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0-WASTE
Carbon Composite Sheet Werkstoffe für Automotiv-Strukturbauteile aus neuartiger Presstechnologie

TEIL II – LIFE CYCLE ASSESSMENT

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1 Introduction

The objective and purpose of this Life Cycle Assessment (LCA) study is to identify and model different material and recycling options of a transmission cross beam (TCB) in order to show and assess the environmental impacts. The TCB is defined as the functional unit and the whole product life cycle is evaluated through a comparative LCA, from extraction of raw materials and energy to end-of-life treatment. The material and energy options are analysed and evaluate as scenarios. The evaluated recycling options include further using materials without any material transformation, as well as traditional recycling options (options with material transformation). The LCA refers to the methodology of the ISO 14040 and 14044 and it is modelled and conducted using the software *Umberto LCA+* and the database *ecoinvent v.3.5*. The results should provide assistance in the decision-making regarding the overall environmental performance of the different material and recycling option.

The general method of LCA is briefly explained in the beginning of the report. Then, the different material and recycling options of the TCB are described. In the next step it is explained how the LCA methodology is applied on the LCA study of the TCB, whereby the structure follows the different phases of LCA. In the next section of the report, the results are analysed and interpreted. The report ends with a conclusion and further recommendations.

2 Content and methods of Life Cycle Assessment (LCA)

2.1 The method of LCA in general

According to the ISO 14040 (2006, p. 4) "LCA addresses the environmental aspects and potential environmental impacts (…) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)". *Figure 1* shows the typical phases of an LCA: Goal and scope definition, inventory analysis, impact assessment and interpretation. In the first phase, the goal and the scope of the LCA study is defined. The scope definition includes the definition of the system boundaries and it always depends on the goal of the LCA study. The second phase includes an inventory of all relevant inputs and outputs. In the next step, the third phase, additional information is added in order to be able to make the results from the inventory analysis more understandable. In the last phase of LCA, the interpretation phase, the results are summed up so that conclusions can be drawn (ISO 14040, 2006).

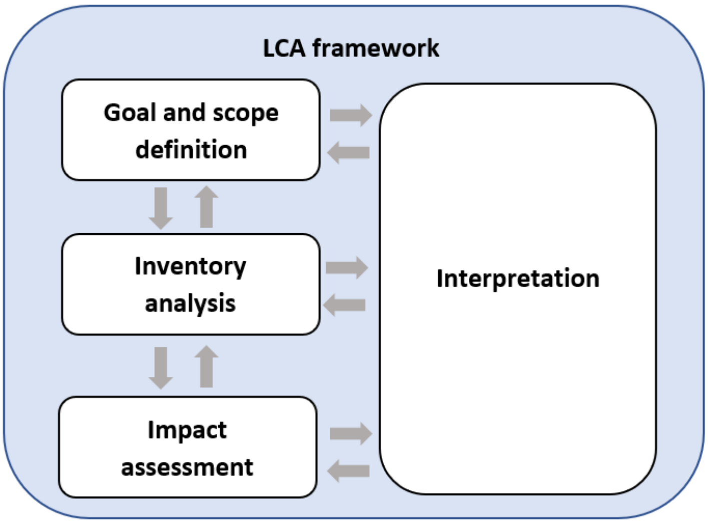

Figure 1: Phases of LCA
Source: Based on ISO 14040, p. 17

2.2 The different material compositions of the transmission cross beam in the LCA study

Through the comparative LCA seven different options of a transmission cross beam were compared with each other. They differ regarding material compositions and assumed recycling strategies. *Table 1* shows the terms of the different material and recycling options. A defined transmission cross beam out of aluminium, named *(a1) Aluminium,* serves as the basis for comparison. The C-SMC and C-SMC Sandwich options are numbered with *(c1) – (c6). (c1), (c2)* and *(c3)* represent the C-SMC options and *(c4), (c5)* and *(c6)* stand for the C-SMC Sandwich options, as it can be seen in *Table 1.*

No.	**Terms for LCA options**	
(a1)	Aluminium (die-casting)	
(c1)	C-SMC	Prepreg
(c2)	C-SMC	Prepreg byproduct (byproduct 50:50 allocation)
(c3)	C-SMC	Mix Prepreg & Prepreg byproduct (byproduct 50:50 allocation)
(c4)	C-SMC Sandwich	Prepreg
(c5)	C-SMC Sandwich	Prepreg byproduct (byproduct 50:50 allocation)
(c6)	C-SMC Sandwich	Mix Prepreg & Prepreg byproduct (byproduct 50:50 allocation)

Table 1: Seven material and recycling options
Source: Compiled by the authors

The manufacturing process of the transmission cross beam is shown in *Figure 2* for the C-SMC options and in *Figure 3* for the C-SMC Sandwich options in a simplified flow chart. While the processes with RED marked numbering show the manufacturing processes with primary carbon fibres, the processes with GREEN marked numbering represent the manufacturing processes with recycled carbon fibres. As it can be seen in *Figure 3*, for the C-SMC Sandwich options processes with primary carbon fibres, as well as processes with recycled carbon fibres are used. In process “9.6 Sandwich Parts manufacturing” these processes come together.

