E-05	4.08E-05	4.96E-05	8.08E-05	8.01E-05	9.43E-05

Table 19: Impact of copper use

	Impact (US$/2010)		
	LC1	LC2	LC3
Individualist	**2.61E-13**	**2.43E-13**	**2.95E-13**
Hierarchist	**1.23E-12**	**1.14E-12**	**1.39E-12**
Egalitarian	**8.65E-10**	**8.05E-10**	**9.80E-10**

Table 19 shows the impact of the different cultural perspectives for which CFs have been provided.

Table 20: Classification of resources in task 1.4

Fossil resource type	Default/specific	Unit
Crude oil, light (>31.1 degree API)	**Default**	kg
Crude oil, medium (22.3-31.1 degree API)	Specific	kg
Crude oil, heavy (10-22.3 degree API)	Specific	kg
Crude oil, extra heavy (<10 degree API)	Specific	kg
Natural gas, low energy (HHV <35 MJ/m3)	Specific	m3
Natural gas, medium energy (HHV 35-40 MJ/m3)	**Default**	m3
Natural gas, high energy (HHV >40 MJ/m3)	Specific	m3
Coal, lignite (HHV <20 MJ/kg)	Specific	kg
Coal, sub-bituminous (HHV 20-24 MJ/kg)	Specific	kg
Coal, steam (HHV >24 MJ/kg)	Specific	kg
Coal, coking (HHV >24 MJ/kg)	**Default**	kg
Coal, anthracite (HHV >24 MJ/kg)	Specific	kg
Crude oil, light (>31.1 degree API)	**Default**	GJ
Crude oil, medium (22.3-31.1 degree API)	Specific	GJ
Crude oil, heavy (10-22.3 degree API)	Specific	GJ
Crude oil, extra heavy (<10 degree API)	Specific	GJ
Natural gas, low energy (HHV <35 MJ/m3)	Specific	GJ
Natural gas, medium energy (HHV 35-40 MJ/m3)	**Default**	GJ
Natural gas, high energy (HHV >40 MJ/m3)	Specific	GJ
Coal, lignite (HHV <20 MJ/kg)	Specific	GJ
Coal, sub-bituminous (HHV 20-24 MJ/kg)	Specific	GJ
Coal, steam (HHV >24 MJ/kg)	Specific	GJ
Coal, coking (HHV >24 MJ/kg)	**Default**	GJ
Coal, anthracite (HHV >24 MJ/kg)	Specific	GJ

Assumptions or manual classification have to be done which can be simplified by providing a default factor for crude oil, hard coal, lignite natural gas, and pit gas. Uranium is not considered as it is not used in the life cycles. Furthermore spatial differentiation has to be made in the resolutions given in the table below.

The inventory data for fossil resource use in the nomenclature used in GaBi is given in Appendix D2.[31]

[31] The data are already calculated for each location.

6.5 Terrestrial ecotoxicity

Terrestrial ecotoxicity is the first emission category. The CFs are provided by the project partner DTU. The units seem to be wrong and cannot be checked as no guidance document available yet. Therefore no further analysis has been made concerning these CFs. As it is likely that the LCI data are given in kg they can be assessed easily. A first estimation about the assessment path is displayed in Figure 15.

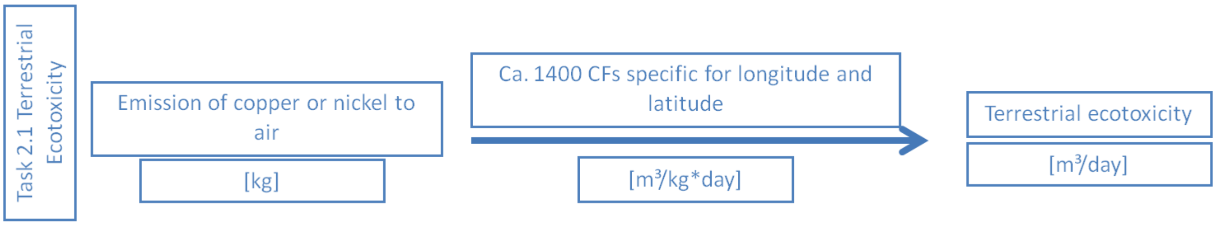

Figure 15: Characterization factor: Task 2.1: terrestrial ecotoxicity

The CFs are given for specific longitude and latitude and therefore do not contain any default factors for the resolutions shown in the table below. Additionally no specification about the population density is made.

Rastatt	Global	European	German
NO	NO	NO	NO

There are no coordinates which are near to Rastatt and therefore the data cannot be used to assess the primary data from Daimler either (Rastatt: 48° 51′ 25″ N, 8° 12′ 10″ E; 48.856944°, 8.202778°)

6.6 Higher predator toxicity

The CFs for higher predator toxicity were also provided by DTU and do not contain any spatial differentiation. The LCI data have to be subdivided into the three categories: emission to air, to freshwater, and to agricultural soil which are included in the LCIA programs. Like that even the secondary data can be assessed like displayed in Figure 13.

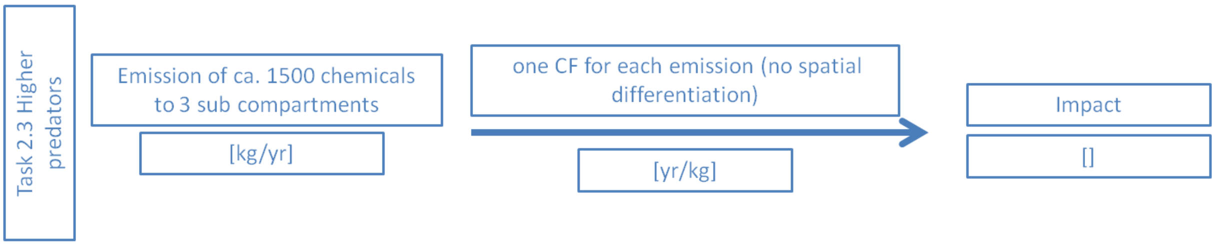

Figure 16: Characterization factor: Task 2.3: higher predator ecotoxicity

The characterisation is used to provide an endpoint level impact score. If spatial differentiation is made in the future the following default CFs are needed for the car life cycle assessment.

Rastatt	Global	European	German
NO	NO	NO	NO

The amount of chemicals in this impact category makes it almost impossible to use the CFs without adding them into a LCIA software first (e.g. GaBi or SimaPro). A problem that might occur is that GaBi uses different nomenclature for the chemicals than DTU.

6.7 Human toxicity of pesticides

The CFs refer to one kg of pesticide applied on wheat, rice, tomato, apple, potato, or lettuce. The endpoint level impact can be displayed for life years lost caused by cancer, by all impacts excluding cancer and by total DALYs. The assessment path is shown in Figure 18. Again no spatial differentiation is made by the method developer DTU.

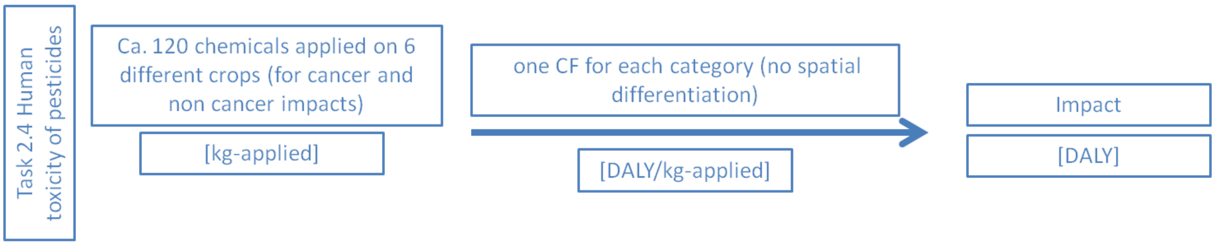

Figure 17: Characterization factor: Task 2.4: human toxicity of pesticides

As none of these crops is a part of the car life cycle it cannot be evaluated in this case study. It might be useful to provide CFs for the application of those chemicals at growing rapeseed as this is an important part of biodiesel production and consequently of LC3.

In a second and third sheet DTU provided spatial differentiation CFs for over 3,000 chemicals. The CFs contain the same chemicals once in continental and once in sub-continental resolution. The assessment path is shown in Figure 19.

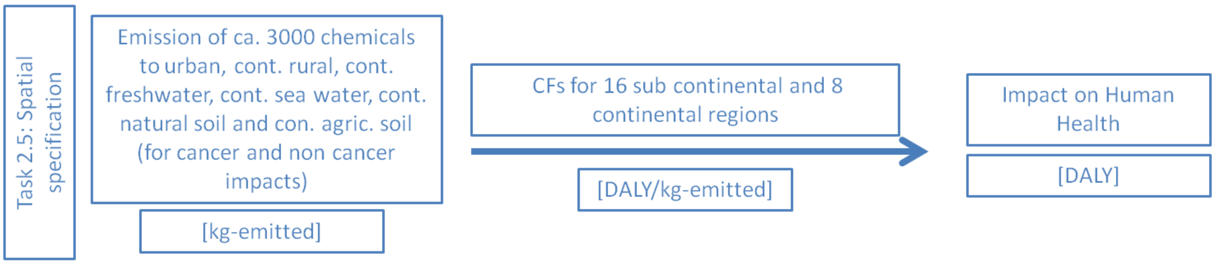

Figure 18: Characterization factor: Task 2.5: spatial specification

The LCI data have to be divided in the categories: Emission to urban air, to continental rural air, to continental freshwater, to continental sea water, to continental natural soil, and to continental agricultural soil. The CFs do distinguish between rural and urban emissions which is done in the Ecoinvent database too (named high and low population density). But this distinction has not been transferred to the LCIA programs. Manually applying the CFs is not an option considering the number of chemicals again. Therefore default CFs for an emission to each sub-compartment without considering the population density would simplify the characterisation of the secondary data through LCIA software.

