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A Comparative Life Cycle Assessment of a Composite Component for Automotive

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In this study we present results on the environmental impacts associated to the production of an interior side door panel made of hemp fiber and epoxy resin, by using the life cycle assessment method. The composite was manufactured through vacuum bag infusion that improves the fiber-to-resin ratio and results in a lighter product. In this case, the weight of the panel is a very important aspect for the impact evaluation because the vehicle use phase is dominant compared to the manufacture and end of life phase. Recycling of the composite through coprocessing in cement kilns was assumed as waste scenario. One limit of thermoset composite wastes is that they are usually landfilled because recycling is not easy. Recent applications of recycled composite have shown that thermoset composite regrind is an ideal raw material for cement manufacturing. The mineral composition of the regrind is consistent with the optimum ratio between calcium oxide, silica, and aluminium oxide. Additionally, the organic fraction supplies fuel for the reaction heat, right at the spot where it is needed most. LCA comparison with petroleum-based composites was carried out.

1. Introduction

In order to systematically consider the environmental aspects, the R&D methodology has to balance the ecological, economical and technological aspects of design and production. Life Cycle Assessment (LCA) is a suitable tool to assess the environmental impacts associated to a product or a service.

Historically, life cycle assessments of bio-based polymers have shown favourable results in terms of environmental impacts and energy use compared to petroleum-based products. However, calculation of these impacts always depends on the system and boundary conditions considered during the study.

Composites of polymers reinforced with natural fibres have received increasing attention during the last years. Natural fibres such as hemp, sisal, flax, jute and wood-fibres possess good reinforcing capability when properly compounded with polymers. These natural fibre-reinforced composites find a wide array of applications in the building and construction industry and the automobile industry. As widely demonstrated in literature, the main advantage of using natural fibre composites is the reduction of the environmental impact due to the reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components as reported by Corbière-Nicollier et al. (2001). In a recent review Weiss et.al. (2012) included 44 LCA studies that cover about 60 individual bio-based materials and 350 different life cycle scenarios.. The reviewed literature suggests that one metric ton of bio-based materials saves, relative to conventional materials, 55 ± 34 gigajoules of primary energy and 3 ± 1 ton of carbon dioxide equivalents of greenhouse gases. However, bio-based materials may increase eutrophication, phosphate equivalents, stratospheric ozone depletion, nitrous oxide equivalents caused by the application of fertilizers and pesticides during industrial biomass cultivation. Additional impacts, such as the potential loss of biodiversity, soil carbon depletion, soil erosion, deforestation, as well as greenhouse gas emissions are referred to land use. In this contest, the choice of using hemp as natural fibre is suggested by the reduced impact involved in hemp cultivation. Hemp is an ideal rotation crop due to its long taproot structure that helps retain topsoil, while

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also replenishing soil quality due to the natural leaf composting that regenerates vital elements in the soil. Furthermore, the unique inherent characteristic of the hemp is to suppress the growth of harmful bacteria and fungi and is commonly used as a companion crop bordering family gardens as a deterrent to insects and infestations. Hemp does not require irrigation unlike other natural fibres (Brook et al., 2008). In 1999, Wötzel et al. developed an LCA study for the interior side panel of an Audi A3 made of hemp/epoxy resin composite. They study the environmental impacts of using hemp/epoxy resin in the composite formulation and compare the results with a conventional side panel manufactured by injection moulding of virgin acrylonitrile-butadiene-styrene (ABS). The results of the Life Cycle Assessments indicate the ecological dominance of the vehicle's use phase compared to its production and recycling phase. Particularly the so-called weight-induced fuel saving coefficients point out the great spectrum (0.15 to 1.0 L/(100 kg**x**100 km) that affects the total result of the LCA significantly. The coefficient for the reduction of fuel consumption on gasoline powered vehicles ranges from 0.34 to 0.48 L/(100 kg **x** 100 km) in the New European Driving Cycle (NEDC), while the saving on diesel vehicles is lower at 0.29 to 0.33 L/ (100 kg**x** 100 km) in the NEDC.