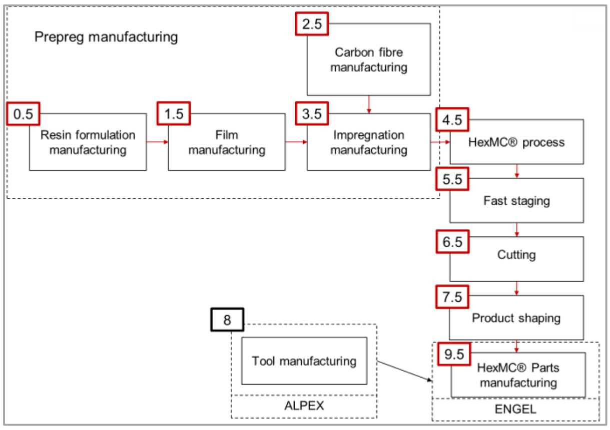

Figure 2: Flow chart of the manufacturing process of a transmission cross beam for the C-SMC options
Source: Compiled by the authors

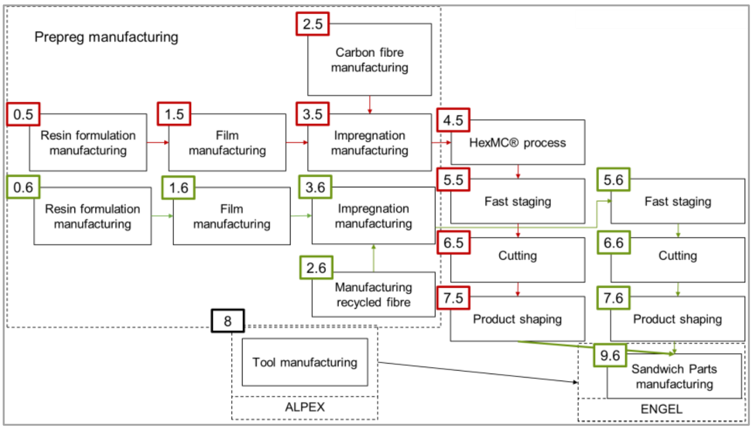

Figure 3: Flow chart of the manufacturing process of a transmission cross beam for the C-SMC Sandwich options
Source: Compiled by the authors

For the three C-SMC Sandwich options recycled carbon fibres from a specific pyrolysis process are partly used (*Figure 3:* “2.6 Manufacturing recycled fibre). In coordination with the iPPE these carbon fibres are seen as a fallow resource and therefore, the cut-off method can be applied. This means that the environmental impacts associated with previous processes of these carbon fibres are not included in the environmental assessment (Klöpffer & Grahl, 2014). However, the data regarding the necessary recycling process, more specifically the pyrolysis process, for the secondary used carbon fibres were not available. Therefore, the significance of the results of the three C-SMC Sandwich options is limited.

As a result, the presentation of the LCA results focus on the comparison of the aluminium option, (a1), with the three C-SMC options (c1 – c3).

The seven options for the LCA models are:

- ***(a1) Aluminium***
  The aluminium option serves as a basis for comparison and consists out of die-cast aluminium (2147g) and polyurethane acoustic foam (340g). For the aluminium option the *ecoinvent 3.5* dataset “market for aluminium, cast alloy [GLO]” (Ecoinvent Centre, 2018a) was chosen for the LCA model, which includes estimations for the transports (Ecoinvent Centre, 2018a).[1]

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[1] At beginning of the current study, there were three *ecoinvent 3.5 dataset options* discussed *for aluminium* in the LCA: (I) “aluminium alloy production, AlLi [GLO]” (Dussault 2018), (II) “market for aluminium, cast alloy [GLO]” (Ecoinvent Centre 2018a) and (III) “market for aluminium alloy, AlLi [GLO]” (Ecoinvent Centre 2018b). In the document of first dataset there is written down that up to 30 % primary aluminium is assumed to be used. Hence, there are assumed to be about 70 % seconddary aluminium, whereby 60 % of the secondary aluminium comes from external sources and 40 % from internal sources, implying closed-loop recycling. This means that in total about 30 % is primary aluminium, about 42 % is secondary aluminium from external sources and about 28 % is secondary aluminium from internal sources (Dussault 2018).
Within the sensitivity analysis of current LCA calculations have been done in view of the environmental impacts of above three aluminium dataset options. The differences in the *midpoint results* are very small concerning almost all impact category. Finally the dataset (II) “market for aluminium, cast alloy [GLO]” (Ecoinvent Centre 2018a) has been chosen, because it is the best technologically related to the transmission cross beam of aluminium. Focusing the *endpoint results* of the sensitivity analysis, the result of (II) is very little worse than the results of the aluminium datasets (I) and (III). So applying (II) is in accordance with the principle of ecological prudence, too.

- ***(c1) C-SMC, Prepreg***
  There are no recycled carbon fibres used for the C-SMC options. In this C-SMC option, for Prepreg manufacturing (processes 0.5 – 3.5 in *Figure 2*) primary material is used. Moreover, carbon residual material with equivalent quality (from another product) is not further used in this option.
- ***(c2) C-SMC, Prepreg byproduct (byproduct 50:50 allocation)***
  There are also no recycled carbon fibres used. However, residual material with equivalent quality from another product is used for the Prepreg-material. Therefore, this residual material can be understood as a byproduct. Regarding the allocation of the environmental impacts of this byproduct the 50:50 rule is applied, as it is assumed that this material is not a fallow resource and that the transmission cross beam production was not the initial purpose of production. Therefore, only half of the environmental impacts associated with the production of the byproduct (carbon residual material) are considered for the production of the transmission cross beam (Klöpffer & Grahl, 2014).
- ***(c3) C-SMC, Mix Prepreg & Prepreg byproduct (byproduct 50:50 allocation)***
  This option is a mix of the other two C-SMC options. It is assumed that one part of the Prepreg-material is produced primary [*(c1)*] and for the other part carbon residual material (from another product) is reused [*(c2)*]. A ratio of 60:40 is assumed, whereby 60 percent represent the byproduct and for this amount again the 50:50 rule is applied regarding the allocation of the environmental impacts.
- ***(c4) C-SMC Sandwich, Prepreg***
  As already mentioned before, all three C-SMC Sandwich options partly use recycled carbon fibres. The cut-off rule is applied for these recycled carbon fibres because they are seen as a fallow resource. Regarding the manufacturing process with primary carbon fibres (the processes with RED marked numbering in *Figure 3*) there are again three different options for the Prepreg-material. In option *(c4) C-SMC Sandwich Prepreg* the Prepreg manufacturing contains only primary material, as it is also the case in option *(c1) C-SMC Prepreg.*
- ***(c5) C-SMC Sandwich, Prepreg byproduct (byproduct 50:50 allocation)***
  Here, also the cut-off rule is applied for the recycled carbon fibres. Furthermore, for this C-SMC Sandwich option it is assumed that regarding the manufacturing process with primary carbon fibres (the processes with RED marked numbering in *Figure 3*) instead of Prepreg manufacturing a byproduct is used, as it is also the case in option *(c2) C-SMC Prepreg byproduct*. Therefore, again the 50:50 allocation rule is applied.
- ***(c6) C-SMC Sandwich, Mix Prepreg & Prepreg byproduct (byproduct 50:50 allocation)***
  The last C-SMC Sandwich option also use recycled carbon fibres with the cut-off rule, as it is also the case for the other two C-SMC Sandwich options [*(c4), (c5)*]. Regarding Prepreg manufacturing this C-SMC Sandwich option represents the equivalent of the C-SMC option *(c3) C-SMC Mix Prepreg & Prepeg byproduct.* This means that with a share of 60 percent the byproduct is reused instead of Prepreg manufacturing and with a share of 40 percent the Prepreg manufacturing includes only primary material. Regarding the byproduct, again the 50:50 rule is applied.