The following shows that 3 of 4 resolution types for assessing the car life cycle are missing.

Rastatt	Global	European	German
NO	NO	YES	NO

The LCI data will not be displayed as a part of this study as not all of the resolutions needed for the case study are provided and will most likely not be provided as part of the LC-IMPACT project as the number of chemicals does not allow this. As there is no global default given either, a comparison to the European default cannot be made.

6.8 Aquatic eutrophication

The CFs provided by DTU assess the marine aquatic eutrophication caused by the emission of nitrogen to four sub-compartments as shown in Figure 19.

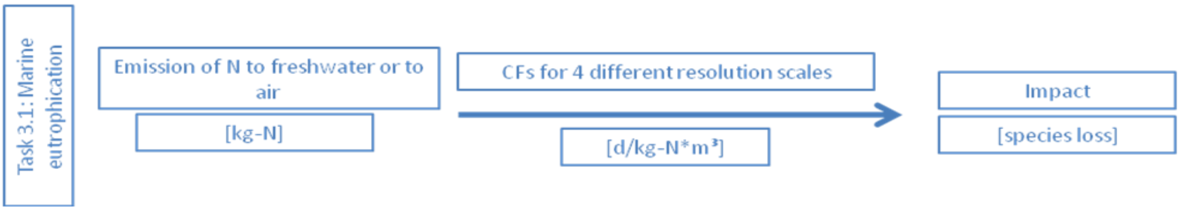

Figure 19: Characterization factor: Task 3.1: marine eutrophication

Factors are given for the emission to a specific Large Marine Ecosystem (LME) and also as a country specific default factor which will be used to assess a part of the operation and the complete maintenance and disposal stage.

No default factor for European and global assessment is provided for 'emissions to marine water'.[32] Therefore the impacts caused by these inventory data are excluded.

The emissions from Rastatt are delivered to the river Rhine, this will result into an emission to the LME North Sea.

The inventory list of GaBi does not contain emissions to groundwater therefore these are disregarded in this analysis. Table 21 shows the result of the inventory analysis used to assess the species loss by marine aquatic eutrophication.

Table 21: Inventory data for marine aquatic eutrophication

	N to freshwater			N to air		
kg	LC1	LC2	LC3	LC1	LC2	LC3
Rastatt	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-07	1.34E-07
DE	1.45E-06	1.78E-06	1.78E-06	1.60E-04	1.60E-04	1.50E-04
EUROPE	2.82E-06	1.86E-06	1.04E-06	4.34E-05	4.04E-05	1.86E-04
GLO	1.23E-08	1.23E-08	1.23E-08	1.86E-07	1.87E-07	1.87E-07
Sum	4.28E-06	3.66E-06	2.83E-06	2.03E-04	2.01E-04	3.36E-04

These numbers include all nitrogen that is chemically bound in nitrate, nitrite, laughing gas, nitrogen oxides, ammonium and ammonium carbonate.

Table 22 shows the result of the characterization of marine aquatic eutrophication. It is visible that the spatial allocation more than doubles the impact in all three scenarios. This is caused by the fact that the CF provider considers marine eutrophication in Germany to be more profound than in a global average.

[32] Meaning emissions directly into a marine ecosystem.

Table 22: Results of marine aquatic eutrophication endpoint scores

[species loss]	LC1	LC2	LC3
specified as said in Chapter 6.1	4.08E+00	4.04E+00	5.99E+00
Global averaged CF only	1.58E+00	1.54E+00	2.47E+00
relative change caused by specification	+159%	+162%	+143%

In a second excel sheet CFs for freshwater eutrophication are provided.

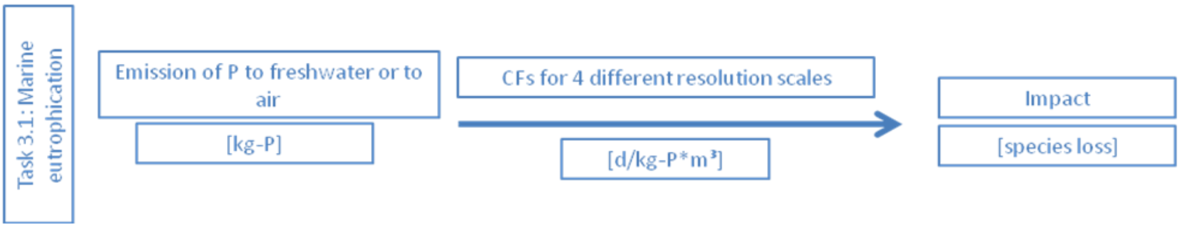

Figure 20: Characterization factor: Task 3.1: freshwater eutrophication

Table 23 shows that the allocation in the four resolution types as mentioned before significantly narrows the impact at the endpoint category. This shows the CF providers pint of view that freshwater eutrophication in Germany has less impact than in a global average.

Table 23: Result of freshwater eutrophication endpoint scores

[species loss]	LC1	LC2	LC3
specified as said in Chapter 6.1	2.92E-08	2.27E-08	1.64E-08
Global averaged CF only	4.94E-08	4.29E-08	3.43E-08
relative change caused by specification	-41%	-47%	-52%

As the species loss caused by the marine eutrophication is some orders of magnitude higher than the one caused by freshwater eutrophication the usage of spatially allocated CFs significantly increases the environmental impact of a light passenger car.

6.9 Acidification

The CFs for acidification were provided by the project partner Quantis. CFs were calculated for a midpoint and an endpoint category as shown in Figure 21.

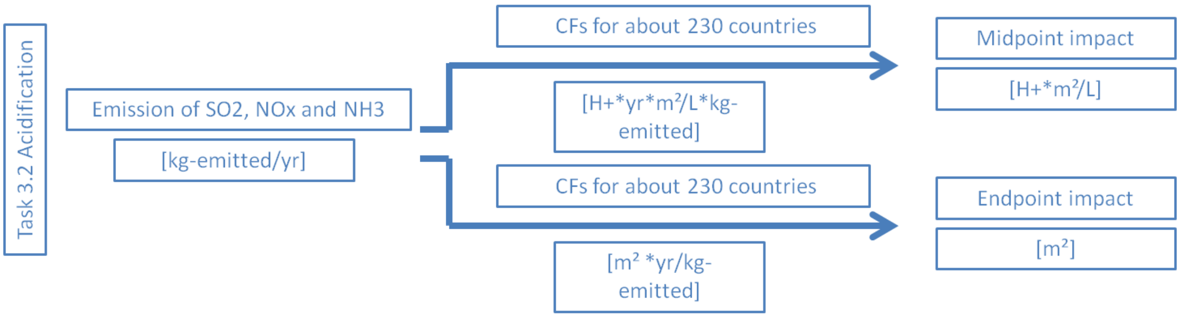

Figure 21: Characterization factor: Task 3.2: acidification

The spatial resolution is on a country scale and contains a European default and therefore misses just a global default and a site specific CF for Rastatt Germany. No difference is made between emission to high and low population density. This might be useful for future calculations.

Rastatt	Global	European	German
NO	NO	YES	YES

The inventory data for this category can be found in Appendix D3

As there is no global default CF, no comparison between a world average result and a site specific result can be made. Consequently the characterization phase was not performed.

6.10 Photochemical ozone and fine particulate matter formation

The CFs developed by the University of Stuttgart are provided in three excel spreadsheets. The CFs for Human health impact and Ecosystem damage are provided as shown in Figures 22-24.

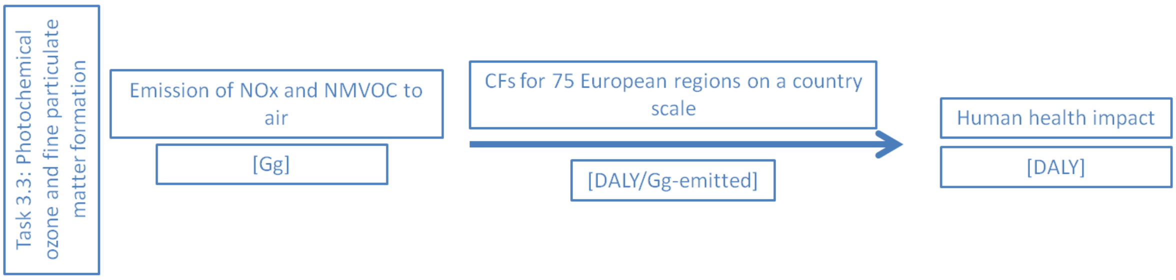

Figure 22: CF Task 3.3: Photochemical ozone and fine particulate matter formation (1)

In the CFs of the human health impact of photochemical ozone formation shown in Figure 22 no distinction between high and low population density was made. This simplifies the assessment of the data through an LCIA software as explained before. But for the future this difference should be considered. The table below shows that only a site specific CF for Rastatt is missing to assess the whole car life cycle for the paths shown in Figures 22 and 23.

Rastatt	Global	European	German
NO	Yes	YES	YES

Figure 23 shows the impact of primary and secondary PM to human health. This time the differentiation between high- and low-population density was considered providing CFs for rural and urban emissions.