The present study is a further development of literature results on the environmental impacts associated to the production of a vehicle side door panel made of hemp fiber and epoxy resin. We want to investigate:

- The impact reduction in the production phase due to use a plant-based epoxy resin;
- The impact reduction in the use phase due to the bag infusion process that improves the fiber-to-resin ratio and results in a lighter product.
- The impact reduction in the end of life phase due to the assumed waste scenario: recycling of the composite regrind through co-processing in cement kilns.

2. Scope and goal definition

The present work is a comparative life cycle study in order to evaluate the main environmental impacts associated to the production of an automotive interior side panel made of plant-based epoxy resin as hemp fibre as reinforcement in comparison with petroleum-based composite. It is assumed that 50% of composite material is recycled at the end of life. This scenario is compared with the landfill scenario that is the common waste treatment for composite materials. The Life Cycle Assessment study was developed according to the ISO 14040 (ISO 14040, 2006) and 14044 (ISO 14044, 2006) methodology and the Simapro 7.2 software (PRè- Product Ecology Consultants, 2006).

2.1 Functional unit and system boundaries

A composite panel made of plant-based epoxy resin and hemp fibre is the functional unit of the study. Data collection was therefore necessary for all the materials.

In the present study we have used hemp bio-mats purchased by Hemcore Ltd, UK. Hemcore BioMat is a completely natural and fully biodegradable hemp fibre fabric. The hemp fibres are extracted in a factory in Essex from hemp straw grown exclusively for Hemcore on British farms. The hemp is grown without the use of herbicides or pesticides and the fibres are extracted in a clean, chemical free and waste free process.

<u>Manufacture phase</u>: a petroleum-based composite panel was manufactured using the epoxy vinyl ester resin Derakane MomentumTM 470–300 purchased by Ashland Italia SpA, Italy, as thermoset matrix and glass random mat (code HP_MP600E) as reinforcement abd processed trough hand lay up technique. The energy consumption during the hand lay-up process is considered negligible.

The plant-based panel was manufactured using hemp mat and the plant-based epoxy resin SuperSap Entropy System supplied by Ferrer Dalmau, Barcelona, Spain. As opposed to traditional epoxies that are composed primarily of petroleum-based materials, Super Sap formulations contain bio-based renewable materials sourced as co-products or from waste streams of other industrial processes, such as wood pulp and bio-fuels production. These natural components have good elongation and high adhesion properties.

<u>Materials transport</u>: The distance between the country of origin of the raw materials and the country of production of the composite finite product was accounted in the analysis.

Use phase: The following assumptions were specified:
- The running capacity during the use phase is 200,000 km (10 y).
- Fuel reduction coefficients on gasoline powered vehicles: 0.3 L/(100 kgx100 km) for a lighter car (lower limit), 0.5 L/(100 kgx 100 km) for a heavier car (upper limit).
- Weight reduction for a single basic component amounts to 280 g using hemp fibre composites.

<u>End of life</u>: Co-processing composites through the cement kiln route is considered the best recycling option (Joint industry position paper, 2011).

Table 1. Specification of the investigated side panels

Plant-based panel (820 g)	**Petroleum-based panel (1,100 g)**
Materials - hemp mat (50 g) - SuperSap epoxy resin (430 g) *Scraps* - SuperSap Epoxy resin (20 g) - Polyethylene (bag and pipe) (50 g) *Energy* - Electricity for vacuum infusion (900 kWh) *Transport* - Hemp (lorry, from England) - SuperSap Epoxy-resin (lorry, from Spain) *Waste scenario* - Recycling	*Materials* - glass fiber (600g) - epoxy resin (500g) *Scraps* - composite 10 g *Human labour (1.5 h)* *Energy* - Negligible for hand lay up *Transport* - glass fibre (lorry, from Germany) - epoxy-resin (lorry, from Germany) *Waste scenario* Landfill