2.3 Applied LCA methodology – Goal and scope

The LCA is modelled and conducted with the software *Umberto LCA+* in combination with the database *ecoinvent 3.5 (with aggregated impacts)*. The functional unit for the LCA study is the function of the defined transmission cross beam of a passenger car. The related reference flows of the different material and recycling options differ regarding the particular weights of the transmission cross beam. The weight of the transmission cross beam for option *(a1) Aluminium* is 2489 g, for the C-SMC options [*(c1, (c2), (c3)*] 1273 g and for the C-SMC Sandwich options [*(c4), (c5), (c6)*] 1279 g. The system boundaries concern the whole life cycle of the transmission cross beam.

Using *Umberto LCA+* it is possible to assign the individual processes to life cycle phases. Usually the phases *Raw Material, Manufacture, Distribution/Retail, Consumer Use* and *Disposal/Recycling* are used (ifu Hamburg GmbH, 2017). However, for the LCA study of the TCB options the names of the LCA phases were adapted. *Figure 4* shows the LCA phases that were used for the study. First, a virtual phase, called *Credits* was added. This phase does not represent a typical life cycle phase; however it has been added with the objective to include the (environmental) credits of recycling in the calculations and to be able to explicitly show them. Furthermore, the phases *Raw Material* and *Manufacturing* are summed up to one phase, since it was not always possible to clearly identify to which of these two phases the impacts of certain processes belong to. All different transport modes and distances over the whole ecological life cycle are summed up to one phase, called *Transports.* Transports are only included directly in the LCA model for the C-SMC and C-SMC Sandwich options. Regarding the aluminium option no transport data was known or collected, but the transport data are an implicit part of the corresponding *ecoinvent 3.5* processes.

Figure 4:LCA phases for the TCB options using Umberto LCA+
Source: Based on ifu Hamburg GmbH 2017, p. 39

The geographical and temporal system boundaries rely on the available *ecoinvent 3.5* data. Regarding the energy mix for all options data sets for Europe are chosen (RER: Geographical Europe) in order to be able to compare them with the transmission cross beam out of aluminium, which serves as the basis for comparison. The temporal system boundaries also rely on *ecoinvent 3.5* datasets, including a time frame from 1990 to 2018.

2.4 Applied LCA methodology – Inventory analysis

Primary data were provided by the iPPE, secondary data were used from the *ecoinvent 3.5* database. Material and energy data for the manufacturing of an appropriate tool, that is needed for the production of the C-SMC and C-SMC Sandwich transmission cross beams, were also considered in the LCA study (see *Figure 2* and *Figure 3:* “8.Tool manufacturing”). It is assumed that this tool can be used for the production of 100 000 transmission cross beams. As the functional unit relies on 1 transmission cross beam, the environmental impacts are calculated for 1 transmission cross beam. Moreover, the environmental impacts resulting during the use phase of the transmission cross beam in the passenger car over a distance of 168 000 km, are included in the LCA study for the weight of a transmission cross beam as 1 use unit.

Furthermore, allocation rules were defined in the inventory analysis. For all *ecoinvent 3.5* datasets the system model APOS (Allocation at the point of substitution) was chosen. This means that the environmental impacts are allocated proportionally to the processes (ecoinvent, n.d.). Furthermore, as already mentioned before, regarding the byproduct in option *(c2), (c3), (c5)* and *(c6)* the 50:50 rule is applied for modelling the LCA. The 50:50 rule is also used for (environmental) credits that arise from recycling. This is the case in option *(a1) Aluminium* where a credit for end-of-life recycling is calculated. Moreover, there are also credits included for the C-SMC and C-SCM Sandwich options. These credits are the result of recycling material losses. On the one hand, the recycling of the material loss of the aluminium inserts is included and on the other hand, a credit is calculated for recycling the material loss of steel that occurs in the tool manufacturing process (see *Figure 2* and *Figure 3*: “8.Tool manufacturing”). As already mentioned before, additionally the cut-off rule is applied for the recycled carbon fibres of the C-SMC Sandwich options, as (soon as) the residual carbon fibres must be seen as fallow resources.