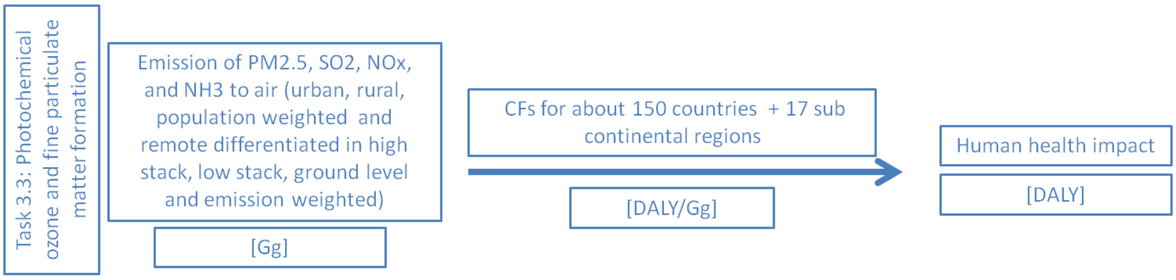

Figure 23: CF Task 3.3: Photochemical ozone and fine particulate matter formation (2)

Figure 24 shows the assessment impact pathway of the impact photochemical ozone formation to ecosystems.

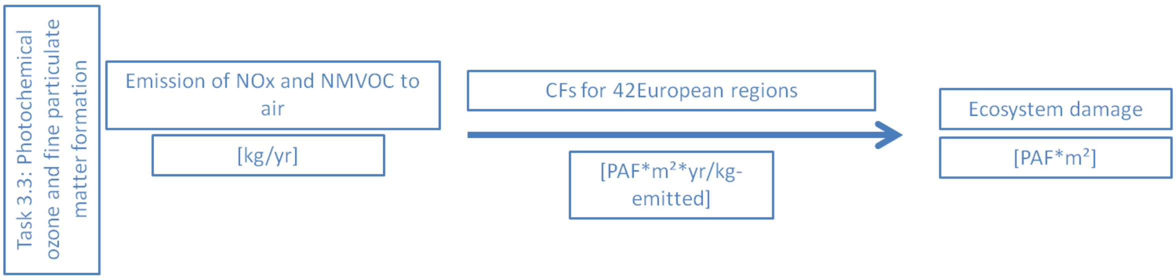

Figure 24: CF Task 3.3: Photochemical ozone and fine particulate matter formation (3)

Rastatt	Global	European	German
NO	Yes	YES	YES

The inventory data for all these characterizations can be found in Appendix D3.

The characterization was performed using the German average CF for impacts that are assigned to the Daimler plant in Rastatt.

The characterization results for human health impacts of primary and secondary particulate matter (PM) are shown in Table 24. In this case the specification as specified in chapter 6.1 increases the impact in all three scenarios. To mention here specifically is that LC3 has the lowest score if characterized by the global CF only and the highest if characterized spatially differentiated. The reader might remember that LC3 consists of a light passenger car driven by biofuel and the two others burn conventional diesel and petroleum. In a comparative LCA study the spatial differentiation would cause an otherwise decision.

Table 24: Result of human health endpoint of fine particulate matter

[DALY]	LC1	LC2	LC3
specified as said in Chapter 6.1	1.46E-07	1.43E-07	1.49E-07
Global averaged CF only	1.26E-07	1.22E-07	1.05E-07
relative change caused by specefication	+ 16%	+ 18%	+ 42%

Table 25 shows the result of the endpoint human health caused by photochemical ozone formation only. On the contrary to the result in human health impact of PM the results of photochemical ozone decrease if specifying the locations.

Table 25: Result of human health endpoint of photochemical ozone formation

[DALY]	LC1	LC2	LC3
specified as said Chapter 6.1	8.19E-12	7.82E-12	4.99E-12
Global averaged CF only	1.81E-11	1.78E-11	1.69E-11
relative change caused by specefication	- 55%	- 56%	- 71%

As the human health impact of PM is some orders in magnitude higher than the ones of ozone the overall toxicity for humans does not differ from the figures shown in Table 24.

Table 26: Result of ecosystem damage endpoint caused by ozone

[PAF/m²]	LC1	LC2	LC3
specified as said before	4.10E-03	3.97E-03	2.83E-03
Global averaged CF only	4.12E-03	3.97E-03	2.66E-03
relative change caused by specefication	0%	0%	+ 6%

In the endpoint category ecosystem damage the results don't change at all in LC1 and LC2 if using a global default CF instead of spatially differentiated factors. However there is a slight increase while using specific CFs in LC3. This is caused by a higher value of the CF for nitrogen oxide emissions in Germany than in a global average.

6.11 Noise

The CFs from the last impact category were provided by CML. The paths on how to assess noise impacts to humans given in Figure 25.

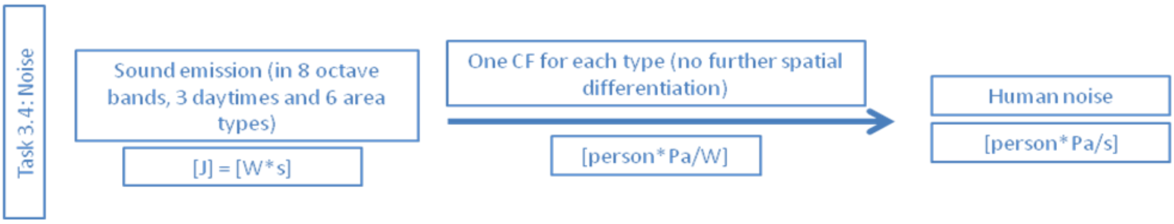

Figure 25: Characterization factor: Task 3.4: Noise

The differentiation is made through the area types only and no country or continent specific CFs have been developed yet.

Rastatt	Global	European	German
NO	NO	NO	NO

In the following pages the noise emission from car operation on German and European roads was performed to show which assumptions have to be made during the calculations.

Here only the impact caused by driving the passenger car in the operation stage has been assessed. Noise caused in processes of the other life cycle stages and during the production of the biodiesel has been disregarded as no resilient data have been provided by Daimler Rastatt.

The noise emission has been calculated based on a guideline provided by Steffano Cucurachi and using traffic noise data and calculation methods from Kephalopoulos et al. (2012).

The first step in the guideline is to collect information about emission location and define emission compartments:

A German and EU27 average was used.

The functional unit is (as in all the other impact categories) the life cycle of one car calculated for: 1 pkm (=0,625 vkm) of transport service.

The car will drive in the following sub-compartments.

- urban
- suburban
- rural

industrial, indoor, and unspecified driving have been disregarded.

The next step is to make assumptions for the assessment:

a. the vehicle type is category 1 (light motor vehicle)
b. the following speeds have been considered :
   - 30 km/h (urban)
   - 50 km/h (sub-urban)
   - 80 km/h (rural)
   - 130 km/h (rural)
c. the sound emissions of one passenger car have been calculated

d. reference conditions
   i. Temperature 10°C (roughly the German yearly average)
   ii. Acceleration and deceleration are excluded[33]
   iii. A normal road surface is considered

Now the calculation can be started:

a. Calculation of rolling noise due to tyre/road interaction with equations 7-1 and 7-2:

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} * \lg\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}(v_m) \qquad (7\text{-}1)$$

with $v_{ref} = 70\ km/h$ and

$$\Delta L_{WR,i,m}(v_m) = \Delta L_{WR,road,i,m}(v_m) + \Delta L_{studded\ tyres,i,m=1}(v_m) + \Delta L_{WP,acc,i,m} + \Delta L_{W,temp} \qquad (7\text{-}2)$$

$\Delta L_{studded\ tyres,i,m=1}(v_m) = 0$ and $\Delta L_{WP,acc,i,m} = 0$ (cf. point 2.)

Coefficients A and B:

Table 27: Coefficients for light motor vehicles (noise emission)

Octave bands centre freq. [Hz]	A_R	B_R	A_P	B_P
63	79,7	30,0	94,5	-1,3
125	85,7	41,5	89,2	7,2
250	84,5	38,9	88,0	7,7
500	90,2	25,7	85,9	8,0
1000	97,3	32,5	84,2	8,0
2000	93,9	37,2	86,9	8,0
4000	84,1	39,0	83,3	8,0
8000	74,3	40,0	76,1	8,0

- studded tyres are disregarded (term =0) $\Delta L_{studded\ tyres,i,m=1}(v_m)$
- Adapting the effect of air temperature $\Delta L_{W,temp}$ through equation 7-3:

$$\Delta L_{W,temp}(\tau) = K * (20 - \tau) \qquad (7\text{-}3)$$

[33] especially caused by a lack of data (acceleration and deceleration distances)

the generic coefficient K= 0,08 dB/°C was used in the calculation (normally for strategic noise mapping purposes)

b) Calculation of propulsion noise produced by the driveline (engine, exhaust, etc.) of the vehicle using equations 7-4 and 7-5

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m} * \left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP,i,m}(v_m) \qquad (7\text{-}4)$$

$$\Delta L_{WP,i,m}(v_m) = \Delta L_{WP,road,i,m}(v_m) + \Delta L_{WP,acc,i,m} + \Delta L_{WP,grad,i,m}(v_m) \qquad (7\text{-}5)$$

each of the summands is considered to be 0 in the context to find an average value for Germany.

combined sound power:

$$L_{W,i,m}(v_m) = 10 * \log(10^{\frac{L_{WR,i,m}(v_m)}{10}} + 10^{\frac{L_{WP,i,m}(v_m)}{10}}) \qquad (7\text{-}6)$$

- Converting the sound power level from dB to watt using equation 7-7:

$$W_{i,m} = 10^{-12} * 10^{L_{W,i,m}/10} \qquad (7\text{-}7)$$

- Calculation of the elementary flow with equation 7-8:

$$m_{i,c} = W_{i,m} * time_c \qquad (7\text{-}8)$$

with $m_{i,c}$= sound emission [J]
and $time_c = \frac{0{,}625km*P}{v}$

Table 28 shows the share P, the speed v and the time calculated by these equations. The functional unit is as said before 1pkm=0,625vkm.