3. Results and Discussion

A comparison between the impact assessment associated to the production of 1kg of glass-fibres and 1 kg of hemp mat is reported in table 2. In this evaluation we consider that our closest glass fibre supplier is based in Germany and our hemp mat supplier is based in the UK. The distance of materials transportation is included in the evaluation. All impact categories are remarkably higher in glass-fibre production than in hemp mat production except for the category land occupation due to hemp cropping (land occupation: 0.0692 m2a for glass-fibres and 1.54 m2a for hemp). In this case study we can state that hemp agriculture practice, even if requires the occupation of arable land, has a positive impact in terms of soil quality improvement because hemp is used for crop rotation. Usually, another limit of renewable materials is that generally they score better than petrochemical polymers with regard to fossil energy use and greenhouse gas emissions while they score worse with regard to ecotoxicity and eutrophication (Weiss et al., 2012). In our case study this limit is overcome by the choice of using organic hemp that avoids the use of fertilization and pesticides. The magnitude of the environmental advantage also depends on the kind of application and obviously on the distance between the country of production of the materials and the country where they are used. Figure 1 is a flowchart of the impact of each component involved in the production of a glass-fibre composite through hand lay up technology.

Table 2: Potential environmental impacts associated to 1 kg of hemp mat and 1 kg of glass-fibres production

Impact Category	Units	Glass fiber	Hemp mat
Abiotic depletion (ADP)	kg Sb eq.	0.02	0.004
Acidification Potential (AP)	kg SO2 eq	0.017	0.0026
Eutrofication potential (EP)	kg PO4--- eq	0.04	0.0006
Global worming Potential	kg CO2 eq	2.95	0.531
Ozone layer Depletion Potential (ODP)	kg CFC11 eq	2.49E-7	6.88E-08
Human Toxicity Potential (HTP)	kg 1.4 DB eq	9.52	0.136
Freshwater Aquatic Ecotoxicity Pot. (FAETP)	kg 1.4 DB eq	0.684	0.0571
Marine Aquatic Ecotoxicity Pot. (MAETP)	kg 1.4 DB eq	1.46E3	131
Terrestrial Ecotoxicity Potential (TETP)	kg 1.4 DB eq	0.0412	0.00152
Land occupation (Ecological footprint)	m2a	0.0692	1.54
Cumulative Energy Demand (CED)	MJ eq	51.3	8.89

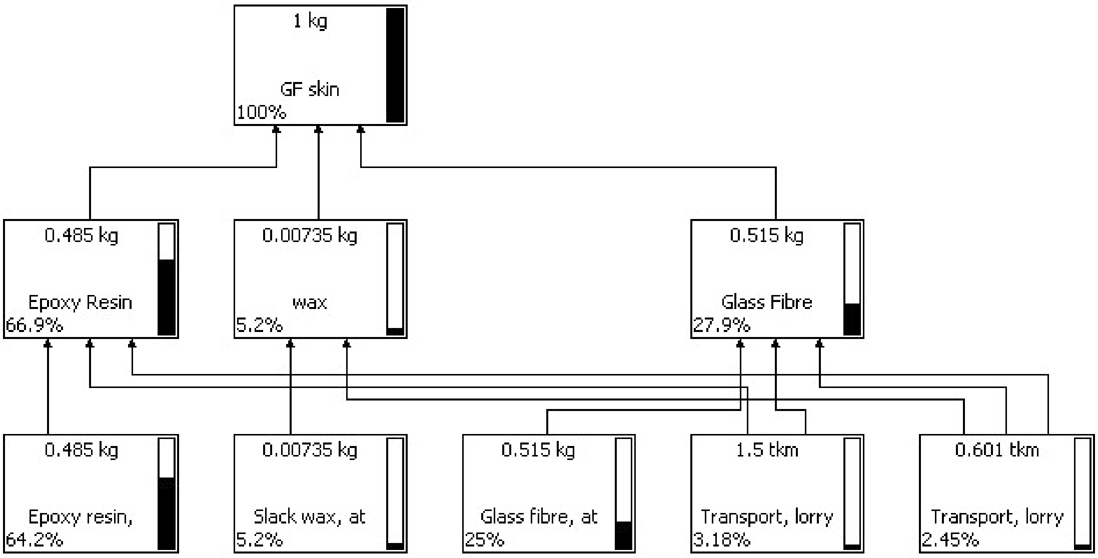

Figure 1: Percentage of impact contribution evaluated for each components of the flowchart referring to the production of 1 kg of glass-fibre/epoxy resin composite.