Figure 5 and *Figure 6* show the Umberto models for the aluminium option and the first C-SMC option with the life cycle phases, mentioned before. The model for option *(a1) Aluminium* can be seen in *Figure 5* and the model for option *(c1) C-SMC Prepreg* in *Figure 6.* The squares with the blue borderline are the processes. The green circles represent input places, the red ones output places and the yellow ones serve as connection places between the processes. It can be seen, that in *Figure 6* the squares are marked with a blue double line. This symbol represents a subnet and behind each subnet another net is hidden (ifu Hamburg GmbH, 2017). The subnets are used for modelling the C-SMC and C-SMC Sandwich option with the objective to simplify the model views.

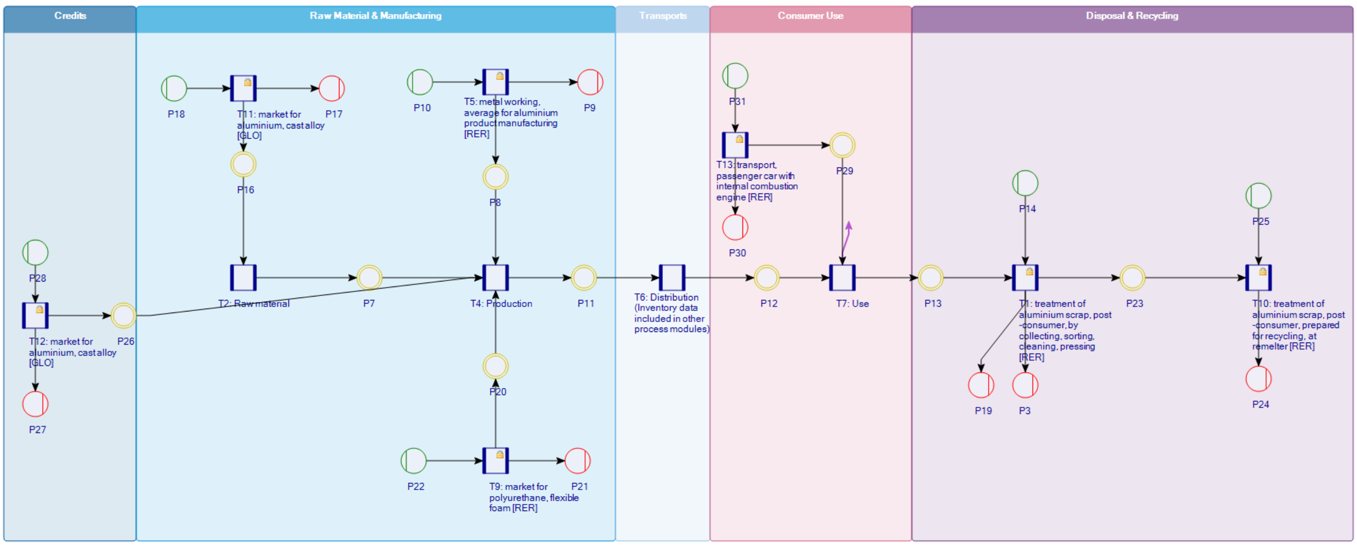

Figure 5: Umberto LCA+ model of the option *(a1) Aluminium*
Source: Own research

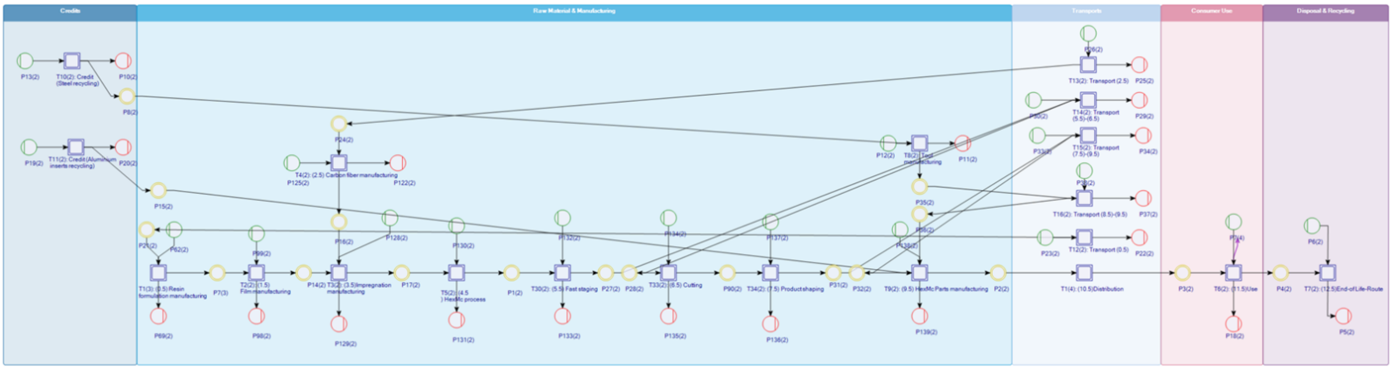

Figure 6: Umberto LCA+ model of the option *(c1) C-SMC, Prepreg*
Source: Own research

2.5 Applied LCA methodology – Impact assessment

A midpoint, as well as an endpoint method, is used for calculating the LCA results. When an endpoint method is used, the results of the impact categories are further aggregated to the 3 damage categories: human health, ecosystem quality and resource availability (Goedkoop et al., 2008). *Figure 7* shows the relationship between the midpoint impact categories and the damage categories by the example of the ReCiPe 2016 method. The 3 damage catagories are also called “Areas of Protection (AoPs)” and represent the endpoints in the ReCiPE method (Huijbregts et al, 2017).

