European Industrial Hemp Association

Hemp Fibres for Green Products – An assessment of life cycle studies on hemp fibre applications

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Bio-Composite

Hemp Insulation

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Imprint

**Hemp Fibres for Green Products –
An assessment of life cycle studies on
hemp fibre applications**

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Pictures

High Carbon Capture by Hemp insulation (Hock, Germany)
Natural fibre door panel for BMW 5 Series, compress moulding (nova-Institute, Germany)

Layout

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Introduction and Scope of the study

The use of fossil fuels is currently centre stage in the on-going political debate. Emissions of greenhouse gases (GHG) are rising to levels that will undoubtedly result in serious consequences for the global climate system. At the same time fossil fuels are depleted, causing sharp price increases and creating relationships of economical dependency and political unrest.
The prevalent opinion is that renewable raw materials, among them natural fibres such as hemp fibres, can have a positive influence on the mitigation of greenhouse gases. Therefore, fossil-based resources for energy and material use are increasingly being replaced by renewable resources with comparable functionality.

Hemp fibres are very suitable replacements for a variety of fossil-based materials. In this study, 19 fossil-based applications are compared to their hemp-based alternatives regarding the environmental impacts on climate change and primary energy use. The products are compared based on their functionality and based on a unit of area. Both approaches are crucial for the comparison and improvement of products. Not only the use of fossil fuels but also the use of land will become a limiting factor in the future. The use of hemp fibres requires land for the cultivation of hemp. However land is not limitlessly available, instead demand for it is growing and land use efficiency will be an increasingly important factor as competition rises for food, feed, energy, materials, urban areas and protected natural zones.

Methodology

Life cycle assessment (LCA)

Life cycle assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. The methodology was established in the early 1990s and soon after was adopted and standardised by the International Organisation for Standardisation (ISO). The standards ISO 14040/14044:2006 currently provide a reference with respect to principles, framework and terminology for conducting and reporting LCA studies and are internationally recognised and used.
A typical LCA consists of the four elements: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation. Goal and Scope Definition describes why and how to use a LCA. During this initial stage decisions are made regarding the definition of the functional unit, system boundaries, allocation procedures, choice of impact categories to be studied and methodology of the impact assessment. The Inventory Analysis quantifies all inputs and outputs of a product system and thus involves data collection and calculation procedures. Impact Assessment translates the inventory data into contributions to environmental impact categories. Interpretation is the final step of LCA. Here, conclusions are drawn from both the Inventory Analysis and Impact Assessment.

LCA is usually used to compare and improve both products and processes. In this study, product pairs of the same functionality are assessed. The focus of this study is on the comparison of hemp fibre based products and their fossil-based, non-renewable counterparts.

Product Carbon Footprint

Apart from the assessment of the full life cycle according to the life cycle methodology, much attention during the last few years has been directed to the accounting of one single impact category of greenhouse gas emissions. Managing greenhouse gas emissions and assigning contribution to climate change is the basis of the currently widely used concept of Carbon Footprint. The term is rooted in the Ecological Footprint method (1994) and in LCA. Although greenhouse gas emissions are accounted for in LCA according to ISO 14040/44 and aggregated in the midpoint impact category of climate change, many methodological problems remain. Therefore, forces have currently combined to develop a standardised methodology that is scientifically substantiated, transparent and internationally recognised and can be used to assess product and service systems, or whole organisations. Currently the most developed standard of Carbon Footprint is the PAS 2050 'Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' developed by BSI British Standards (PAS 2050 2008). Furthermore under current development is the 'Product Life Cycle Accounting and Reporting Standard' developed by the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) expected to be published by March 2011 (The Greenhouse Gas Protocol Initiative 2009). And the standard 'Carbon Footprints of Products' ISO 14067 based on the existing standards ISO 14040/44 and ISO 14025, is also planned to be published in March 2011.

This study: Meta-analysis of LCA studies on hemp fibre products

The concept of meta-analysis is adopted for the purpose of this study and is used as the basis for the presented study. Meta-analysis is originally a statistical procedure for assessing a set of multiple studies by identifying similarities and variations and to explain reasons for the encountered deviations.

In order to deploy the concept of meta-analysis in the assessment of life cycle analysis, the currently available LCA studies on hemp fibre applications were analysed. The selected studies compare renewable applications (partially) based on hemp fibres or hemp shives with fossil-based materials. The material groups analysed are hemp fleece, hemp fibre reinforced plastics (bio-composites), hemp insulation and building materials, hemp textiles and hemp pulp/paper.
Through the analysis and the subsequent synthesis of a number of life cycle studies, an overview regarding a specific problem definition can be

obtained. This approach enables the comparison and comprehensive evaluation among life cycle studies. The life cycle studies are selected regarding common characteristics. A meta-analysis of life cycle assessment studies enables the generalisation of conclusions and can reveal strength and weaknesses of the product system analysed. Results are more comprehensive and therefore provide better guidelines for future decisions.

Functional unit

For the analysis of the LCA studies, two functional units were chosen.

- In order to be able to compare two products/applications from two different materials according to certain environmental impacts, one constant has to be fixed. This constant is the desired function of the product and must be identical. Schematically, the comparison of a fossil-based application and a hemp-based alternative per environmental impact category (EI) with the same functionality (f) can be expressed by the following:

$$(EI_{fossil} - EI_{hemp}) / f = saved\ EI / f.$$

  The results of this simple calculation describe the difference in environmental impact and hence the saved environmental impact (saved EI) when a fossil-based application is replaced by its hemp-based alternative. In the case where the hemp-based application shows higher environmental impacts, results are negative. The results of the comparative analysis of each application pair are presented in the section 'Results of the LCA meta-analysis'.

- In order to be able to compare pairs of applications that do not have the same functionality, it is possible to define a reference value which serves as the basis of comparison. As all hemp-based applications are as a matter of fact made from renewable resources, it is possible to select a defined area of land [one hectare (ha)] as the means of comparison. The function:

$$\frac{saved\ EI / f}{ha_{hemp} / f} = EI\ savings / ha$$

  provides a formula with which it is possible to identify the applications that contribute most to environmental savings and hence to an efficient and sustainable use of land. Through such an analysis it is possible to compare all forest- and agro-based products such as bio-materials, bio-fuels and bio-energy. In the section 'Summary' the results of the analysis are presented.

With regard to the cultivation of hemp, direct and indirect land use changes are currently considered as not relevant. The cultivation of hemp for hemp-based fibre applications is considered to take place in Europe where direct land use changes are assumed to be negligible. The cultivation, production and use of hemp fibres is currently low and is not expected to cause shifts in land use elsewhere in the world.

Impact categories

Energy use and climate change are important characteristic values in describing environmental impacts. Both terms are defined as impact categories in the methodology of LCA. The selection of impact categories has been made according to availability of data, robustness and ranking of importance in the current political debate. Furthermore, fossil energy demand can be used as a screening indicator for environmental performance as it is a driver of several environmental impacts (Huijbregts et al. 2006).

Some of the analysed studies deviate from the current practice of accounting for energy use and climate change. As for the impact category of climate change, some studies only account for carbon dioxide emissions instead of carbon dioxide equivalents. This difference can have a significant impact on the overall results. If only carbon dioxide emissions were calculated this is indicated in the study. In the case of energy use different definitions have been established all of which relate to the overall demand of primary energy that arises during the life of a product. Differentiated are (fossil) Cumulated Energy Demand (CED) and Non-Renewable Energy Use (NREU). Except for the difference of excluding non-fossil energy, NREU explicitly accounts for nuclear energy use whereas fossil CED does not. Differences in results can be large depending of the energy mix in the country studied and the amount of fossil energy used. In this study, differences could not be equalised but were assumed to be small. It was not always clear by which criteria energy use was assessed in all the studies. Energy use in this study therefore refers to fossil primary energy use without differentiating the type of fossil energy used.