The major impact is associated to the epoxy resin (66.9%) while the impact due to the glass-fibres is 27.9 %. When looking at the flowchart relating to the hemp/epoxy resin composite (Figure 2) we can notice that the impact associated to the hemp mat is less than for glass fibres (7.29 %). Consequently, the overall impact result of the hemp/epoxy resin is lower than the impact of the glass-fibers/epoxy resin. In order to further reduce the impact of the system we decided to replace the petroleum based epoxy resin with the SuperSap bio-based epoxy resin.

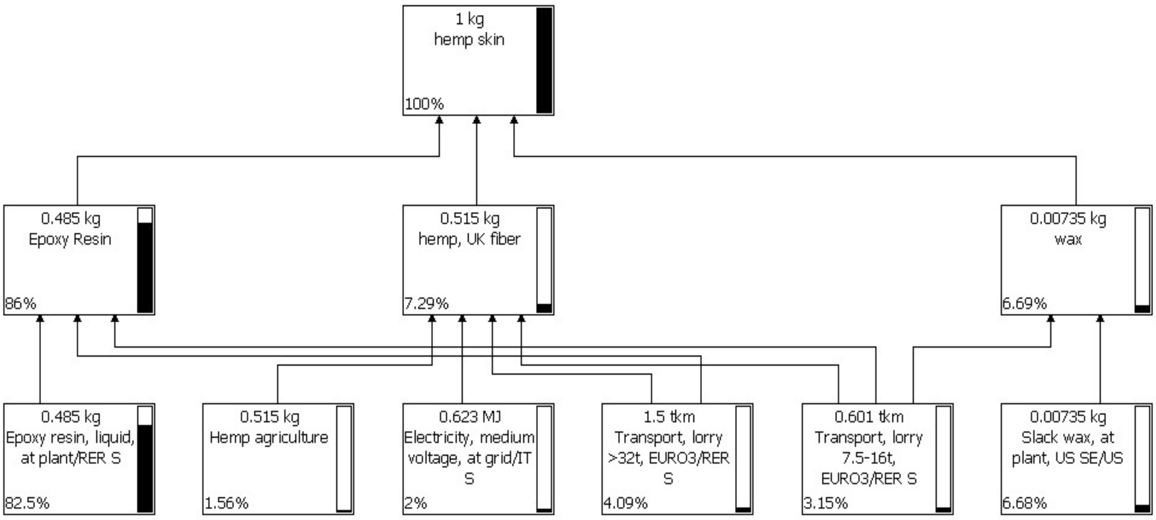

Figure 2: Percentage of impact contribution evaluated for each components of the flowchart referring to the production of 1 kg of hemp/epoxy resin composite

Table 3: Potential environmental impacts associated to 1 ton of petroleum based epoxy resin and 1 ton of plant-derived SuperSap Entropy resin

Impact Category	Units	Petroleum based epoxy resin	SuperSap Entropy
Abiotic depletion (ADP)	kg Sb eq.	59.4	0.01
Acidification Potential (AP)	kg SO2 eq	40.3	25.44
Eutrofication potential (EP)	kg PO4--- eq	6.6	6.9
Global worming Potential	kg CO2 eq	6663	4079
Ozone layer Depletion Potential (ODP)	kg CFC11 eq	1.26E-6	0.00
Human Toxicity Potential (HTP)	kg 1.4 DB eq	490.44	545.17
Freshwater Aquatic Ecotoxicity Pot. (FAETP)	kg 1.4 DB eq	246.5	66.39
Terrestrial Ecotoxicity Potential (TETP)	kg 1.4 DB eq	29.1	228.63
Cumulative Energy Demand (CED)	MJ eq	2.16	1.90

Data results reported in table 3 show a significant reduction in CO2 and Greenhouse gas emissions for the SuperSap formulations as well as reduced power and water consumption. Furthermore, biomass sourced as a co-product or from waste streams of other industrial processes significantly reduces carbon footprint and does not compete with food sources. We can state that, along with good mechanical strength and optional fast or slow working times, these formulations are also eco-friendly.