Table 28: Shares of sub-compartments in EU27 and Germany

		urban	suburban	rural	rural (motorway)
	speed [km/h]	30	50	80	130
EU27	share (P)	0.14	0.14	0.58	0.14
Germany	share (P)	0.13	0.13	0.54	0.20
EU27	time [s]	10.13	6.08	16.31	2.42
Germany	time [s]	9.75	5.85	15.19	3.46

- Applying the new characterisation factors

To ease the calculation it was assumed that the car drives during the day only. Therefore the CFs displayed in Table 29 have been applied.

Table 29: CFs used in human noise calculation [person*Pa/W]

Octave bands centre freq. [Hz]	day urban	day suburban	day rural
63	3.11E+04	3.91E+04	1.44E+03
125	6.97E+04	8.75E+04	3.23E+03
250	1.67E+05	2.10E+05	7.74E+03
500	3.11E+05	3.91E+05	1.43E+04
1000	4.48E+05	5.63E+05	2.04E+04
2000	2.93E+05	6.40E+05	2.17E+04
4000	2.75E+05	6.01E+05	1.59E+04
8000	2.43E+05	5.29E+05	5.47E+03

The result of the human noise impact is [person*Pa/s]:

Eu27	**3.40E+04**
Germany	**3.47E+04**

The impact is a little higher in Germany than it is in the EU27 caused by the higher share of the motorway in rural driving. NFs are provided for the European and global scale. As none specifically for Germany is provided, the multiplication of the results by the averaged NFs wouldn't change the result. In the following the applicability of all developed CFs will be summarized.

7 Conclusion on Applicability of the new CFs

Several difficulties have occurred while assessing the newly developed CFs. The most significant one is that the spatial differentiation inside the different work packages and even inside one task differs between the following resolution types:

- country specific
- wetland specific
- for longitude and latitude
- regions (country specific)
- regions (continental and sub-continental)
- regions (WWF ecoregions)
- population density (urban, suburban, rural, industrial)

Even inside one resolution type the number of data varies enormously. If one might try to apply all of these newly developed CFs, it is required to allocate all the related processes in the production chain into all of these resolution types. This will increase the required working effort to perform the LCA. This fact is independent from how the allocation is technically made: by assumptions, cut-off criteria or even a complete analysis. It would ease the process of applying the spatially specific CFs if all of them had the same resolution.

For the car life cycle a resolution in a country scale would be practicable and necessary. Even if in the future all production processes can be allocated precisely, the operation of a car will still take place in a wider area. Additional default CFs for Europe and global are necessary for processes that cannot be allocated and as reference factors to assess if the spatial differentiation is beneficial. As primary data for the production plant in Rastatt are available this is a good chance to apply site specific CFs and then be able to compare this very specific result with a result characterized by a default factor to estimate the benefit of the finer spatial resolution in the newly developed CFs.

Another problem that appeared is that the different method developers use different fragmentations of the same impact group. Like that some differ in different types of crude oils other do not. Those distinguishing different oils then use varying ways to sub-divide it. As it is easier to summarize categories into a unspecific resource, a factor for unspecified flows always need to be provided.

Concerning the problem of how to implement the new CFs to LCIA software no final suggestion can be made.

Inserting new flow types (for example SO_2, to air, emitted in DE) into LCIA software would make the overall amount of flows several times higher depending on which spatial resolution method is used. But first one resolution type has to be defined.

Additionally the overall idea of spatial differentiation makes it harder to perform an LCA because practitioners have to locate all the processes in the production chain individually. This makes it even more expensive and effort-consuming, and consequently less attractive to perform an LCA.

Neither the database Ecoinvent nor the softwares SimaPro or GaBi are designed to assess life cycles in a spatial differentiated way. The LCI data that have been collected in the database do not represent an average for the country where the production takes place. Consequently they cannot be used to substitute the LCIs of the real production chain which was done by LCA practitioners until now.

Concerning the results of the characterizations in chapter 6, one recognizes that the impact of spatial allocation differs between the different scenarios and the categories. In some cases the impact is higher if specified, in others it is lower. In one case the specification didn't change the result of the characterization.

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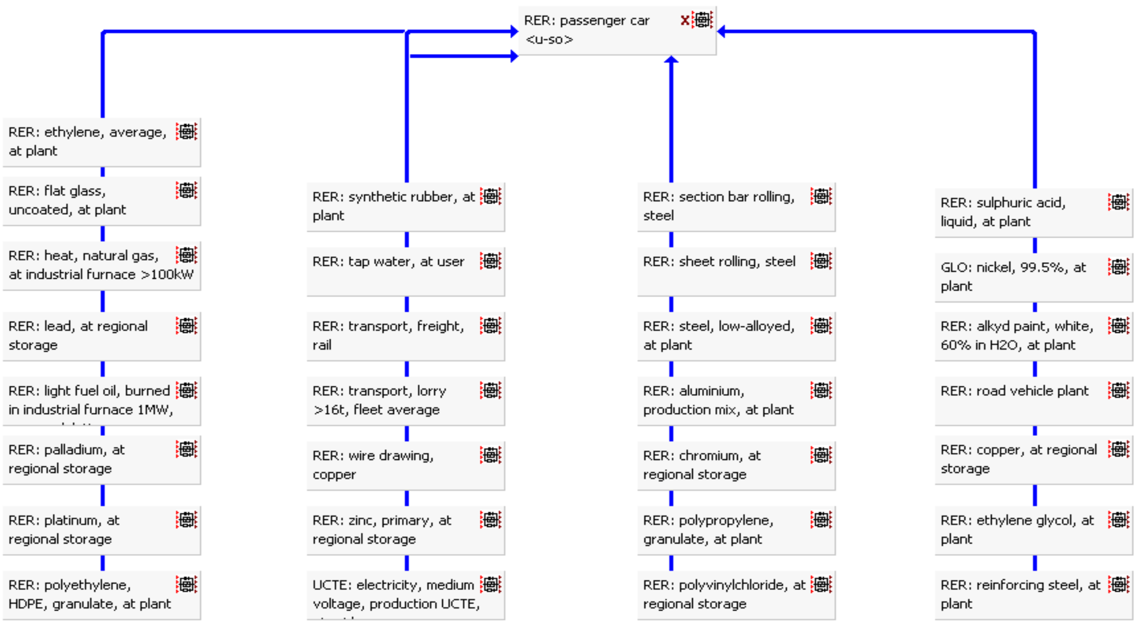
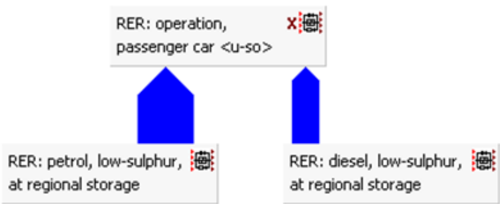
9 Appendix

10 Appendix A: Charts of the second level LC phases production and operation in LC1

2nd level of the life cycle - production (system is valid for LC 1-3):



2nd level of the life cycle - operation (only valid for LC 1-2)



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12 Appendix B: Result of the manual hot spot analysis with GaBi

Weak points

1st level: 10% cut off criteria with at least 90% of impact to be covered

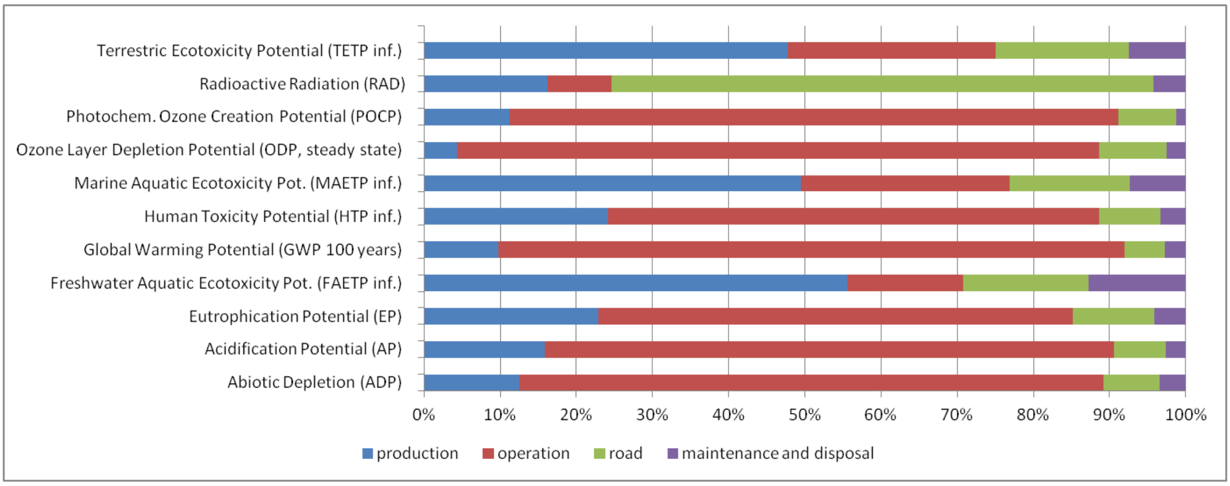
2nd level: the two most important (at production: the three most important) flows