System boundaries

Life cycle assessments in theory encompass the analysis from cradle-to-grave (CG) including crop cultivation or respectively, extraction of raw materials, processing of the material, transport, use and the management of waste. However, the complexity of cradle-to-grave studies or so called full LCAs in many cases does not allow its completion. Often cradle-to-factory gate (CF) studies are carried out instead which consider only the environmental impacts from raw material extraction until the processing of the product. Most of the analysed LCAs in this study are cradle-to-factory gate analyses but some cradle-to-grave analyses are also among the studies. Studies are indicated using the abbreviations CF and CG.

Critical issues

The comparison of renewable and non-renewable products of different product groups regarding their environmental impact usually comes with a number of critical issues that can potentially influence the validity of the results. These issues include the choice of the fossil-based reference product, delineation of the system, allocation procedures for by-products and assumptions regarding agricultural yields and agricultural practice. The selected studies differ considerably with respect to quality and quantity of published background data and the degree of detail regarding methodology and results. The differences between the studies were not adjusted for.

Biogenic carbon storage

Internationally so far, no agreement has been reached on how to integrate the storage of biogenic carbon in LCA and Carbon Footprinting (further readings for example: PAS 2050 (2008) and Grießhammer and Hochfeld (2009)). For the purpose of this study it has therefore been decided to show results with and without the storage of biogenic carbon. The storage of biogenic carbon was only calculated for cradle-to-factory gate studies. This was done by adding up all fossil greenhouse gas emissions which are released during the entire production process of a product and subsequently deducting the bio-based carbon (as CO_2) that is embedded in the product. When biogenic storage is not accounted for the bio-based carbon was not deducted. The life-time of a product and its role in sequestering carbon for shorter or longer periods of time was not taken into account.

Advantages of hemp cultivation

Hemp is a fast growing annual crop with an average straw yield of 6 t/ha (with up to 12 t/ha). The crop originates from the temperate regions of central Asia but is nowadays cultivated worldwide. Hemp requires nutrient rich, moist, well structured and drained soils. Due to its vigorous growth, shading capacity and disease resistance, hemp can be grown without the use of herbicides, pesticides or fungicides. Inputs of fertilisers are low. Hemp has a deep rooting system and has hence a favourable influence on the soil structure. A study by Bócsa and Karus (1998) reports 10–20 percent higher wheat yields after the cultivation of hemp. Hemp is suitable as a good break crop from cereals and curtails the presence of nematodes and fungi.

Main hemp applications

The hemp plant yields fibre, shives and seeds for further production. The focus of this study is on fibres, one study also looks at hemp shive application in construction. Hemp fibres are used in the production of a variety of applications, such as in bio-composites (EIHA members: ca. 40 percent), insulation materials (EIHA members: ca. 40 percent) and many other applications (EIHA members: ca. 20 percent), such as fleeces for horticulture production (water cress), mulching and animal bedding mats, cellulose and pulp and paper applications. The shives are mainly used as horse bedding and increasingly in hemp lime construction.

Results of the LCA Meta-Analysis

Hemp fibre

For the extraction of hemp fibres the field-retted and dried hemp straw is separated in a fibre decortication plant into fibres and shives. The fibres are treated depending on the intended application. The extraction of long fibres mostly used for the manufacture of textiles requires more care and is time-consuming. The modern short (total) fibre line currently mainly used in Europe yields 0.55 t of shives and 0.28 t of fibres per 1 t of hemp straw Carus et al. (2008). Figure 1 shows the primary energy use for the production of a number of non-renewable materials compared to hemp fibres. With about 5 GJ/t the production of hemp fibres shows by far the lowest production energy of all the materials.

Figure 2 presents a pie diagram of the energy requirements of different stages in hemp fibre production. It becomes clear that the agricultural inputs of fertilisers and machinery dominate the results by 65 percent. The cultivation of hemp is a low input crop which does not require the use of herbicides, pesticides or fungicides. However, a decrease of synthetic fertilisers and a replacement by organic fertilisers and the minimum use of machinery could decrease the energy requirements of this most energy intensive stage of hemp fibre production.

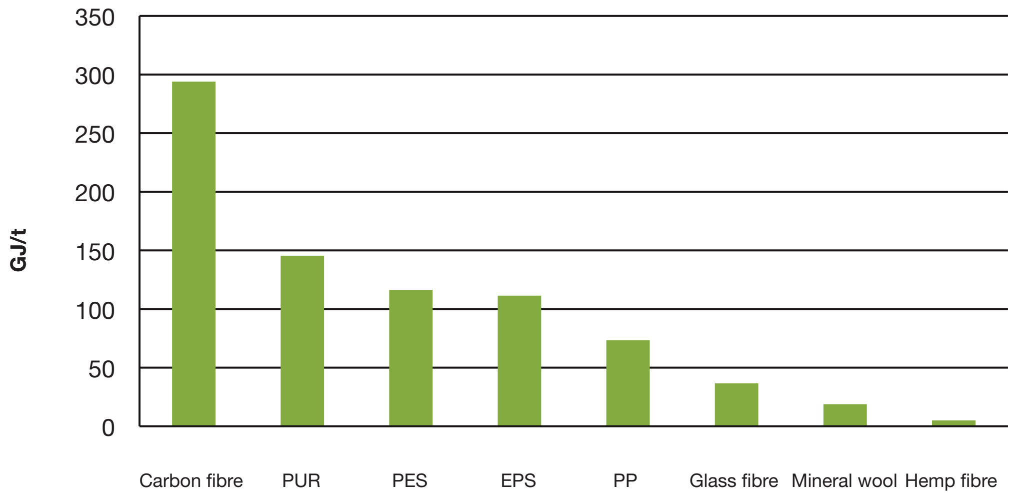

Figure 1: Primary energy use of different materials in GJ/t; Data sources: Carbon fibre: Zogg (1996), Stiller (1999), JCMA (2009); Polyurethane (PUR): Buschmann (2003), Danner (2008); Polyester (PES): Buschmann (2003), Danner (2008); Expanded polystyrene (EPS): Buschmann (2003), Danner (2008); Polypropylene (PP): Boustead (2005); Glass fibre: Diener & Siehler (1999), Corbiere-Nicollier et al. (2001), Buschmann (2003), Danner (2008); ineral wool: Buschmann (2003), Danner (2008); Hemp fibre: Carus et al. (2008)

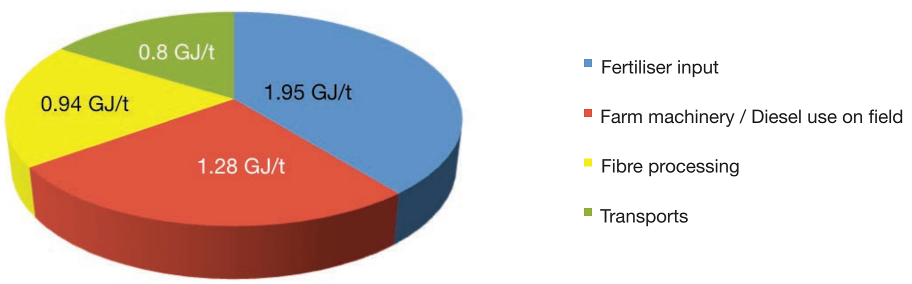

Figure 2: Primary energy use in the different stages of hemp fibre production (total fibre line) given in GJ/t hemp fibre (according to Carus et al. (2008))

Hemp fibre fleece

Hemp fleeces are used as intermediates for bio-composites and as geo- and agricultural textiles and can be used in earthworks and water engineering, for example, to protect from erosion or to divide soil layers. Hemp fleeces are also used in horticulture (water cress) as a mulching material for the suppression of weeds, for plant propagation and as a substrate. Hemp fleece is 100 percent made from hemp and biodegradable. The latter characteristic is especially advantageous for outdoor usage.