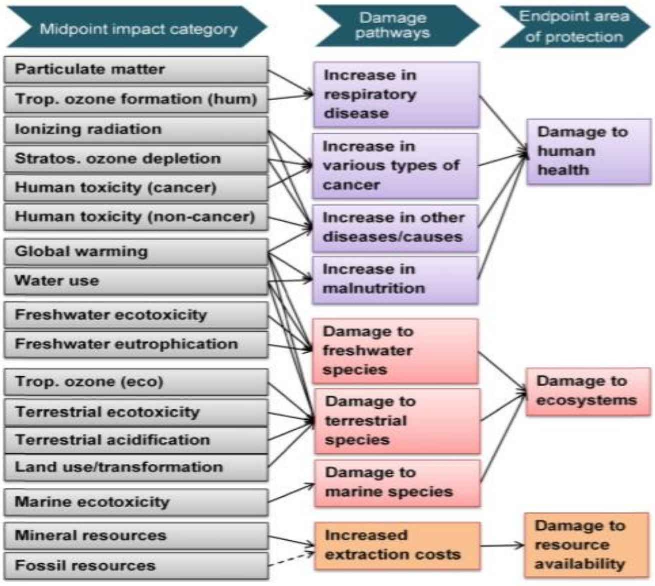

Figure 7: Relationship between the ReciPe midpoint impact categories and the 3 damage categories/endpoints
Source: Huijbregts et al. 2017, p. 140

For the analysis of the results at the **MIDPOINT LEVEL** the ILCD 1.0.8 2016 method is chosen, as in the LCA study conducted by EVEA (Causse et al., 2017) for Hexcel Corporation this method is also used. Moreover, for the ILCD 1.0.8 2016 midpoint method there are resident equivalents available that serve as normalization factor (Benini et al., 2014). ILCD stands for International Life Cycle Data system and has been developed since 2005 with the objective to provide consistency and high quality (European Union, 2014-2019). There also exists the ILCD Handbook which includes documents that deal with recommendations for life cycle impact assessment and the related methods (Wolf et al., 2012).

Regarding the analysis at the **ENDPOINT LEVEL**, the ReCiPe Endpoint (H, A) Method is chosen. The ReCiPe method has been given this name for two reasons. The first one is that it provides a “recipe” for the calculation of life cycle impact category indicators and the second one is that the ReCiPe is an acronym of the initials of the institutes that were the main contributors of this method, including RIVM and Radboud University, CML and PRé (Goedkoop et al. 2008). Using the ReCiPe method one can choose between three different perspectives, the individualist, the hierarchist and egalitarian perspective. The first one, the individualist perspective follows a short-term approach and includes technological optimism with regard to human adaption. The hierarchist perspective relies on scientific consensus and is neither seen as optimistic nor pessimistic. The last perspective, the egalitarian one, is the most precautionary perspective. It assumes the longest time frame and considers all available impact pathways (Huijbregts et al., 2016). For the current LCA study the hierarchist perspective was chosen for the endpoint analysis.

3 Results of the Life Cycle Assessment study - Interpretation

The results focus on the comparison between the transmission cross beam out of aluminium and the three C-SMC options. The results of the C-SMC Sandwich options are not analysed in detail because it was not possible to make the pyrolysis data available.

3.1 Results at midpoint level

Figure 8 shows the results of the ILCD midpoint method for the impact categories: climate change, GWP 100a; freshwater and terrestrial acidification (ecosystem quality); freshwater ecotoxicity (ecosystem quality), freshwater eutrophication (ecosystem quality); marine eutrophication (ecosystem quality); terrestrial eutrophication (ecosystem quality); carcinogenic effects (human health); ionising radiation (human health); non-carcinogenic effects (human health); ozone layer depletion (human health); photochemical ozone creation (human health); respiratory effects, inorganics (human health); land use (resources); and mineral, fossil and renewables (resources). The result of the transmission cross beam out of aluminium, which is set to 100 percent, and the three C-SMC options are shown relatively to the aluminium option. It can be seen that all C-SMC options provide better results than the results of the transmission cross beam out of aluminium. The impact category ionising radiation (human health) is the only exception. Regarding this impact category the transmission cross beam out of aluminium performs better than the transmission cross beam with option *(c1) C-SMC Prepreg.* However, this is only relevant for the first C-SMC option. This means that the other two C-SMC options have less environmental impacts than the aluminium option also in the impact category ionising radiation (human health). The differences between the results of the C-SMC options arise from the assumption of the reuse of the residual material as a byproduct. Therefore, option *(c2) C-SMC Prepreg byproduct* provides the best results when looking at all impact category.[2]

[2] Without considering the C-SMC Sandwich options.