CML2001 - Nov. 2010	1st level		2nd level					
	life cycle phase	overall impact [%]	flow name	percentage of impact	flow name	percentage of impact	flow name	percentage of impact
Abiotic Depletion (ADP)	operation	77	RER: petrol, low-sulphur, at regional storage	68	RER: diesel, low-sulphur, at regional storage	32		
	production	12	RER: reinforcing steel, at plant	31	UCTE: electricity, medium voltage, production	23	RER: polyethylene, HDPE, granulate, at plant	9
	road	7	CH: road	57	CH: operation, maintenance, road	43		
		96						
Acidification Potential (AP)	operation	75	RER: operation, passenger car <u-so>	51	RER: petrol, low-sulphur, at regional storage	36		
	production	16	UCTE: electricity, medium voltage, productior	19	RER: reinforcing steel, at plant	18	RER: platinum, at regional storage	17
		91						
Eutrophication Potential (EP)	operation	62	RER: petrol, low-sulphur, at regional storage	44	RER: operation, passenger car <u-so>	36		
	production	23	UCTE: electricity, medium voltage, productior	33	RER: reinforcing steel, at plant	25	RER: copper, at regional storage	14
	road	11	CH: operation, maintenance, road	70	CH: road	30		
		96						
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	production	56	RER: reinforcing steel, at plant	28	UCTE: electricity, medium voltage, production	20	RER: copper, at regional storage	14
	road	16	CH: operation, maintenance, road	78	CH: road	22		
	operation	15	RER: petrol, low-sulphur, at regional storage	69	RER: diesel, low-sulphur, at regional storage	27		
	maint. & disp.	13	disposal, passenger car	52	maintenance, passenger car	48		
		100						
Global Warming Potential (GWP 100 years)	operation	82	RER: operation, passenger car <u-so>	83	RER: petrol, low-sulphur, at regional storage	12		
	production	10	RER: reinforcing steel, at plant	31	UCTE: electricity, medium voltage, production	27	RER: aluminium, production mix, at plant	10
		92						
Human Toxicity Potential (HTP inf.)	operation	64	RER: operation, passenger car <u-so>	74	RER: petrol, low-sulphur, at regional storage	18		
	production	24	RER: copper, at regional storage	33	RER: steel, low-alloyed, at plant	15	UCTE: electricity, medium voltage, production UCTE, at grid	13
	road	8	CH: operation, maintenance, road	81	CH: road	19		
		96						
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	production	50	UCTE: electricity, medium voltage, productior	24	RER: reinforcing steel, at plant	21	RER: aluminium, production mix, at plant	18
	operation	27	RER: petrol, low-sulphur, at regional storage	68	RER: diesel, low-sulphur, at regional storage	30		
	road	16	CH: operation, maintenance, road	82	CH: road	18		
		93						
Ozone Layer Depletion Potential (ODP, steady state)	operation	84	RER: petrol, low-sulphur, at regional storage	67	RER: diesel, low-sulphur, at regional storage	33		
	road	9	CH: road	66	CH: operation, maintenance, road	34		
		93						
Photochem. Ozone Creation Potential (POCP)	operation	80	RER: operation, passenger car <u-so>	71	RER: petrol, low-sulphur, at regional storage	22		
	production	11	RER: passenger car <u-so>	37	RER: reinforcing steel, at plant	22	UCTE: electricity, medium voltage, production UCTE, at grid	7
		91						
Radioactive Radiation (RAD)	road	71	CH: operation, maintenance, road	97	CH: road	3		
	production	16	UCTE: electricity, medium voltage, productior	63	RER: reinforcing steel, at plant	14	RER: aluminium, production mix, at plant	8
	operation	8	RER: petrol, low-sulphur, at regional storage	71	RER: diesel, low-sulphur, at regional storage	29		
		95						
Terrestric Ecotoxicity Potential (TETP inf.)	production	48	RER: reinforcing steel, at plant	35	RER: steel, low-alloyed, at plant	30	RER: chromium, at regional storage	8
	operation	27	RER: petrol, low-sulphur, at regional storage	59	RER: diesel, low-sulphur, at regional storage	24		
	road	17	CH: operation, maintenance, road	69	CH: road	31		
		92						

13 Appendix C Assessment of LC 1-3 with the original CML2001 version

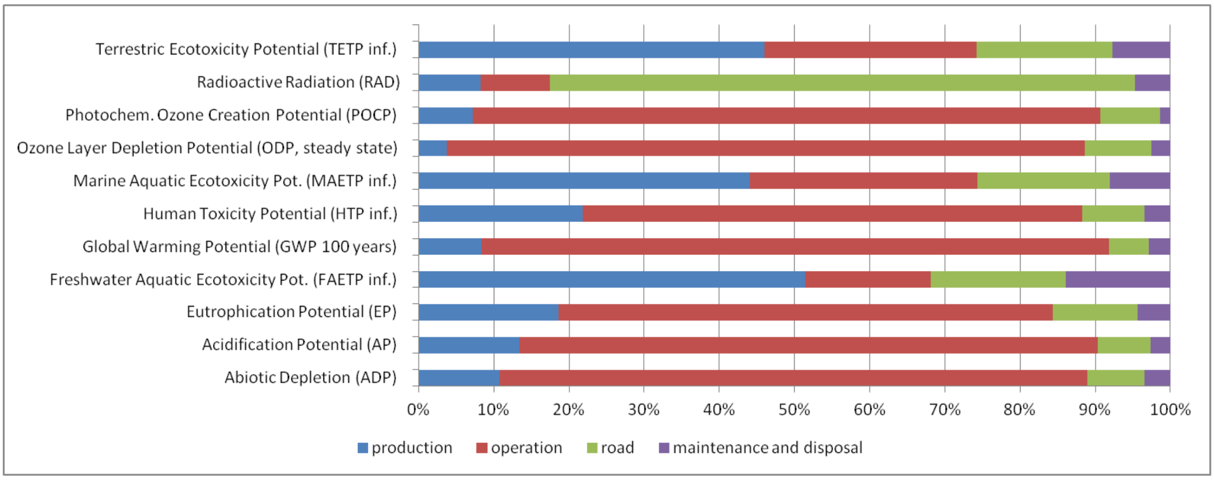
14 Appendix C1: assessment of LC1 with the original CML version

CML2001	absolut value	unit	normalized Europe	unit
Abiotic Depletion (ADP)	1,2E-03	[kg Sb-Equiv.]	6,02E-14	[]
Acidification Potential (AP)	6,9E-04	[kg SO2-Equiv.]	1,85E-14	[]
Eutrophication Potential (EP)	2,1E-04	[kg Phosphate-Equiv.]	1,25E-14	[]
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	2,3E-02	[kg DCB-Equiv.]	3,36E-14	[]
Global Warming Potential (GWP 100 years)	1,8E-01	[kg CO2-Equiv.]	2,76E-14	[]
Human Toxicity Potential (HTP inf.)	7,7E-02	[kg DCB-Equiv.]	7,47E-15	[]
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	6,6E+01	[kg DCB-Equiv.]	4,28E-13	[]
Ozone Layer Depletion Potential (ODP, steady state)	2,1E-08	[kg R11-Equiv.]	1,86E-16	[]
Photochem. Ozone Creation Potential (POCP)	1,8E-04	[kg Ethene-Equiv.]	1,57E-14	[]
Radioactive Radiation (RAD)	7,7E-10	[DALY]	1,17E-14	[]
Terrestric Ecotoxicity Potential (TETP inf.)	6,9E-04	[kg DCB-Equiv.]	1,07E-14	[]



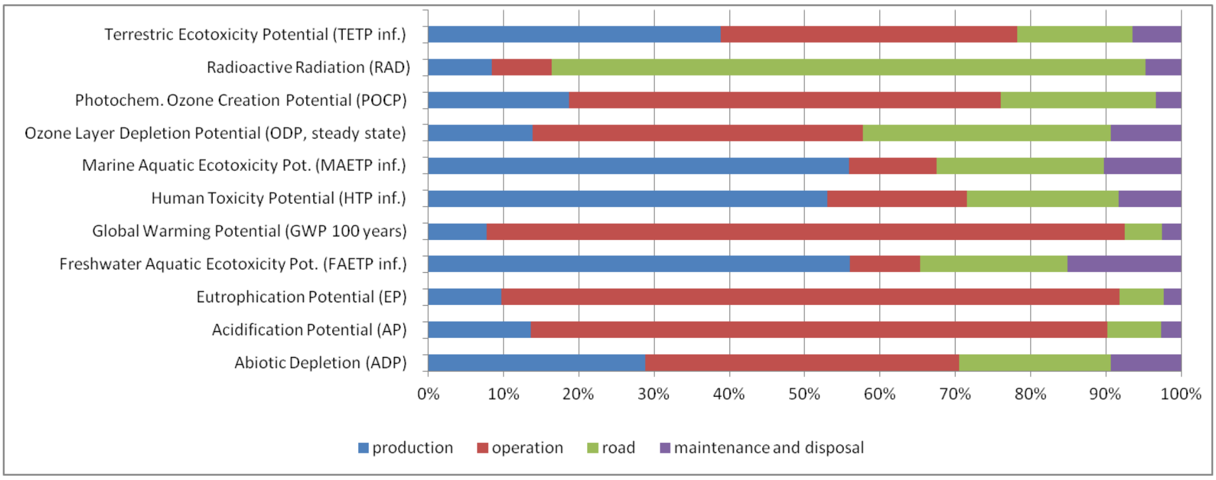
15 Appendix C2: assessment of LC2 with the original CML version