One LCA study (Evans et al. 2006) was found comparing a hemp and a polypropylene (PP) fleece that met the requirements for this study. For the comparison from cradle-to-factory gate it was found that the hemp fleece requires 76 percent less energy than its synthetic counterpart. 34 percent of GHG emissions can be saved (not accounting for biogenic carbon storage) when hemp fleece is used instead of polypropylene.

Hemp fleece shows high saving potentials in terms of energy and GHG emissions compared to polypropylene fleece.

Hemp fibre reinforced plastics (bio-composites)

Hemp fibre reinforced plastics are materials that are composed of a polymer and hemp fibres through which the composite receives its stability. Hemp fibre reinforced plastics are mainly used in the automobile industry for interior but also exterior applications, and also as furniture or for the production of other consumer products like briefcases. The material shows the favourable mechanical properties of rigidity and strength in combination with low density. The material, moreover, does not splinter and leaves no edges which is an important characteristic especially in the case of automobile accidents. Hemp fibre reinforced plastics typically substitute plastic polymers such as acrylonitrile butadiene styrene (ABS) or glass fibres reinforced polypropylene (PP-GF). The majority of the currently produced applications are manufactured through thermoplast and thermoset compress moulding for which the natural fibre fleece and the polymer material are heated and pressed together. A wide range of natural fibre automobile interior applications are produced this way including: door panels and car boot trims, rear shelf and roof liner panels, dashboards, pillar trims, seat shells, under bodies and other applications. Another, currently less common technique is the process of injection moulding which is expected to quickly gain market shares in the near future.

Nine LCA studies were included in the analysis of hemp fibre reinforced plastics. All compared applications show energy and greenhouse gas savings compared to their fossil-based counterparts. Because of the heterogeneity of compared materials however, data should be cautiously compared. The savings of energy use and GHG emissions are shown in percent (see Table 1). Because of data availability, percentage-based energy and GHG savings could not be calculated for all studies. Data is more consistently availability for the land-use based approach (see summary).

There is a large difference in results when cradle-to factory gate (C-F) and cradle-to-grave (C-G) studies are compared. The cradle-to-grave approach contrary to the cradle-to factory gate approach includes the use and waste disposal management of a product. The cradle-to-grave studies analysed in this report take the waste disposal phase into account but not the use phase. Incineration with energy recovery was in all studies the selected waste disposal option. This waste management option results in the savings of energy and GHG emissions through the generation of credits because of the recovery of energy. Studies that include this waste management option show therefore larger energy and GHG savings compared to the studies that limit their analysis to a cradle-to factory gate basis. A decisive factor in this is the heating value of the incinerated product. Bio-based hemp fibres have a lower heating value compared to fossil-based plastic polymers. For glass fibre based composites only the plastic polymers can be incinerated but not the glass fibres.

When hemp fibre-based reinforced plastics are used instead of fossil-based reinforced plastics, 22–45 percent of energy can be saved, when the analysis is carried out until the factory gate. One study, carried out on a cradle-to-grave basis, suggests savings of 62 percent. GHG emissions analysed on a cradle-to-grave basis and not taking into account the storage of carbon, suggest savings between 12–55 percent. When the storage of carbon is included, GHG savings are consequently higher (61 and 71 percent). For the discussion regarding carbon storage in products, see section Carbon storage.

In Table 1, all of the hemp fibre reinforced plastics contain, to a greater or lesser extent, fossil-based resources which contribute largely to the overall energy use of the composite material. One example is given in Figure 1 which shows the production stages for the manufacture of an automotive door panel from hemp fibres and an epoxy resin (also see Table 1). Around 80 percent of the total energy use arises from the manufacture of the epoxy resin and the hardener, whereas in total only 5 percent is related to the production of hemp fibres. Quantified on a weight basis the epoxy resin contributes to 34 percent and the hemp fibres to 66 percent to the total weight of the automotive door panel. In theory therefore, the latter implies that the higher the hemp fibre content of the application, the smaller the use of energy and the emissions of greenhouse gases. The relatively low energy and GHG savings of study 8 of Table 1, where 90 percent of the resources are derived from renewable resources, are attributable to vegetable oil based polymer. With the increasing rationalisation of the hemp fibre based production lines, energy requirements and GHG emissions are expected to decrease.

	Compared application	Author, Year	Country	C-F	C-G	Hemp fibre content (wt. %)[6)]	Energy savings in % when fossil-based composites are replaced by hemp-based composites	GHG savings in % when fossil-based composites are replaced by hemp-based composites	GHG savings in % when fossil-based composites are replaced by hemp-based composites
	Hemp fibre based reinforced plastics (bio-composites)							not accounted for biogenic carbon storage	accounted for biogenic carbon storage
1	Hemp fibre/Epoxy vs. ABS[1)] automotive interior panel (a)	Müller-Sämann et al. 2003	Germany		x	n.a.	*)	*)	*)
2	Hemp fibre/Epoxy vs. ABS[1)] automotive interior panel (b)	Müller-Sämann et al. 2003	Germany		x	n.a.	*)	*)	*)
3	Hemp fibre/EPDM[2)]/PP vs. Glass fibre/EPDM[2)]/PP automotive insulation application	Schmidt and Beyer 1998	Germany		x	30	*)	*)	*)
4	Hemp fibre/PP vs. Glass fibre/PP mat	Pervaiz and Sain 2003	Canada		x	65	62%	40%[5)]	*)
5	Hemp fibre/PP vs. Glass fibre composit	Boutin et al. 2006	France	x		30	32%	43%	71%
6	Hemp fibre/PP vs. PP composite	Boutin et al. 2006	France	x		30	22%	23%	61%
7	Hemp fibre/Epoxy vs. ABS automotive door panel	Wötzel et al. 1999a, Wötzel and Flake 1999b, Wötzel and Flake 2001	Germany	x		66	45%	12%	28%
8	Hemp fibre/PTP[3)] vs. Glass fibre/Polyester bus exterior panel	Müssig et al., 2006, Schmehl et al., 2007, Schmehl et al., 2008	Germany	x		28 (+62[4)])	26%	41%	74%
9	Hemp fibre/PP vs. Glass fibre/PP battery tray	Magnani 2010	Germany	x[7)]		n.a.	*)	55%	*)

1) ABS: Acrylonitrile Butadiene Styrene, 2) EPDM: Ethylene Propylene Diene Monomer, 3) PTP: Polymer material made of Triglycerides and Polycarbon acid anhydrides, 4) Based on vegetable oil, 5) only CO_2 emissions, 6) The numbers in brackets refer to the content of renewable resources other than hemp fibres which are used in the production of the product, 7) The data refers to a cradle-to-factory gate analysis including the use phase, *) Analysed study does not give sufficient information to allow the calculation of energy and/or GHG savings