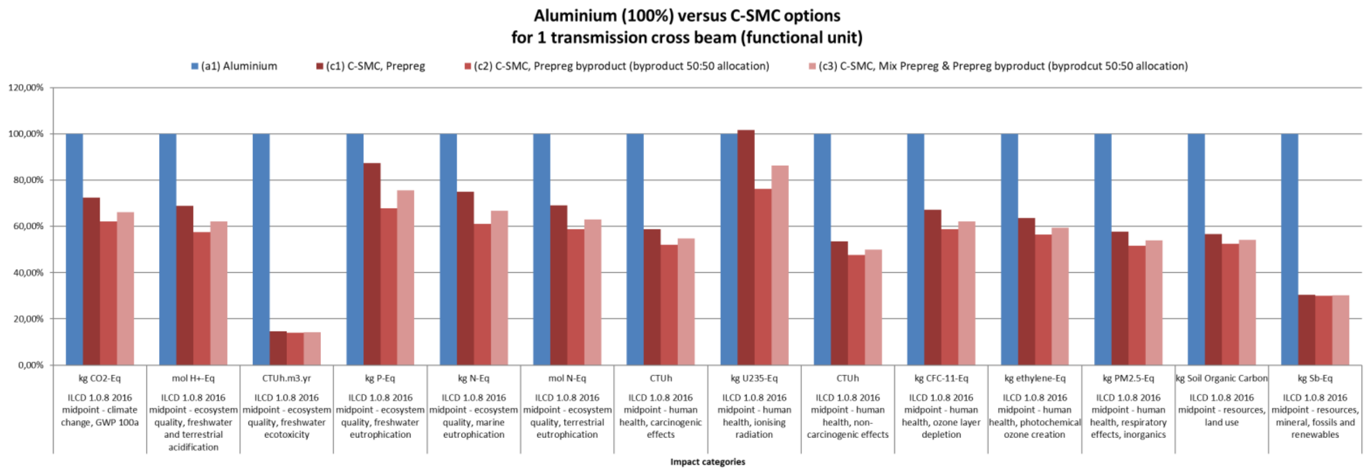

Figure 8: Aluminium versus C-SMC options with the ILCD 1.0.8 2016 midpoint method
Source: Own research

Table 2 shows the results without the comparison through percentage values for the respective impact categories. Here, the results of the three C-SMC Sandwich options [*(c4)**, *(c5)** and *(c6)**] are also included without the recycling/pyrolysis process.

Impact category (Unit)	**(a1)**	**(c1)**	**(c2)**	**(c3)**	**(c4)***	**(c5)***	**(c6)***
climate change, GWP 100a (kg CO2-Eq)	1,07E+02	7,77E+01	6,67E+01	7,11E+01	7,55E+01	6,62E+01	6,99E+01
ecosystem quality, freshwater and terrestrial acidification (mol H+-Eq)	4,86E-01	3,35E-01	2,79E-01	3,02E-01	3,23E-01	2,76E-01	2,95E-01
ecosystem quality, freshwater ecotoxicity (CTUh.m3.yr)	1,20E+04	1,75E+03	1,68E+03	1,70E+03	1,74E+03	1,68E+03	1,70E+03
ecosystem quality, freshwater eutrophication (kg P-Eq)	2,73E-02	2,38E-02	1,85E-02	2,06E-02	2,26E-02	1,81E-02	1,99E-02
ecosystem quality, marine eutrophication (kg N-Eq)	1,04E-01	7,79E-02	6,35E-02	6,93E-02	7,43E-02	6,22E-02	6,71E-02
ecosystem quality, terrestrial eutrophication (mol N-Eq)	1,08E+00	7,46E-01	6,34E-01	6,79E-01	7,22E-01	6,27E-01	6,65E-01
human health, carcinogenic effects (CTUh)	9,46E-06	5,56E-06	4,93E-06	5,18E-06	5,47E-06	4,94E-06	5,15E-06
human health, ionising radiation (kg U235-Eq)	9,92E+00	1,01E+01	7,57E+00	8,57E+00	9,36E+00	7,24E+00	8,09E+00
human health, non-carcinogenic effects (CTUh)	4,12E-05	2,20E-05	1,96E-05	2,06E-05	2,16E-05	1,95E-05	2,03E-05
human health, ozone layer depletion (kg CFC-11-Eq)	1,57E-05	1,05E-05	9,22E-06	9,75E-06	1,03E-05	9,17E-06	9,62E-06
human health, photochemical ozone creation (kg ethylene-Eq)	3,48E-01	2,21E-01	1,97E-01	2,07E-01	2,17E-01	1,97E-01	2,05E-01
human health, respiratory effects, inorganics (kg PM2.5-Eq)	7,88E-02	4,55E-02	4,06E-02	4,26E-02	4,47E-02	4,05E-02	4,22E-02
resources, land use (kg Soil Organic Carbon)	2,74E+02	1,55E+02	1,44E+02	1,49E+02	1,53E+02	1,44E+02	1,48E+02
resources, mineral, fossils and renewables (kg Sb-Eq)	4,75E-02	1,45E-02	1,43E-02	1,44E-02	1,44E-02	1,42E-02	1,43E-02

Table 2: Aluminium versus C-SMC and C-SMC Sandwich options with the ILCD 1.0.8 2016 midpoint method
*without pyrolysis
Source: Own research

It is obvious that the specific C-SMC Sandwich option always has less environmental impacts than the corresponding C-SMC option with the same Prepreg manufacturing assumption. This means that *(c4)*

C-SMC Sandwich Prepreg has less environmental impacts than *(c1) C-SMC Prepreg,* but it does not perform better than *(c2) C-SMC Prepreg byproduct* and *(c3) C-SMC Mix Prepreg & Prepreg byproduct.*

When the C-SMC and C-SMC Sandwich options are ranked, starting with the highest environmental impacts, the following order results, whereby it has to be considered that the pyrolysis data are not included in the results of the C-SMC options (green) and hence, these options tend to be ecologically better off:

(c1) > (c4)* > (c3) > (c6)* > (c2) > (c5)*

Figure 9 shows the results of *Figure 8* relative to normalization factors. In this case the normalization factors are the resident equivalents per EU inhabitant per year (Benini et al., 2014). This means that if the result is a value higher than 1 (in *Figure 9*), the transmission cross beam leads to higher environmental impacts in the specific impact category over its whole life cycle than the average EU inhabitant per year in this impact category.