Another aspect that we have analysed to reduce the impacts was the waste treatment at the end of life. Recycling scenario was compared with landfill scenario as shown in Figure 3. A comparison of damages hemp/epoxy composite is reported. These environmental damages are quantified by damage model Recipe End Point that considers three main damage categories: Human Health, Ecosystem Quality and Resources. Human Health is includes affections of health like the number of years of disability and anticipated death. The following reasons are considered: respiratory and carcinogenic effects, effects of climate change, ozone layer depletion and ionizing radiation. The unit of the category is quantified in DALYs (Disability-Adjusted Life Years). In the category Ecosystem Quality the damage of ecosystems by ecotoxic substances, acidification, eutrophication and by use and transformation of natural space is quantified by the loss of species per year. The assessment of the demand of minerals and fossil fuels is done in the category Resources benchmarking the quality of future resources. A lost of quality is caused by decreased concentration of the resource, so that a higher energy demand for the extraction is needed. This higher energy demand (MJ) is the unit of this category.

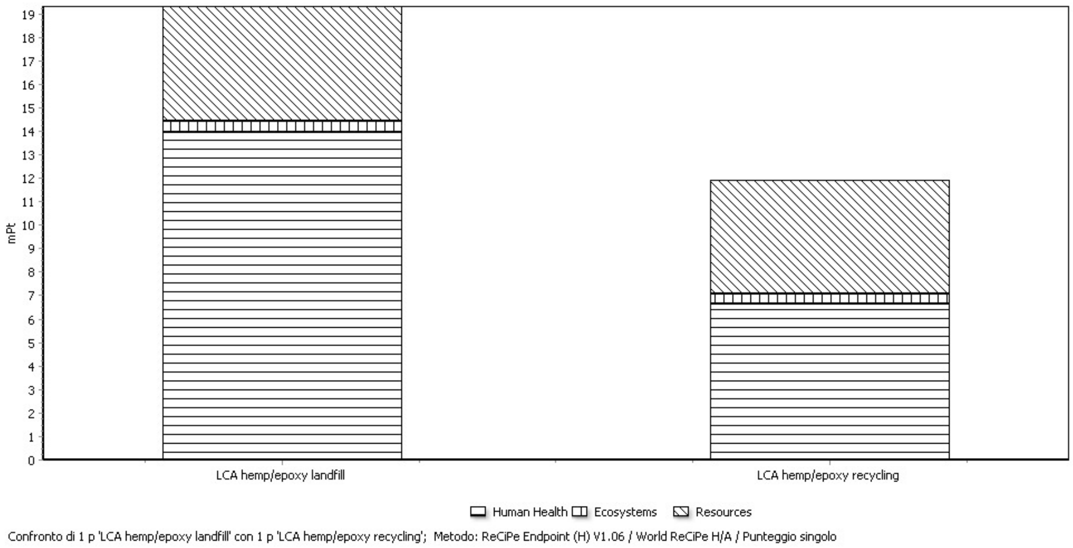

Figure 3. Comparison of landfill and re cycling waste scenarios for hemp/epoxy resin composite

4. Conclusions

In conclusion, the LCA comparison results presented in the present paper evaluate the impact reduction in the production phase due to use of plant-based materials; the impact reduction in the use phase due to the weight reduction of 280 g for the panel made of hemp fibre and processed through vacuum bag infusion; the impact reduction at the end of life due to the recycling waste scenario. LCA was used as a tool for eco-design, in order to find out the best choice in terms of materials and processes that drives towards a more sustainable product.

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