Table 1: Overview of the compared composites

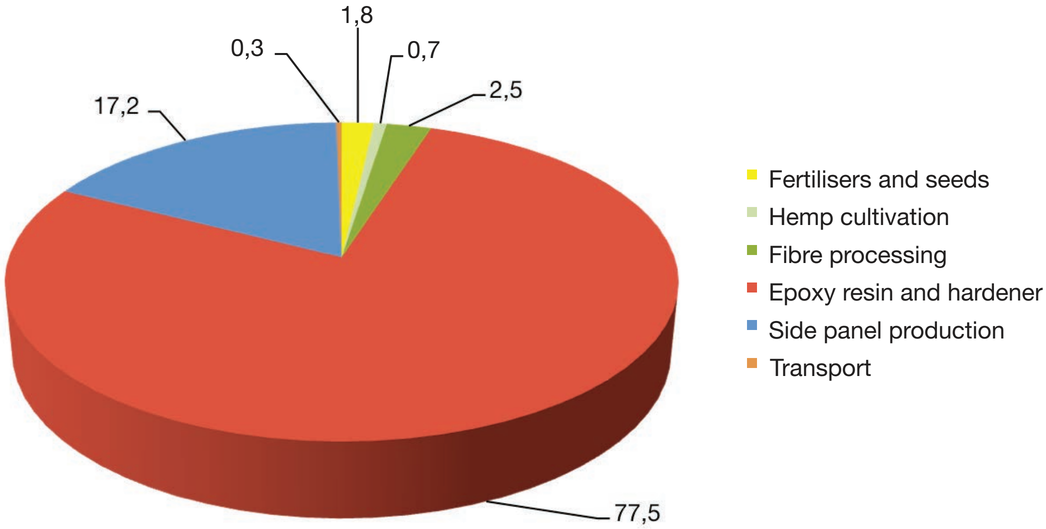

Figure 3: Cradle-to-factory gate energy use of a hemp fibre/epoxy automotive door panel; division in production stages; data are given in percent (according to Wötzel et al. 1999a)

A significant reduction in energy use and GHG emissions can be achieved through the replacement of materials with a lower density. A lower density results in a lower weight of the application. This characteristic plays a role particularly in the use phase of a car but can also play a role in production related transports of the applications. Hemp fibres for example have a density of 1.5 g/cm³ compared to glass fibres having a density of 2.5 g/cm³. Plastic polymers have a density between 0.8 and 1.4 g/cm³. Magnani (2010) (study 9 of Table 1) confirms this: GHG savings of 55 percent compared to the glass fibre/PP battery tray are through the inclusion of the use phase and subsequent weight reduction achieved. Around 80 percent of the total carbon dioxide emissions of a passenger car during its entire life cycle (including use and waste management) source from driving the car (ca. 70 percent) and from required fuel supplies (ca. 10 percent) (e.g. VW 2008). Wötzel & Flake (2001) calculate average fuel savings of 2.4 litres per car during its use phase by using two hemp fibre epoxy side panels (total weight reduction 0.6 kg). Carus et al. (2008) estimate the average use of natural fibres in passenger cars at 3.6 kg/car (2005). Large executive cars nowadays use around 20–30 kg of natural fibres and if all natural fibre applications developed for use in automobiles were applied, 30–50 kg of natural fibres could be used (Carus et al. 2008). The latter examples show that through the use of natural fibre applications, large savings can be achieved during the use phase of a car.

Conclusion

All compared hemp fibre reinforced plastics show energy and greenhouse gas savings in comparison with their fossil-based counterparts. The inclusion of waste management in life cycle analysis is able to give more accurate results regarding actual energy and GHG savings for a product over its entire life. The incineration with energy recovery shows higher energy and GHG savings compared to an analysis from cradle-to factory gate. The choice of the waste disposal option (incineration or recycling) influences the result of final energy and GHG emission savings and is to be investigated per individual study. The inclusion of the use phase would be likely to contribute to savings.

Hemp fibre reinforced plastics contain, to a smaller or larger extent, fossil-based resources. Fossil-based composites have in comparison higher energy use and emit more greenhouse gases. The replacement of glass fibres is preferable as they are of higher density and therefore a reduction of weight can be achieved with their replacement. In order to decrease the use of fossil energy and mitigate GHG emissions, inputs of fossil-based materials should be decreased as much as possible or replaced by bio-based plastics.

Hemp-based insulation and building materials

There is a wide range of insulation and building materials made from hemp. Most common are insulation materials which are produced from hemp fibres and a synthetic support fibre. Hemp fibres are also used for the production of loose fill materials. Hemp shives are pressed into particle boards or used for the production of pour-in insulation or as hemp-lime concrete building materials.

Hemp insulation offers a number of technical, environmental and health benefits compared to the synthetic counterparts manufactured from glass fibres, mineral wool, expanded polystyrene (EPS) or polyurethane (PUR). Hemp fibre insulation materials have for example a higher heat capacity and higher bulk density and therefore show better insulating capacity and better sound absorption. Nevertheless in the following LCAs only the thermal insulation properties were taken into account and compared with synthetic insulation materials.

Three LCA studies of insulation materials and one study of a hemp-lime concrete building material were identified and analysed in this study (Table 2).

All hemp fibre based insulation materials stand out due to their higher energy demand and GHG emission data compared to the non-renewable insulation materials (hence most of the data on energy and GHG emission savings of Table 2 are negative).
One reason is that the polyester support fibre used to ensure the stability of the insulation material largely dominates the results. In the study of Pless (2001) and Bos & Deimling (2010), more than half of the energy and GHG emissions arise from the synthetic support fibre which only contributes around 15 percent of the weight. Including packaging materials up to three-quarters of the total energy consumption is caused by the non-renewable component of the insulation material. This means that the substitution of the polyester fibre with a suitable and possibly non-renewable support fibre could contribute positively to a decrease of total energy demands. This is shown by the studies of Bos & Deimling (2010) and Bos (2010) who compare two hemp-based insulation materials of which one uses polylactic acid (PLA) as a support fibre and the other polyester. PLA is derived from 100 percent renewable resources. A comparison of the materials shows that the energy demand for the production of the hemp fibre/PLA insulation is around 200 MJ/m³ lower compared to the hemp/PES insulation material. Greenhouse gas emissions on the other hand are higher for the hemp fibre/PLA insulation (around 10 t CO_2 eq./m³) when the storage of biogenic carbon is not taken into account. Accounting for the storage of biogenic carbon results in around 7 t CO_2 eq./m³ fewer emissions for the hemp fibre/ PLA insulation. GHG emissions are lower when biogenic carbon storage is included as both hemp and PLA have the ability to sequester carbon.

Both of the hemp fibre based insulation materials were compared to a glass fibre insulation material analysed in study of Pless (2001). The selected mineral insulation material is another reason why hemp-based insulation materials perform less favourable compared to the mineral insulation materials. Because the hemp fibre based insulation and the mineral insulation material originate from different studies, the system boundaries are not fully comparable and can only give a rough indication of possible results. Pless (2001) moreover points out that the results of the glass fibre insulation material should be used with caution as results might be too low – because the information used is based on industry averages, level of detail between the studies is not comparable, and not all the processes and emissions are included. The energy demand of glass wool lies more likely around the 500-800 MJ/m³ and for GHG emissions around 35-75 kg CO_2 eq./m³ (average for a number of studies, needs to be approved). Pless (2001) assumes an energy demand for glass fibre insulation of 460 MJ/m³ and GHG emissions of 28 kg CO_2 eq./ m³ given in the study of Pless (2001).

Yet another reason for the relatively poor performance of the hemp fibre based insulation material is that it has almost twice the bulk density of the glass fibre insulation material. With regard to this, Pless (2001) suggests that the use phase is a very important stage in the life cycle of a product. While the high bulk density of the hemp fibre based insulation material causes a higher energy demand during production and transport, this characteristic can, during the use phase, contribute to an advantageous energy and GHG balance. The higher bulk density can in fact balance large temperature amplitudes and results in energy and hence GHG savings. Impacts can also be lowered by reducing the density of the hemp fibre based insulation material (Murphy and Norton 2008).