CML2001	absolut value	unit	normalized Europe	unit
Abiotic Depletion (ADP)	1,2E-03	[kg Sb-Equiv.]	5,90E-14	[]
Acidification Potential (AP)	6,7E-04	[kg SO2-Equiv.]	1,80E-14	[]
Eutrophication Potential (EP)	2,0E-04	[kg Phosphate-Equiv.]	1,19E-14	[]
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	2,1E-02	[kg DCB-Equiv.]	3,07E-14	[]
Global Warming Potential (GWP 100 years)	1,8E-01	[kg CO2-Equiv.]	2,72E-14	[]
Human Toxicity Potential (HTP inf.)	7,5E-02	[kg DCB-Equiv.]	7,24E-15	[]
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	6,0E+01	[kg DCB-Equiv.]	3,86E-13	[]
Ozone Layer Depletion Potential (ODP, steady state)	2,1E-08	[kg R11-Equiv.]	1,85E-16	[]
Photochem. Ozone Creation Potential (POCP)	1,7E-04	[kg Ethene-Equiv.]	1,50E-14	[]
Radioactive Radiation (RAD)	7,1E-10	[DALY]	1,07E-14	[]
Terrestric Ecotoxicity Potential (TETP inf.)	6,7E-04	[kg DCB-Equiv.]	1,03E-14	[]



16 Appendix C3: assessment of LC3 with the original CML version

CML2001	absolut value unit	normalized Europe unit
Abiotic Depletion (ADP)	4,5E-04 [kg Sb-Equiv.]	2,20E-14 []
Acidification Potential (AP)	6,6E-04 [kg SO2-Equiv.]	1,77E-14 []
Eutrophication Potential (EP)	3,9E-04 [kg Phosphate-Equiv.]	2,26E-14 []
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	1,9E-02 [kg DCB-Equiv.]	2,83E-14 []
Global Warming Potential (GWP 100 years)	1,9E-01 [kg CO2-Equiv.]	2,95E-14 []
Human Toxicity Potential (HTP inf.)	3,1E-02 [kg DCB-Equiv.]	2,99E-15 []
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	4,7E+01 [kg DCB-Equiv.]	3,05E-13 []
Ozone Layer Depletion Potential (ODP, steady state)	5,7E-09 [kg R11-Equiv.]	5,00E-17 []
Photochem. Ozone Creation Potential (POCP)	6,5E-05 [kg Ethene-Equiv.]	5,79E-15 []
Radioactive Radiation (RAD)	7,0E-10 [DALY]	1,05E-14 []
Terrestric Ecotoxicity Potential (TETP inf.)	7,9E-04 [kg DCB-Equiv.]	1,22E-14 []



LC-IMPACT

SEVENTH FRAMEWORK PROGRAMME

17 Appendix D: spatially differentiated inventory data

18 Appendix D1: for land use

	GLO			RER			DE			Rastatt		
m2*yr	LC1	LC2	LC3	LC1	LC2	LC3	LC1	LC2	LC3	LC1	LC2	LC3
Occupation, arable	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,25E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Occupation, arable, non-irrigated	1,01E-08	1,02E-08	1,02E-08	9,75E-06	9,64E-06	6,49E-04	2,46E-05	2,46E-05	2,46E-05	0,00E+00	0,00E+00	0,00E+00
Occupation, construction site	2,53E-08	2,56E-08	2,56E-08	6,02E-06	5,88E-06	2,96E-05	1,30E-06	1,32E-06	1,32E-06	0,00E+00	0,00E+00	0,00E+00
Occupation, dump site	6,44E-07	6,44E-07	6,44E-07	4,32E-05	3,68E-05	6,18E-05	1,75E-05	1,89E-05	1,89E-05	0,00E+00	0,00E+00	0,00E+00
Occupation, dump site, benthos	3,48E-09	4,24E-09	4,24E-09	1,65E-05	1,64E-05	2,04E-06	5,77E-07	5,97E-07	5,97E-07	0,00E+00	0,00E+00	0,00E+00
Occupation, forest, intensive	4,75E-07	4,75E-07	4,75E-07	1,04E-05	8,12E-06	1,03E-05	5,49E-06	5,53E-06	5,53E-06	0,00E+00	0,00E+00	0,00E+00
Occupation, forest, intensive, normal	1,72E-06	1,72E-06	1,72E-06	5,00E-04	3,27E-04	5,01E-04	2,26E-04	2,45E-04	2,45E-04	0,00E+00	0,00E+00	0,00E+00
Occupation, forest, intensive, short-cycle	5,31E-10	5,56E-10	5,56E-10	1,91E-06	1,91E-06	2,98E-06	6,10E-08	6,20E-08	6,20E-08	0,00E+00	0,00E+00	0,00E+00
Occupation, industrial area	2,52E-07	2,53E-07	2,53E-07	1,88E-04	1,47E-04	2,16E-05	1,03E-05	1,12E-05	1,12E-05	0,00E+00	0,00E+00	0,00E+00
Occupation, industrial area, benthos	2,98E-11	3,72E-11	3,72E-11	1,27E-07	1,27E-07	1,91E-08	5,81E-09	5,95E-09	5,95E-09	0,00E+00	0,00E+00	0,00E+00
Occupation, industrial area, built up	1,74E-07	1,74E-07	1,74E-07	3,71E-05	2,04E-05	4,02E-05	7,01E-06	7,07E-06	7,07E-06	0,00E+00	9,35E-06	9,35E-06
Occupation, industrial area, vegetation	6,87E-08	6,88E-08	6,88E-08	1,74E-05	7,97E-06	9,50E-06	7,27E-06	7,32E-06	7,32E-06	0,00E+00	8,41E-06	8,41E-06
Occupation, mineral extraction site	8,78E-08	8,80E-08	8,80E-08	2,63E-05	2,20E-05	2,61E-05	2,20E-05	2,35E-05	2,35E-05	0,00E+00	0,00E+00	0,00E+00
Occupation, permanent crop, fruit, intensive	5,76E-10	6,12E-10	6,12E-10	2,74E-06	2,73E-06	1,83E-06	8,57E-08	8,70E-08	8,70E-08	0,00E+00	0,00E+00	0,00E+00
Occupation, shrub land, sclerophyllous	1,89E-08	1,89E-08	1,89E-08	8,26E-07	6,87E-07	2,24E-06	1,40E-06	1,40E-06	1,40E-06	0,00E+00	0,00E+00	0,00E+00
Occupation, traffic area, rail embankment	2,22E-09	2,86E-09	2,86E-09	5,10E-06	4,90E-06	6,93E-06	1,17E-06	1,21E-06	1,21E-06	0,00E+00	0,00E+00	0,00E+00
Occupation, traffic area, rail network	2,45E-09	3,16E-09	3,16E-09	5,64E-06	5,42E-06	7,66E-06	1,29E-06	1,34E-06	1,34E-06	0,00E+00	0,00E+00	0,00E+00
Occupation, traffic area, road embankment	2,76E-08	2,77E-08	2,77E-08	5,80E-06	4,01E-06	7,53E-06	9,96E-04	9,97E-04	9,97E-04	0,00E+00	0,00E+00	0,00E+00
Occupation, traffic area, road network	1,93E-07	1,93E-07	1,93E-07	6,66E-05	6,55E-05	3,28E-05	4,71E-03	4,71E-03	4,71E-03	0,00E+00	8,01E-06	8,01E-06
Occupation, urban, discontinuously built	2,25E-11	2,26E-11	2,26E-11	1,23E-08	1,22E-08	4,73E-07	1,74E-08	1,74E-08	1,74E-08	0,00E+00	0,00E+00	0,00E+00
Occupation, water bodies, artificial	4,77E-08	4,79E-08	4,79E-08	2,84E-05	1,99E-05	1,59E-05	3,78E-05	3,91E-05	3,91E-05	0,00E+00	0,00E+00	0,00E+00
Occupation, water courses, artificial	2,53E-07	2,53E-07	2,53E-07	2,70E-05	2,33E-05	1,42E-05	3,18E-05	3,23E-05	3,23E-05	0,00E+00	0,00E+00	0,00E+00

19 Appendix D2: for resource use

Ressource use [kg]	GLO			RER			DE			Rastatt		
	LC1	LC2	LC3	LC1	LC2	LC3	LC1	LC2	LC3	LC1	LC2	LC3
Crude oil (resource)	7,33E-06	7,36E-06	7,36E-06	4,46E-02	4,45E-02	2,53E-03	3,24E-03	3,26E-03	3,26E-03	0,00E+00	0,00E+00	0,00E+00
Hard coal (resource)	5,23E-06	5,26E-06	5,26E-06	5,59E-03	4,62E-03	4,72E-03	1,89E-03	2,19E-03	2,19E-03	0,00E+00	0,00E+00	0,00E+00
Lignite (resource)	6,25E-06	6,27E-06	6,27E-06	4,06E-03	2,33E-03	2,49E-03	2,37E-03	3,03E-03	3,03E-03	0,00E+00	0,00E+00	0,00E+00
Natural gas (resource)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Uranium (resource)	2,76E-10	2,77E-10	2,77E-10	1,72E-07	1,04E-07	9,77E-08	4,93E-07	5,06E-07	5,06E-07	0,00E+00	0,00E+00	0,00E+00
Ressource use Nm³												
Natural gas (resource)	5,39E-06	8,45E-06	8,45E-06	4,71E-03	4,40E-03	9,25E-03	1,32E-03	1,39E-03	1,39E-03	0,00E+00	0,00E+00	0,00E+00