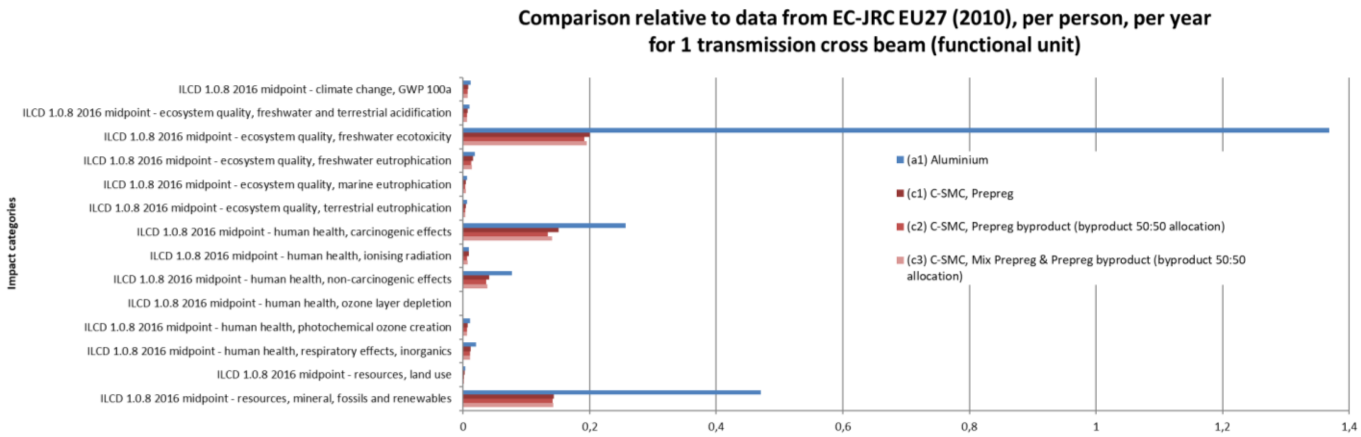

Figure 9: Results of the ILCD 1.0.8 2016 midpoint method relative to normalization factors
Source: Own research

3.2 Results at endpoint level

The results of the 3 damage categories, ecosystem quality, human health and resources, as well as the endpoint result that aggregates the results of the 3 damage categories to one endpoint category, are shown in *Figure 10*.

The analysis of the results of the 3 damage categories shows that the transmission cross beam consisting of aluminium has more “environmental points” than the C-SMC options. This means all in all, that the three C-SMC options are more environmentally friendly than the aluminium option. The environmental differences between the three C-SMC options - representing by ReCiPe endpoints - result from the different assumptions concerning Prepreg manufacturing.

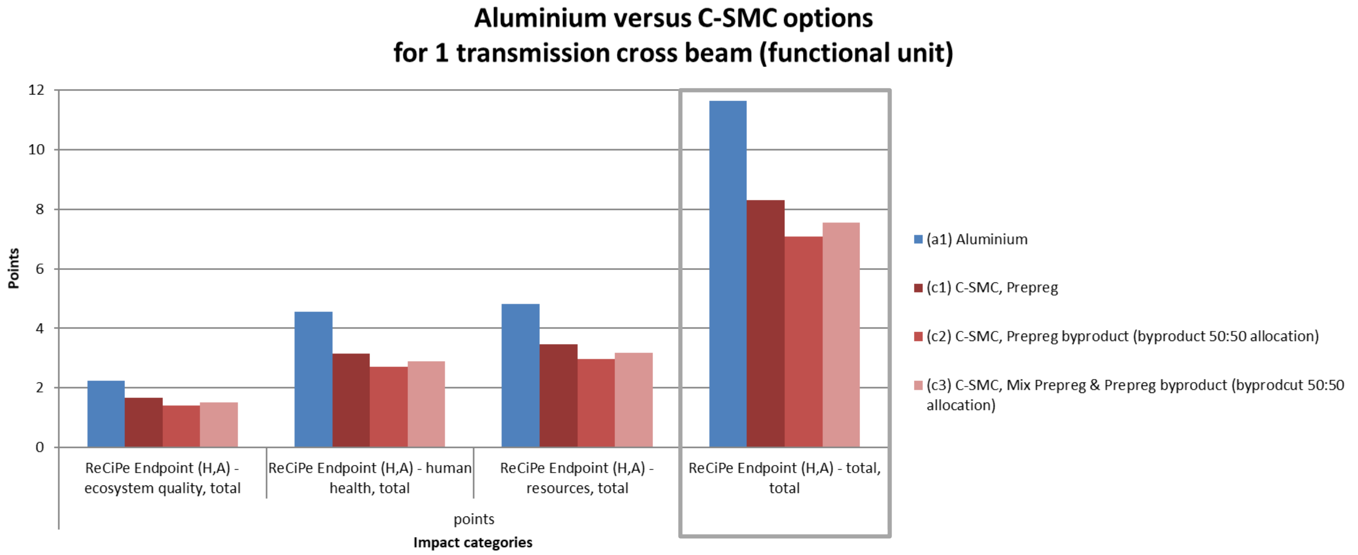

Figure 10: Aluminium versus C-SMC options with the ReCiPe Endpoint (H, A) method
Source: Own research

Using the ReCiPe Endpoint (H, A) method it was additionally analysed which life cycle phase leads to the most environmental impacts. The aluminium option *(a1) Aluminium* was compared to the C-SMC options with the most “environmental points”, option *(c1) C-SMC Prepreg. Figure 11* shows the results separated according to the life cycle phases for the aluminium option and *Figure 12* for the C-SMC option. In both figures, the recycling credits are not included. As already mentioned before, it was not possible to directly include the transport data for the aluminium option. Therefore, there are no “environmental endpoints” for the transports phase in *Figure 11.*

In *Figure 11* and *Figure 12* it can be seen that most of the environmental impacts are assigned to the *Consumer Use* phase. In this phase the different results of the two options are only defined by the different weights of the transmission cross beams. Hence, when comparing the results of *Figure 11* and *Figure 12,* the advantage in the *Consumer Use* phase that comes with a lighter weight becomes obvious.