The analysed building material hemp shive/lime/wood wall show energy savings of 12 percent and GHG savings of 8 percent compared to the concrete-EPS wall.
In cradle to grave analyses biogenic carbon storage is neutralized as the carbon that was temporarily stored in the product is returned to the atmosphere. Only in a cradle-to-factory gate analysis can the biogenic carbon be deducted from the total CO_2 eq. emissions. The average life span of insulation materials is according to Pless (2001) and Murphy and Norton (2008) 50 years and for concrete constructions 100 years (Boutin et al. 2006). It can be argued that because of such a relatively long life span the biogenic carbon enclosed in the product should for the life time of the product be sequestered (see section 'Biogenic carbon storage'). Table 2 shows GHG emission savings with and without biogenic carbon sequestration. Accounting for biogenic carbon storage results in a considerable GHG savings in favour of the hemp fibre based insulation material.

Hemp fibre based loose fill materials, particle boards and pour-in insulations primarily made from hemp can be assumed to show large energy and GHG savings. Unfortunately a study was not found to underpin this assumption.

	Compared application	Author, Year	Country	C-F	C-G	Hemp fibre content (wt.%)[1)]	Energy savings in % when fossil-based insulation and building materials are replaced by a hemp-based alternative	GHG savings in % when fossil-based insulation and building materials are replaced by a hemp-based alternative	GHG savings in % when fossil-based insulation and building materials are replaced by a hemp-based alternative
Hemp-based insulation and building materials								not accounted for biogenic carbon storage	accounted for biogenic carbon storage
1	Hemp fibre/PLA vs. Glass fibre insulation	Bos and Deimling 2010; Bos 2010; Pless 2001	Germany	x		~ 87 (+10)	-133%	-174%	65%
2	Hemp fibre/PES vs. Glass fibre insulation	Bos and Deimling 2010; Bos 2010; Pless 2001	Germany	x		~ 87	-171	-137%	40%
3	Hemp fibre/PES vs. Glass fibre insulation	Pless 2001	US	x		~ 82	-109%	-124%	143%
4	Hemp fibre/Recycled cotton vs. Mineral wool insulation	Murphy and Norton 2008; Norton et al. 2009	England	x		35 (+35)	-56%	-8%	72%
5	Hemp shive/Lime/Wood vs. Concrete/EPS wall	Boutin et al. 2006	France	x		~29 (+~19)	12%	8%	159%

[1)] The numbers in brackets refer to the content of renewable resources other than hemp fibres which are used in the production of the product

Table 2: Overview of the hemp-based insulation and building materials (the flax insulation materials included in the land-based analysis of the Summary (see eg. Table 3) are because of insufficient information not included here)

Conclusions

More than half of the energy consumption for the hemp fibre based insulation materials is caused by the polyester support fibre. A reduction or elimination of the polyester support fibre in the insulation material would contribute to the decrease of the total energy use. Renewable resource based support fibres (such as PLA) exist and promise beneficial potentials. The relatively higher density of the hemp fibre based insulation causes on the one hand, larger energy and GHG burdens which can, on the other hand, be outbalanced by the insulation performance during the useful life of the product. Data on energy demand and GHG emission data for the glass fibre insulation material are in some studies likely assumed to be too low. Accounting for biogenic carbon storage results in a considerable GHG savings in favour of the hemp fibre based insulation material.

The quality of the individual studies on hemp insulation and subsequent mineral counterparts do not allow clear recommendations on the prefer ability of one or the other material. It is therefore advisable to commission a complete LCA study which reflects the current state of art along the entire production chain of hemp and mineral insulation materials.

Hemp-based textiles

Hemp fibres have traditionally been used for garment production but were replaced through the emergence of cotton in the market. Nowadays, a small niche market for hemp garments exists but due to outdated machinery production costs are five to ten times higher compared to the production of cotton or synthetic fibres (Schmitz 2006). One of the challenges for hemp fibres in textile production lies in the development of economically viable fibre decortication facilities.

Two LCA studies (Cherrett et al., 2005 and Turunen & Van der Werf, 2006) were found on hemp textiles production but could not be compared because of differing system boundaries. Studies were therefore analysed individually.

Cherrett et al. (2005) compare the production of yarns from hemp, cotton and polyester. For hemp yarn production, three different production systems were compared including the traditional method of dew retting and scutching, the semi-traditional method of dew-retting and chemical degumming and the more advanced harvesting method of green decortication in combination with chemical degumming. For cotton the production in India as well as the U.S. was analysed. The study moreover includes a comparison of organic and conventional cultivation methods. All analysed natural yarns from both hemp and cotton show overall large energy and GHG savings compared to polyester yarn. The energy and GHG savings for hemp compared to polyester range from 69 – 86 percent and 23 – 50 percent respectively. For cotton, savings vary from 70 – 88 percent for energy and 18 – 68 percent for GHG emissions. Organic cotton production in India and in the U.S. shows the lowest energy (ca. 12 GJ/t) and GHG (ca. 3 t/t CO_2) impact and is around 40 percent lower compared to conventional cotton production. The three different hemp production systems vary in their energy use and GHG emissions. The lowest impact is shown in the traditional yarn production, including dew retting and scrutching (around 21 GJ and 4 t CO_2 per tonne of fibre for conventional production) compared to the green decortication method which uses chemical degumming to extract the fibres (around 33 GJ and 6 t CO_2 per tonne of fibre for conventional production). Organic hemp yarn production by contrast is shown to be around 20 percent lower compared to conventional hemp production. This lower saving is due to the fact that during organic hemp cultivation no synthetic fertilisers, herbicides and pesticides are used.

Turunen et al. (2006) compare three different fibre yielding techniques but do not take the comparison of the synthetic counterpart, nor of cotton into account. The study suggests that around 85 percent of the total energy consumption originates from the production of yarn only, while around 6 percent stems from fibre processing and 6 percent from the cultivation of crops. This seems very high and is not confirmed by the study of Cherrett et al. (2005). The traditional hemp fibre extraction method described by Turunen & Van der Werf (2006) includes the drying of hemp stems in the field and the retting in open pools. Together with the process of scrutching 28 GJ per tonne of fibre are used and about 3.5 t CO_2 eq per tonne of fibre are emitted in this process. Including the stage of yarn production, the results rise to 255 GJ and 18 t CO_2 eq per tonne of yarn. The method of growing and processing baby hemp described by Turunen et al. (2006) results in a similar energy use and GHG emission compared to the traditional method but is questionable due to the high input of herbicides. The third method of using field decortication and retting the hemp stems in warm water tanks inoculated with selected bacteria and scrutching results in 130 GJ and 8 t CO_2 eq per tonne of fibre.

Conclusion

LCA studies on hemp textiles are scarce and results differ to an extent that make a comparison un-feasible. The study of Cherrett et al. (2005) worked out the advantage of the natural fibres hemp and cotton in energy use and GHG emissions compared to the polyester fibre. Both studies correspond to the fact that hemp uses considerably less water and pesticides during the crop cultivation phase compared to cotton. However, due to the use of outdated technology, the hemp fibre process stage is high in energy and hence intensive in GHG emissions, whereas the cotton fibre and yarn manufacture is a well-conceived and mechanised process. In summary it can be said that the largest impacts on energy use and GHG emissions arise during the cultivation phase of cotton and during the fibre and yarn production of hemp. Organic production shows clear advantages.

Pulp and paper from hemp fibres

Hemp pulp and paper was traditionally made from worn-out rags instead of from fresh hemp fibres. With the invention of the chemical extraction of fibres from wood, the manufacture of hemp paper faded into the background and wood-based paper production developed into a bulk material. Hemp pulp is currently only used for the production of specialty papers like cigarette paper (> 90 percent), bank notes and dielectric and medical paper. The extraction of cellulose from hemp requires a special process for which there is a lack of facilities. Because of the scale of production and the use of outdated equipment, the cost of hemp pulp is three to six times higher compared to conventional wood-based pulp production (Van Roekel 1994, Kaup and Karus 2000, Ernst & Young 2005). Another difficulty which causes an increase of the hemp pulp price is that the hemp is harvested once and needs to be stored all year long.