20 Appendix D3: for acidification, photochemical ozone and fine particulate matter formation

kg-SO2	LC1	LC2	LC3
Rastatt	0,00E+00	1,11E-08	1,11E-08
DE	3,81E-05	3,91E-05	3,82E-05
EUROPE	2,76E-04	2,60E-04	1,11E-04
GLO	8,08E-06	8,08E-06	8,08E-06
Sum	3,22E-04	3,08E-04	1,57E-04

kg-Nox	LC1	LC2	LC3
Rastatt	0,00E+00	3,48E-07	3,48E-07
DE	3,75E-04	3,76E-04	3,71E-04
EUROPE	1,09E-04	1,02E-04	9,44E-05
GLO	3,84E-07	3,87E-07	3,87E-07
Sum	4,84E-04	4,78E-04	4,66E-04

	to air			to fresh water			to sea water		
kg-NH3	LC1	LC2	LC3	LC1	LC2	LC3	LC1	LC2	LC3
Rastatt	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
DE	1,31E-05	1,31E-05	3,64E-06	1,53E-07	1,55E-07	1,55E-07	2,76E-09	2,79E-09	2,79E-09
EUROPE	1,24E-06	9,76E-07	8,94E-05	1,45E-07	1,35E-07	1,31E-06	1,25E-07	1,25E-07	2,50E-09
GLO	4,38E-08	4,38E-08	4,38E-08	2,27E-10	2,27E-10	2,27E-10	1,21E-11	1,22E-11	1,22E-11
Sum	1,44E-05	1,41E-05	9,31E-05	2,99E-07	2,90E-07	1,46E-06	1,28E-07	1,27E-07	5,30E-09

kg-PM2.5	LC1	LC2	LC3
Rastatt	0,00E+00	1,57E-08	1,57E-08
DE	2,10E-05	2,11E-05	2,55E-05
EUROPE	1,48E-05	1,35E-05	1,04E-05
GLO	1,10E-07	1,10E-07	1,10E-07
Sum	3,59E-05	3,47E-05	3,60E-05

kg-NMVOC	LC1	LC2	LC3
Rastatt	2,00E-05	2,44E-06	2,44E-06
DE	1,99E-04	2,00E-04	4,59E-05
EUROPE	8,29E-05	8,17E-05	5,21E-05
GLO	7,15E-08	7,40E-08	7,40E-08
Sum	3,02E-04	2,84E-04	1,00E-04

21 Appendix E: Result of the uncertainty analysis

The following tables show the range in which the different impact categories vary. E1 shows the variation of a complete life cycle (LC1) and E2 shows the variation in the operation phase of LC3. Both Tables relate to the functional unit of 1pkm.

22 Appendix E1 Uncertainty in LC1

Label	LC1	Low	High
Abiotic depletion	100	4,22E+01	7,91E+01
Acidification	100	4,27E+01	8,77E+01
Eutrophication	100	4,56E+01	8,75E+01
Global warming 20a	100	4,25E+01	8,10E+01
Global warming 100a	100	4,30E+01	8,12E+01
Global warming 500a	100	4,30E+01	8,16E+01
Upper limit of net global warming	100	4,28E+01	8,16E+01
Lower limit of net global warming	100	4,30E+01	8,14E+01
Ozone layer depletion 5a	100	5,52E+01	1,39E+02
Ozone layer depletion 10a	100	5,54E+01	1,40E+02
Ozone layer depletion 15a	100	5,57E+01	1,41E+02
Ozone layer depletion 20a	100	5,58E+01	1,42E+02
Ozone layer depletion 25a	100	5,60E+01	1,43E+02
Ozone layer depletion 30a	100	5,61E+01	1,44E+02
Ozone layer depletion 40a	100	5,64E+01	1,44E+02
Ozone layer depletion steady state	100	5,60E+01	1,45E+02
Human toxicity 20a	100	4,53E+01	8,72E+01
Human toxicity 100a	100	4,53E+01	8,72E+01
Human toxicity 500a	100	4,52E+01	8,71E+01
Human toxicity infinite	100	4,46E+01	8,56E+01
Freshwater aquatic ecotox. 20a	100	5,50E+01	1,72E+02
Freshwater aquatic ecotox. 100a	100	5,48E+01	1,71E+02
Freshwater aquatic ecotox. 500a	100	5,45E+01	1,69E+02
Fresh water aquatic ecotox. infinite	100	5,39E+01	1,66E+02
Marine aquatic ecotox. 20a	100	4,68E+01	1,10E+02
Marine aquatic ecotox. 100a	100	4,92E+01	1,29E+02
Marine aquatic ecotox. 500a	100	5,01E+01	1,33E+02
Marine aquatic ecotoxicity infinite	100	5,00E+01	1,43E+02
Terrestrial ecotoxicity 20a	100	4,78E+01	1,26E+02
Terrestrial ecotoxicity 100a	100	5,07E+01	1,77E+02
Terrestrial ecotoxicity 500a	100	5,22E+01	1,95E+02
Terrestrial ecotoxicity infinite	100	4,86E+01	1,41E+02
Marine sediment ecotox. 20a	100	4,73E+01	1,14E+02
Marine sediment ecotox. 100a	100	4,92E+01	1,29E+02
Marine sediment ecotox. 500a	100	5,02E+01	1,32E+02
Marine sediment ecotox. infinite	100	5,08E+01	1,46E+02
Freshwater sediment ecotox. 20a	100	5,54E+01	1,74E+02
Freshwater sediment ecotox. 100a	100	5,54E+01	1,76E+02
Freshwater sediment ecotox. 500a	100	5,48E+01	1,74E+02
Freshwater sediment ecotox. infinite	100	5,43E+01	1,71E+02
Average European (kg NOx eq)	100	4,62E+01	9,51E+01
Average European (kg SO2-Eq)	100	4,28E+01	8,78E+01
Land competition	100	5,86E+01	1,71E+02
Ionising radiation	100	6,85E+01	5,14E+02
Photochemical oxidation	100	4,89E+01	1,43E+02
Photochemical oxidation (low NOx)	100	5,43E+01	2,04E+02
Malodours air	100	5,19E+01	1,12E+02
Equal benefit incremental reactivity	100	5,31E+01	1,97E+02
Max. incremental reactivity	100	4,96E+01	1,27E+02
Max. ozone incremental reactivity	100	5,08E+01	1,63E+02

23 Appendix: E2: Uncertainty in biodiesel operation

Label	1pkm biodiesel transport	Low	High
Abiotic depletion	100	5,55E+00	7,17E+00
Acidification	100	2,10E+01	3,32E+01
Eutrophication	100	3,09E+01	3,14E+01
Global warming 20a	100	4,46E+00	4,73E+00
Global warming 100a	100	4,45E+00	4,71E+00
Global warming 500a	100	4,44E+00	4,71E+00
Upper limit of net global warming	100	4,46E+00	4,72E+00
Lower limit of net global warming	100	4,46E+00	4,72E+00
Ozone layer depletion 5a	100	5,21E+00	6,31E+00
Ozone layer depletion 10a	100	5,21E+00	6,41E+00
Ozone layer depletion 15a	100	5,24E+00	6,46E+00
Ozone layer depletion 20a	100	5,26E+00	6,57E+00
Ozone layer depletion 25a	100	5,31E+00	6,66E+00
Ozone layer depletion 30a	100	5,33E+00	6,79E+00
Ozone layer depletion 40a	100	5,40E+00	6,94E+00
Ozone layer depletion steady state	100	5,63E+00	7,53E+00
Human toxicity 20a	100	2,43E+01	7,28E+01
Human toxicity 100a	100	2,43E+01	7,28E+01
Human toxicity 500a	100	2,44E+01	7,33E+01
Human toxicity infinite	100	2,25E+01	6,64E+01
Freshwater aquatic ecotox. 20a	100	1,31E+01	4,69E+01
Freshwater aquatic ecotox. 100a	100	1,44E+01	5,22E+01
Freshwater aquatic ecotox. 500a	100	1,52E+01	5,21E+01
Fresh water aquatic ecotox. infinite	100	1,72E+01	5,35E+01
Marine aquatic ecotox. 20a	100	1,49E+02	6,15E+02
Marine aquatic ecotox. 100a	100	5,90E+01	2,44E+02
Marine aquatic ecotox. 500a	100	4,85E+01	2,01E+02
Marine aquatic ecotoxicity infinite	100	2,31E+01	6,35E+01
Terrestrial ecotoxicity 20a	100	4,59E+00	4,91E+00
Terrestrial ecotoxicity 100a	100	4,71E+00	5,01E+00
Terrestrial ecotoxicity 500a	100	5,23E+00	6,89E+00
Terrestrial ecotoxicity infinite	100	7,44E+00	1,54E+01
Marine sediment ecotox. 20a	100	2,68E+03	1,12E+04
Marine sediment ecotox. 100a	100	6,01E+01	2,52E+02
Marine sediment ecotox. 500a	100	5,02E+01	2,12E+02
Marine sediment ecotox. infinite	100	2,69E+01	7,75E+01
Freshwater sediment ecotox. 20a	100	7,01E+01	2,93E+02
Freshwater sediment ecotox. 100a	100	1,17E+02	4,86E+02
Freshwater sediment ecotox. 500a	100	1,34E+02	5,14E+02
Freshwater sediment ecotox. infinite	100	1,45E+02	4,91E+02
Average European (kg NOx eq)	100	1,49E+01	2,14E+01
Average European (kg SO2-Eq)	100	1,46E+01	2,29E+01
Land competition	100	4,61E+00	4,95E+00
Ionising radiation	100	1,21E+01	7,58E+01
Photochemical oxidation	100	7,09E+00	1,94E+01
Photochemical oxidation (low NOx)	100	5,23E+00	6,49E+00
Malodours air	100	2,93E+01	4,40E+01
Equal benefit incremental reactivity	100	6,94E+00	8,56E+00
Max. incremental reactivity	100	1,04E+01	1,41E+01
Max. ozone incremental reactivity	100	7,15E+00	8,93E+00

24 Appendix F: Characterization factors for GWP100 in the software GaBi and Simapro

The following tables show that the same method is interpreted in two different ways by the software providers PE International (GaBi) and Pré (Simapro). In Simapro the CML2001 method distinguishes in fossil and biotic carbon dioxide which GaBi doesn't. Looking into the source Guinée et al. (2001c) one will see that the original provider doesn't distinguish in those two types of CO2 emissions. Some other smaller differences in the methods of the two systems are caused by updates which were integrated in the software in different times.