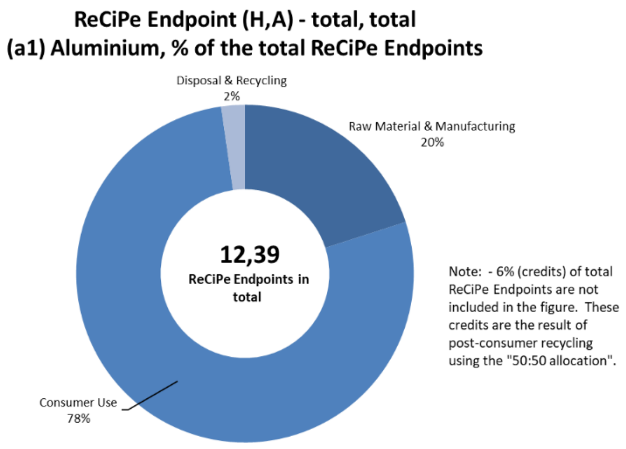

Figure 11: *(a1) Aluminium* in life cycle phases using the ReCiPe Endpoint (H, A) method
Source: Own research

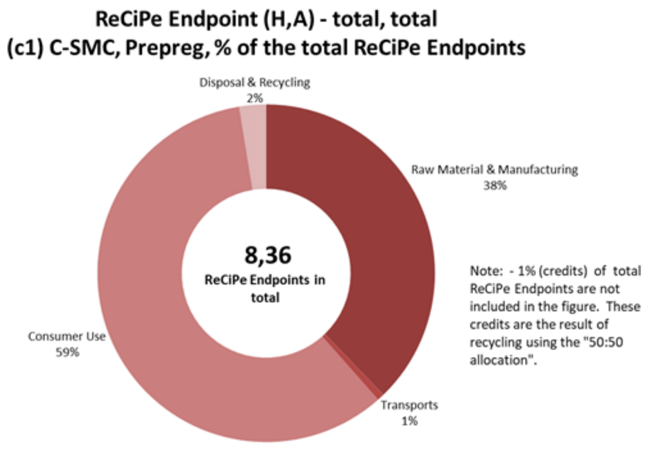

Figure 12: *(c1) C-SMC, Prepreg* in life cycle phases using the ReCiPe Endpoint (H, A) method
Source: Own research

4 Conclusion and further recommendations

Regarding to goal and scope of the LCA the inventory data was provided on one hand by iPPE and on other hand from ecoinvent 3.5 database (integrated in Umberto LCA+). The collection of proper data was one of the main challenges. Different allocation rules are applied for the processes and the different material and recycling options. It was applied a midpoint, as well as an endpoint method for calculating and analysing the LCA results. At the end the results are discussed, the different scenarios were compared and rated.

The comparative LCA study shows that the C-SMC options have lower environmental impacts than the aluminium option in almost all impact categories.

Whereas generic and specific data for all C-SMC and C-SMC Sandwich options were available or could be made available, for the aluminium option there were only generic data available. That's why the models for the C-SMC and C-SMC Sandwich options are more differentiated and are shown in more details. It has to be pointed out that there were no data available about the pyrolysis process for the C-SMC Sandwich options and therefore, the LCA results of *(c4)* – *(c6)* do not include the related environmental impacts or possible environmental credits.

5 References

Literature

Benini, L.; Mancini, L.; Sala, S.; Manfredi, S.; Schau, E. M.; Pant, R. (2014). Normalisation method and data for environmental footprints. European Commission, Joint Research Center, Institute for Environment and Sustainability. Luxemburg: Publications Office of the European Union.

Causse, S; Loiseau, G.; Villalon, E. (2017). Life cycle analysis of an “eco-based“ composite and identification of eco-design opportunities for Hexcel [EVEA].

Dussault, M. (2018). aluminium alloy production, AlLi, Allocation, APOS, ecoinvent database version 3.5.

Ecoinvent Centre (2018a). market for aluminium, cast alloy, GLO, Allocation, APOS, ecoinvent database version 3.5.

Ecoinvent Centre (2018b). market for aluminium alloy, AlLi, Allocation, APOS, ecoinvent database version 3.5.

Goedkoop, M.; Heijungs, R.; Huijbregts, M.; Schryver, A. de; Struijs, J.; van Zelm, R. (2008). ReCiPE 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level.

Huijbregts, M. A. J.; Steinmann, Z. J. N.; Elshout, P. M. F.; Stam, G.; Verones, F.; Vieira, M.; Zijp, M.; Hollander, A.; van Zelm, R. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. The International Journal of Life Cycle Assessment 22(2), 138–147.

Huijbregts, M.A.J; Steinmann, Z.J.N.; Elshout, P.M.F.; Stam, G.; Verones, F.; Vieira, M.D.M.; Hollander, A.; Zijp, M.; van Zelm, R. (2016). ReCiPe2016: A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization. RIVM Report 2016-0104. Bilthoven: National Institute for Public Health and the Environment.

ifu Hamburg GmbH (2017). Umberto® LCA+. User Manual. DocVersion 3.55.

Klöpffer, Walter; Grahl, Birgit (2014). Life Cycle Assessment (LCA). A Guide to Best Practice. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA.

Wolf, M-A..; Pant, R.; Chomkhamsri, K.; Sala, S.; Pennington, D. (2012). The International reference Life Cycle Data system (ILCD) handbook. Towards more sustainable production and consumption for a resource-efficient Europe. Luxembourg: Publications Office of the European Union.

Standards and rules

ISO 14040: Environmental management - Life cycle assessment - Principles and framework; German and English version EN ISO 14040:2006

ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines; German and English version EN ISO 14044:2006

Internet references

ecoinvent (n.d.). System Models in ecoinvent 3. https://www.ecoinvent.org/database/system-models-in-ecoinvent-3/system-models-in-ecoinvent-3.html, checked on 18.07.2019.

European Union (2014-2019). ILCD International Life Cycle Data system. https://eplca.jrc.ec.europa.eu/ilcd.html, checked on 20.08.2019.

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