Compared to conventional wood paper hemp paper has superior qualities like higher strength, length and fineness which does not justify a simple one-to-one comparison based on the factors cited above. The LCA studies analysed could not resolve this dilemma as there were no studies found that directly and based on the same functionality, compare hemp and wood pulp. We nevertheless analysed the available LCA studies on hemp pulp and give an indication of the energy used and GHG emitted during the production of hemp pulp and also of wood pulp. Two LCA studies were found that analyse the environmental impact of hemp pulp. The study of da Silva Vieira et al. (2010) compared hemp and eucalyptus pulp and the study of González-García et al. (2010) assessed the impact of hemp/flax pulp. No studies were found that compare the hemp pulp/paper production process with the conventional wood-based pulp/paper process. Da Silva Vieira et al. (2010) reports 8.5 t CO_2 eq. per tonne hemp pulp and 1.7 t CO_2 eq. per tonne eucalyptus pulp using the Kraft pulp production process. The higher impact on climate change are, according to the author, due to higher fertiliser inputs and mechanical operations in the agricultural stage and a higher use of chemical additives during the pulp production process. González-García et al. (2010) found GHG emission of hemp/flax (50/50 wt. %) pulp using the soda-anthraquinone process of 7.03 t CO_2 eq./t. No data on energy use were found in either study LCA. Databases and literature were roughly scanned for energy and GHG emission data on wood-based pulp/paper. The results of the comparison of five studies shows average energy requirements of 18 GJ/t and average GHG emissions of 0.4 t CO_2 eq./t wood-based pulp (EC 2001, Hischier 2007, PRé 2007, Gemis 2010). This data is significantly lower compared to the hemp pulp data.

Summary

The depicted data points in Figure 4 and 5 (see also Table 3 for an overview of the compared studies) are presented on the basis of a hectare of land and largely summarise the results of the previous analysis. The demand for land is growing and its use will in the future be increasingly embattled. It is therefore important to compare applications from renewable resources and to quantify energy and greenhouse gas emissions savings when a hemp-based application is used instead of the fossil-based counterpart.

Hemp fleece shows high saving potentials in terms of energy and GHG emissions compared to polypropylene fleece per area of land. More studies would however be needed in order to confirm the results found.

All hemp fibre reinforced plastics show energy and GHG emission savings compared to their fossil-based counterparts. These savings are on average higher than those of all other hemp applications. Regarding the hemp fibre reinforced plastics, the studies 1 and 2 show the highest energy and GHG savings. As explained in the previous sections, this difference is largely due to the definition of system boundaries and the chosen allocation method. The fossil-based component greatly contributes to the energy consumption and to the GHG emissions of the entire composite material. In order to decrease the use of fossil energy and mitigate GHG emissions, inputs of fossil-based materials should be decreased as much as possible or replaced by bio-based plastics. The replacement of glass fibres is recommended because of its comparably larger density and this will, especially in the use phase of the application, contribute to savings.

The assessed hemp-based insulation materials show higher energy requirements and emit more greenhouse gases compared to the glass fibre insulation materials. Savings are therefore negative. Three main reasons come to the fore.

1.) The synthetic polyester fibre (used to support the material) contributes to more than half of the energy requirements and GHG emissions. Together with the packaging three-quarters of the total energy consumption is caused by the non-renewable component of the insulation material.

2.) The glass fibre insulation material used to compare the hemp-based insulation materials (studies 1, 2 and 3) might be too low in energy requirement and should be re-examined.

3.) The hemp-based insulation material has almost twice the bulk density of the glass fibre insulation material. While the density of the material negatively influences the environmental performance of the hemp-based insulation material during production and transport, it can during the use phase show advantages regarding the energy and GHG balance. For more detailed information see the section on insulation and building materials.

The hemp lime wall shows energy and GHG savings compared to the insulation materials.

The results of study 6 and 7 in Figure 4 and Figure 5 which both originate from the study of Müller-Sämann et al. (2003) are remarkable and describe two alternatives. High savings were realised by using a flax-based insulation material instead of mineral wool insulation. Because many properties of hemp and flax are very similar, including for example thermal conductivity and density characteristics, these results are surprising. The main differences compared to the other studies on insulation materials are that the waste management (incineration with energy recovery) is included and that system expansion is used as an allocation method. The difference between studies 6 and 7 is that flax shives and seeds which are the by-products of the insulation production are in case (a) used to make a particle board and the flax seeds can be used as bird feed instead of sunflower seeds. Alternative case (b) assumes that the flax shives are used as animal bedding and therefore replace the production of sawdust and wheat straw. In summary, this means that the choice of allocation method and system boundaries can drastically influence the result of the LCA study. Negative results can in this way be transformed into energy and greenhouse gas savings.

Both hemp and cotton textiles show energy and GHG savings compared to the polyester material. Hemp textiles show larger energy and GHG emission savings compared to cotton textiles. The reason for this are the different yields of the two natural fibres. Cotton fibre reaches an average yield of 0.5 t/ha in India and 0.9 t/ha in the U.S. (UNCTAD 2007) but can be much lower in the absence of irrigation (average 0.4 t/ha according to Soth et al. 1999). The average yield per hectare of hemp fibre (1.5 t/ha) is much higher.

The studies 1 to 5 from Figure 4 and Figure 5 refer to the analysis of a number of well-to-wheel bio-fuel studies from different renewable resources that were compared to non-renewable fuels. Author and year of the studies are given in Table 3. More detailed information can be obtained from the study of Carus et al. (2010). The comparison with various bio-fuels gives an insight into the competitive ability of the hemp-based applications.

With the exception of the hemp-based insulation materials, all applications depicted in Figure 4 and 5 show energy and GHG savings. The dispersion of the data points is large but some clusters can be identified.

The largest energy and GHG savings are achieved by the hemp-based composites. The highest savings in this group are reached by the studies that analyse the life cycle from cradle-to-grave and that take allocation into account.

1	Hemp fibre vs. PP fleece	Hemp fibre/Epoxy vs. ABS automotive interior panel (a)	Hemp fibre/PLA vs. Glass fibre insulation ○	Hemp vs. PES yarn	Bio-diesel/ Vegetable oils from rapeseed; Bio-ethanol from wheat and maize [1,2,3)]
2		Hemp fibre/Epoxy vs. ABS automotive interior panel (b)	Hemp fibre/PES vs. Glass fibre insulation ○	Cotton vs. PES yarn	Bio-ethanol from sugarbeets [1,2,3,4)]
3		Hemp fibre/EPDM/PP vs. Glass fibre/EPDM/PP automotive insulation application	Hemp fibre/PES vs. Glass fibre insulation ○		Bio-gas from maize and lignocelluloses [1,3)]
4		Hemp fibre/PP vs. Glass fibre/PP mat	Hemp fibre/Recycled cotton vs. Mineral wool insulation ○		BTL [2,3,4)]
5		Hemp fibre - PP vs. Glass fibre composite	Hemp shive/Lime/Wood vs. Concrete/EPS wall △		Electricity and heat production (pellets from short-rotation plantations) [5,6)]
6		Hemp fibre/PP vs. PP composite	Flax fibre vs. Mineral wool insulation material (a) ◇		
7		Hemp fibre/Epoxy vs. ABS automotive door panel	Flax fibre vs. Mineral wool insulation material (b) ◇		
8		Hemp fibre/PTP vs. Glass fibre/Polyester bus exterior panel			
9		Hemp fibre/PP vs. Glass fibre/PP battery tray			

[1)] Quirin et al. (2004); [2)] KTBL (2008); [3)] Schmitz et al. (2009); [4)] Rettenmaier et al. (2008); [5)] Reinhardt et al. (2007); [6)] WBGU (2008); [7)] study 9 is not depicted in the Figures 4, 5 and 6 as there was no hectare-based information available

Table 3: Explanatory table for the Figures 4, 5 and 6

Hemp fleece and hemp textiles show energy and GHG savings. Results nevertheless cannot be generalised because of the limited number of studies available.