25 Appendix F1: Characterization factors for GWP100 in GaBi

Carbon dioxide [Inorganic emissions to air]	1	kg	1
Carbon dioxide [Renewable resources]	1	kg	1
Carbon dioxide (biotic) [Inorganic emissions to air]	1	kg	1
Carbon dioxide (biotic) [Inorganic emissions to air]	1	kg	1
Carbon dioxide, land transformation [Inorganic emissions to air]	1	kg	1
Methyl bromide [Halogenated organic emissions to air]	0,2	kg	5
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	0,1	kg	10
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	0,0625	kg	16
Hydrocarbons (unspecified) [Organic emissions to air (group VOC)]	0,0621118	kg	16,1
VOC (unspecified) [Organic emissions to air (group VOC)]	0,0621118	kg	16,1
VOC (unspecified) [Hydrocarbons to fresh water]	0,0621118	kg	16,1
VOC (unspecified) [Hydrocarbons to sea water]	0,0621118	kg	16,1
Methane [Organic emissions to air (group VOC)]	0,04347826	kg	23
Methane (biotic) [Organic emissions to air (group VOC)]	0,04347826	kg	23
Trichloromethane (chloroform) [Halogenated organic emissions to air]	0,03333333	kg	30
R 41 [Halogenated organic emissions to air]	0,01030928	kg	97
R 123 (dichlorotrifluoroethane) [Halogenated organic emissions to air]	0,00833333	kg	120
R 152a (difluoroethane) [Halogenated organic emissions to air]	0,00833333	kg	120
1,1,1-Trichloroethane [Halogenated organic emissions to air]	0,00714286	kg	140
R 225ca (dichloropentafluoropropane) [Halogenated organic emissions to air]	0,00555556	kg	180
Nitrous oxide (laughing gas) [Inorganic emissions to air]	0,00337838	kg	296
R 143 (trifluoroethane) [Halogenated organic emissions to air]	0,0030303	kg	330
R32 (difluoromethane) [Halogenated organic emissions to air]	0,00181818	kg	550
R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air]	0,0016129	kg	620
R 225cb (dichloropentafluoropentane) [Halogenated organic emissions to air]	0,0016129	kg	620
R 245ca (pentafluoropropane) [Halogenated organic emissions to air]	0,0015625	kg	640
R 141b (dichloro-1-fluoroethane) [Halogenated organic emissions to air]	0,00142857	kg	700
R 134 [Halogenated organic emissions to air]	0,00090909	kg	1100
Halon (1211) [Halogenated organic emissions to air]	0,00076923	kg	1300
R 134a (tetrafluoroethane) [Halogenated organic emissions to air]	0,00076923	kg	1300
R 43-10 (decafluoropentane) [Halogenated organic emissions to air]	0,00066667	kg	1500
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	0,00058824	kg	1700
Carbon tetrachloride (tetrachloromethane) [Halogenated organic emissions to air]	0,00055556	kg	1800
R 142b (chlorodifluoroethane) [Halogenated organic emissions to air]	0,00041667	kg	2400
R 125 (pentafluoroethane) [Halogenated organic emissions to air]	0,00029412	kg	3400
R 227ea (septifluoropropane) [Halogenated organic emissions to air]	0,00028571	kg	3500
R 143a (trifluoroethane) [Halogenated organic emissions to air]	0,00023256	kg	4300
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	0,00021739	kg	4600
Tetrafluoromethane [Halogenated organic emissions to air]	0,00017544	kg	5700
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	0,00016667	kg	6000
Halon (1301) [Halogenated organic emissions to air]	0,00014493	kg	6900
R 115 (chloropentafluoroethane) [Halogenated organic emissions to air]	0,00013889	kg	7200
Perfluorobutane [Halogenated organic emissions to air]	0,00011628	kg	8600
Perfluoropropane [Halogenated organic emissions to air]	0,00011628	kg	8600
Perfluoropentane [Halogenated organic emissions to air]	0,00011236	kg	8900
Perfluorohexane [Halogenated organic emissions to air]	0,00011111	kg	9000
R 236fa (hexafluoropropane) [Halogenated organic emissions to air]	0,00010638	kg	9400
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	0,00010204	kg	9800
Perfluorocyclobutane [Halogenated organic emissions to air]	0,0001	kg	10000
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to fresh water]	9,43E-05	kg	10600
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to sea water]	9,43E-05	kg	10600
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	9,43E-05	kg	10600
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	8,40E-05	kg	11900
R 23 (trifluoromethane) [Halogenated organic emissions to air]	8,33E-05	kg	12000
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	7,14E-05	kg	14000
Sulphur hexafluoride [Inorganic emissions to air]	4,50E-05	kg	22200

26 Appendix F2: Characterization factors for GWP100 in Simapro

Carbon dioxide	000124-38-9	1	kg CO2 eq / kg
Carbon dioxide, fossil	000124-38-9	1	kg CO2 eq / kg
Carbon dioxide, land transformation	000124-38-9	1	kg CO2 eq / kg
Methane, iodotrifluoro-	002314-97-8	1	kg CO2 eq / kg
Carbon monoxide	000630-08-0	1,57	kg CO2 eq / kg
Carbon monoxide, fossil	000630-08-0	1,57	kg CO2 eq / kg
Methane, bromo-, Halon 1001	000074-83-9	5	kg CO2 eq / kg
Methane, dichloro-, HCC-30	000075-09-2	10	kg CO2 eq / kg
Methane, monochloro-, R-40	000074-87-3	16	kg CO2 eq / kg
Methane, biogenic	000074-82-8	20	kg CO2 eq / kg
Methane	000074-82-8	23	kg CO2 eq / kg
Methane, fossil	000074-82-8	23	kg CO2 eq / kg
Chloroform	000067-66-3	30	kg CO2 eq / kg
Methane, fluoro-, HFC-41	000593-53-3	97	kg CO2 eq / kg
Ethane, 1,1-difluoro-, HFC-152a	000075-37-6	120	kg CO2 eq / kg
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	000306-83-2	120	kg CO2 eq / kg
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	140	kg CO2 eq / kg
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	000422-56-0	180	kg CO2 eq / kg
Methane, dichlorofluoro-, HCFC-21	000075-43-4	2,10E+02	kg CO2 eq / kg
Dinitrogen monoxide	010024-97-2	296	kg CO2 eq / kg
Ethane, 1,1,2-trifluoro-, HFC-143	000430-66-0	330	kg CO2 eq / kg
Methane, bromodifluoro-, Halon 1201	001511-62-2	470	kg CO2 eq / kg
Methane, difluoro-, HFC-32	000075-10-5	550	kg CO2 eq / kg
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	002837-89-0	620	kg CO2 eq / kg
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	000507-55-1	620	kg CO2 eq / kg
Propane, 1,1,2,2,3-pentafluoro-, HFC-245ca	000679-86-7	640	kg CO2 eq / kg
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	001717-00-6	700	kg CO2 eq / kg
Ethane, 1,1,2,2-tetrafluoro-, HFC-134	000359-35-3	1100	kg CO2 eq / kg
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	000811-97-2	1300	kg CO2 eq / kg
Methane, bromochlorodifluoro-, Halon 1211	000353-59-3	1300	kg CO2 eq / kg
Pentane, 2,3-dihydroperfluoro-, HFC-4310mee	138495-42-8	1500	kg CO2 eq / kg
Methane, chlorodifluoro-, HCFC-22	000075-45-6	1700	kg CO2 eq / kg
Methane, tetrachloro-, CFC-10	000056-23-5	1800	kg CO2 eq / kg
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	000075-68-3	2400	kg CO2 eq / kg
Ethane, pentafluoro-, HFC-125	000354-33-6	3400	kg CO2 eq / kg
Propane, 1,1,1,2,3,3,3-heptafluoro-, HFC-227ea	000431-89-0	3500	kg CO2 eq / kg
Ethane, 1,1,1-trifluoro-, HFC-143a	000420-46-2	4300	kg CO2 eq / kg
Methane, trichlorofluoro-, CFC-11	000075-69-4	4600	kg CO2 eq / kg
Methane, tetrafluoro-, CFC-14	000075-73-0	5700	kg CO2 eq / kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	000076-13-1	6000	kg CO2 eq / kg
Methane, bromotrifluoro-, Halon 1301	000075-63-8	6900	kg CO2 eq / kg
Ethane, chloropentafluoro-, CFC-115	000076-15-3	7200	kg CO2 eq / kg
Butane, perfluoro-	000355-25-9	8600	kg CO2 eq / kg
Propane, perfluoro-	000076-19-7	8600	kg CO2 eq / kg
Pentane, perfluoro-	000678-26-2	8900	kg CO2 eq / kg
Hexane, perfluoro-	000355-42-0	9000	kg CO2 eq / kg
Propane, 1,1,1,3,3,3-hexafluoro-, HCFC-236fa	000690-39-1	9400	kg CO2 eq / kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	000076-14-2	9800	kg CO2 eq / kg
Butane, perfluorocyclo-, PFC-318	000115-25-3	10000	kg CO2 eq / kg
Methane, dichlorodifluoro-, CFC-12	000075-71-8	10600	kg CO2 eq / kg
Ethane, hexafluoro-, HFC-116	000076-16-4	11900	kg CO2 eq / kg
Methane, trifluoro-, HFC-23	000075-46-7	12000	kg CO2 eq / kg
Methane, chlorotrifluoro-, CFC-13	000075-72-9	14000	kg CO2 eq / kg
Sulfur hexafluoride	002551-62-4	22200	kg CO2 eq / kg