Bio-fuel and bio-energy have in the last years received much attention because of their controversial environmental impact. Therefore a large number of LCA-related studies of high quality have been released in this field. LCA related bio-material studies, among which are the hemp fibre studies, are available in smaller number and in lower quality. The comparison of Figure 4 and 5 should therefore be looked at with appropriate caution. The LCAs on bio-fuel and bio-energy originate mostly from meta-analyses. Also, studies are carried out from well-to-wheel (including the extraction of fuels until combustion in the tank) which is the equivalent of a cradle-to-grave analysis. Many of the bio-fuel studies account for allocation based on system expansion which result in large savings. Based on these last facts, it has to be recognised that a comparison of bio-fuel/bio-energy and hemp-based products can only give a rough indication. Hemp-based products would perform much better if the use and waste management stage were included in the studies and if the allocation procedure were carried out in full detail.

Figure 6 depicts the differences in GHG savings on the basis of one hectare for cradle-to-factory gate analyses when biogenic carbon is not taken into account (base case) and when biogenic carbon is accounted for. As biogenic carbon is, during the life time of a product, embedded and hence stored in a product, it can be argued that the biogenic carbon should be accounted for (also see the sections ‘Product carbon footprint’ and ‘Biogenic carbon storage’ of this study). It becomes obvious that the deduction of biogenic carbon accounts for a substantial increase in GHG savings. The hemp-based insulation materials which emit more GHG emissions than the fossil-based counterparts when biogenic carbon is not deducted, account for considerable savings when biogenic carbon is deducted. For example, in comparison to packaging materials (with a life-time of less than one year) and automobile composites (life-time of 5 to 10 years), insulation and construction materials have a much higher life-time of 50 to 100 years. In this period of time, the carbon remains embedded in the product and is hence not released into the atmosphere.

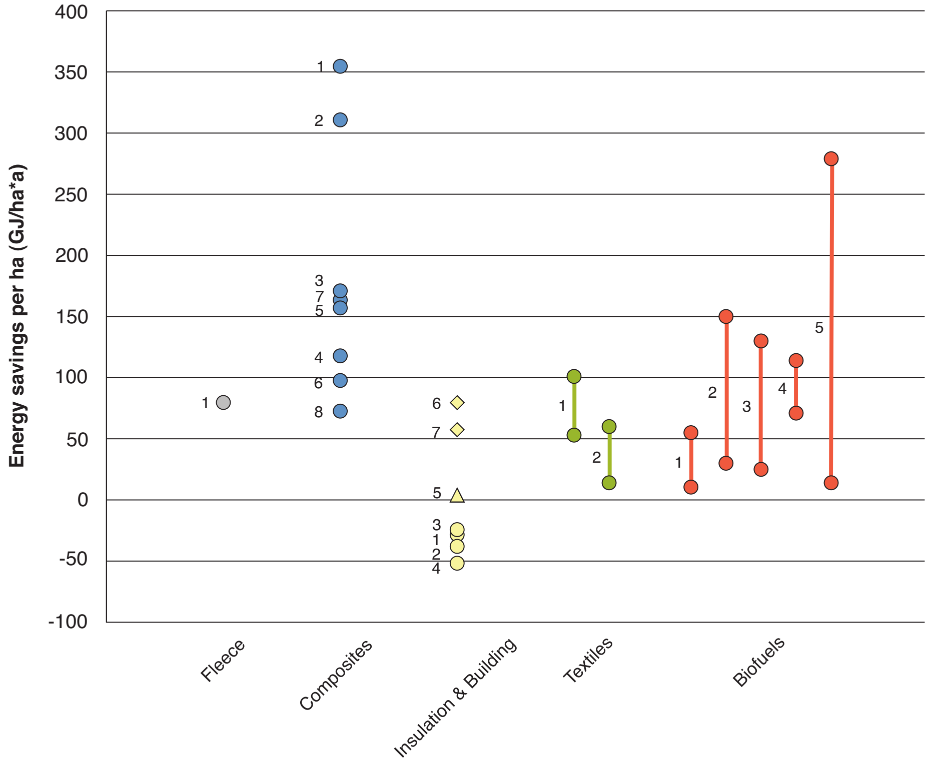

Figure 4: Energy savings per ha (GJ/ha*a) for the hemp fibre applications of hemp fleece, hemp fibre reinforced plastics, hemp insulation and building materials and hemp textiles in comparison to bio-fuels/bio-energy

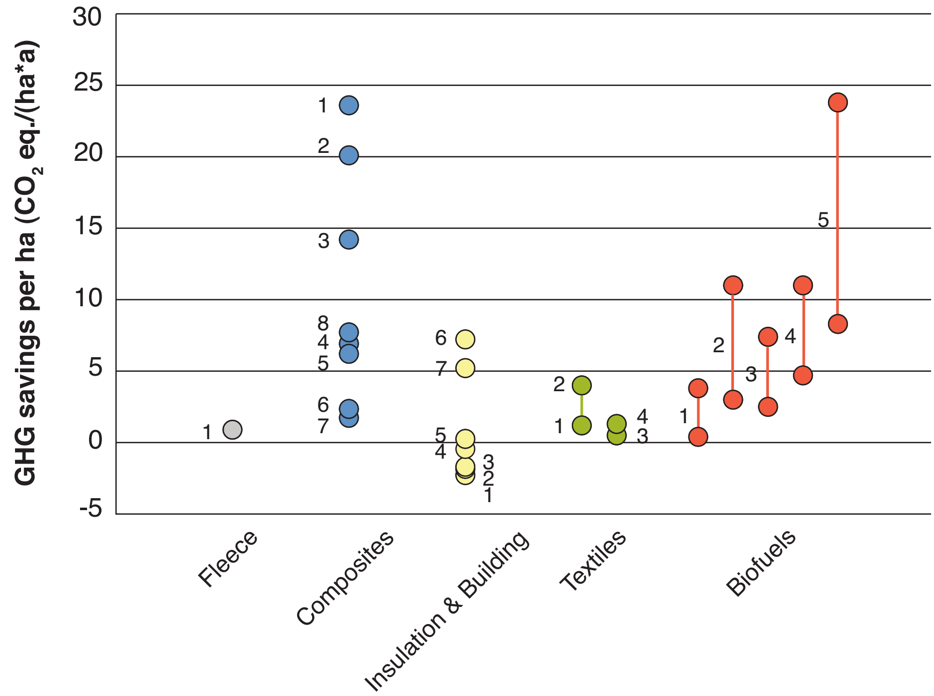

Figure 5: GHG savings per ha and year (CO_2 eq./ha*a) for the hemp fibre applications of hemp fleece, hemp fibre reinforced plastics, hemp insulation and building materials and hemp textiles in comparison to bio-fuels/bio-energy.

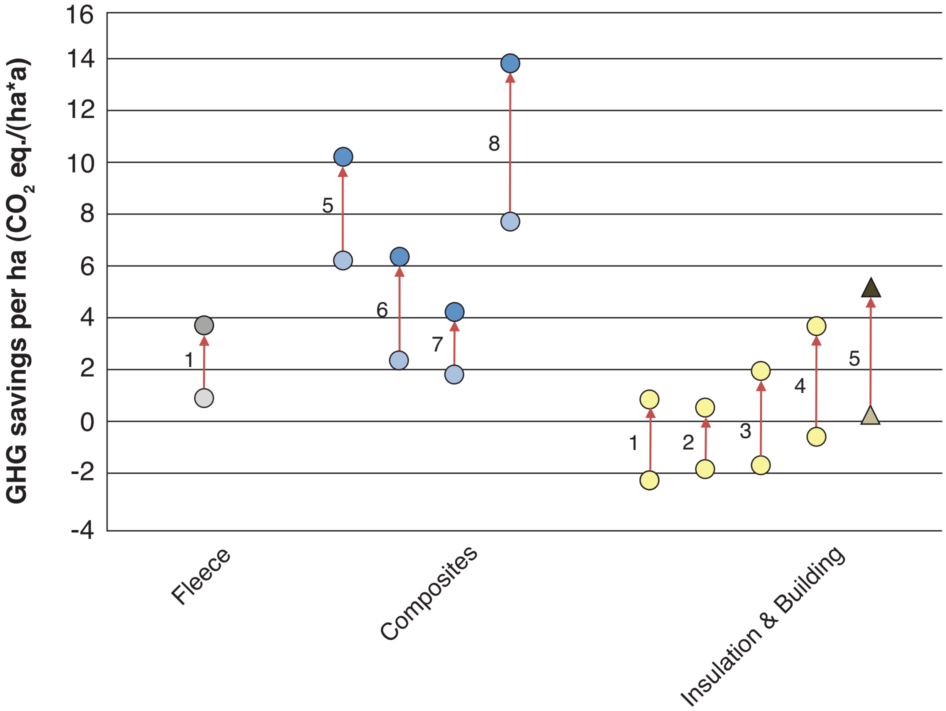

Figure 6: GHG savings per hectare and year (CO_2 eq./ha*a) for individual applications from the product groups of hemp fleece, hemp fibre reinforced plastics and insulation and building; the value with less savings per application does not take the storage of carbon into account, the value with relatively more savings accounts for carbon storage

Conclusions and recommendations

Apart from a few exceptions hemp-based applications use less energy resources and emit less greenhouse gases compared to the fossil-based applications of the same functionality.

Data on hemp-based composites show most positively because of the availability of literature. In this product group the largest energy and GHG savings are achieved. Figure 7 and Figure 8 again show the considerable savings that are reached when the functionally-equal hemp-based composites are used instead of fossil-based composites.

The data available for hemp-based insulation materials show less favourable results compared to fossil-based insulation. Energy use and GHG emissions are higher compared to the fossil-based counterparts, and GHG savings are only attained when biogenic carbon is deducted in the analysis from cradle-to-factory gate.

The available data on hemp fleece and hemp textiles indicate that large savings with regard to energy use and GHG emissions are possible.

The study further shows that the choice of the allocation method as well as the determined system boundaries has large effects on the overall results of the analysis. An assessment from cradle-to-grave including waste management and use phase and the comprehensive analysis of the allocation methodology would likely result in much larger energy and GHG savings compared to the results presented here. The currently presented energy and GHG savings of hemp-based applications are seen because of different assumption and methodological choices in the range of bio-fuels and bio-energy. Hemp-based applications would score most likely better if methodologies were adjusted.

Energy requirements and GHG emissions of hemp-based applications can be further reduced by a number of measures. Especially during the production of hemp-based composites and insulation materials, large amounts of fossil resources are used which contribute largely to environmental burdens. To improve the environmental impact with regard to energy use and GHG emissions, it would be crucial to decrease the use of fossil-based materials. Furthermore, the production technology for most hemp-based applications is still at an early stage. In the future energy and GHG emission savings will increase through technological progress. Additionally, the application of fertilisers during hemp cultivation contributes to a great extent to fossil energy requirements and GHG emissions. A decrease in the use of synthetic fertilisers and the replacement by organic fertilisers would decrease the energy requirements of this very energy intensive stage of hemp fibre production.

There is a need for the further exploration of LCA studies on hemp-based application especially with regard to the entire life cycle of the products and the choice of the allocation method.

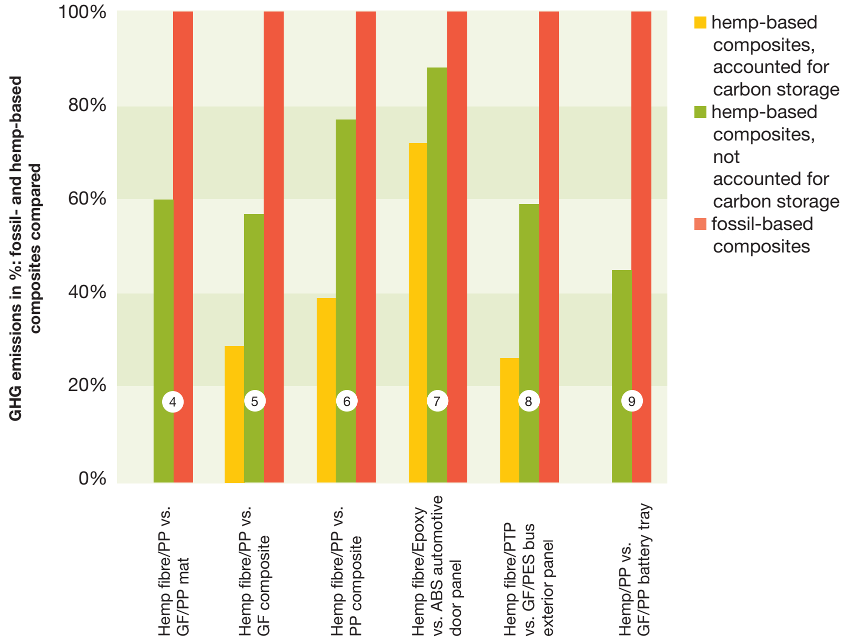

Figure 7: Energy requirements expressed in percent for the production of fossil-based and hemp-based composites for a number of studies (also see explanations of Table 3)

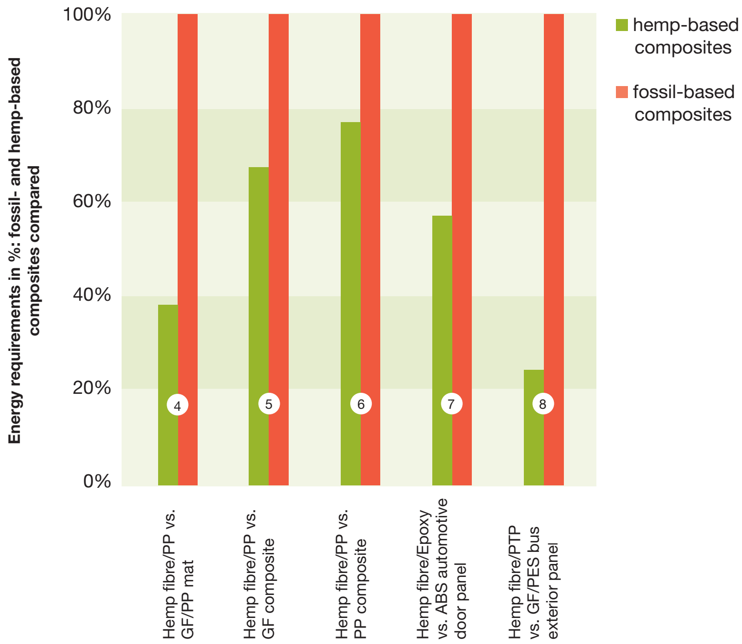

Figure 8: GHG emissions expressed in percent for the production of fossil-based and hemp-based composites for a number of studies – where available showing the effects of biogenic carbon storage (also see explanations of Table 3)

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