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The environmental impacts of the production of hemp and flax textile yarn

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ABSTRACT

This study aimed to quantify major environmental impacts associated with the production of hemp yarn using Life Cycle Analysis (LCA). A reference scenario of traditional hemp warm water retting was compared to: (1) bio-retting, i.e. hemp green scutching followed by water retting, (2) babyhemp, based on stand retting of pre-mature hemp, (3) dew retting of flax. Overall, neither of the alternative scenarios was unambiguously better than the reference. The impacts of the hemp reference scenario and the flax scenario were similar, except for pesticide use (higher for flax) and water use during processing (higher for hemp). Bio-retting had higher impacts than the reference scenario for climate change and energy use, due to higher energy input in fibre processing. Babyhemp had higher impacts than the reference scenario for eutrophication, land occupation and pesticide use. A reduction of the environmental impacts of hemp yarn should give priority to reduction of energy use in the fibre processing and yarn production stages and to reduction of eutrophication in the crop production phase.

1. Introduction

Ever since Eve ate the apple, clothing and textiles in general have been indispensable parts of our human existence. These days, textile manufacture and retail are a big business, as the lifetime of a product is determined not so much by its wearability than by ever changing fashion trends.

Cotton and synthetic fibres meet most of the world's textile demand (WWF, 1999). Both are associated with major environmental problems: synthetic fibres deplete fossil energy resources, while contemporary cotton cultivation is characterised by high water requirements and use of substantial amounts of fertilisers and pesticides (WWF, 1999). There is an increasing recognition that a shift towards non-cotton natural fibres could contribute greatly to the sustainability of the textile industry. In the European context, alternative fibre crops such as hemp and flax are interesting, because they grow well Europe wide, while cotton thrives only on the most southern edge of the continent. Furthermore, fibre crop cultivation is compatible with the recent European Union (EU) agricultural policy promoting a switch from food to non-food crops.

In November 2002, a comprehensive EU-funded 3-year study called HEMP-SYS was started (Amaducci, 2003). This project has the aim of promoting the development of a competitive, innovative and sustainable hemp fibre textile industry in the EU, by developing an improved, ecologically sustainable production chain, for high quality hemp fibre textiles, coupled to an integrated quality system for stems, raw and processed fibres, yarns and fabrics based on eco-labelling criteria. Within the framework of the project, the present study aims to quantify major impacts associated with the production of hemp yarn for textile using Life Cycle Analysis (LCA), to generate propositions for modifications of the production chain, leading to reduced environmental impacts.

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No studies using LCA to assess the environmental impacts of the production of hemp yarn or of yarn from other bast fibre crops (e.g. flax, jute) were found in the scientific literature. Detailed results concerning the environmental impacts of hemp field production in comparison to those of a range of other crops were published (van der Werf, 2004).

2. Materials and methods

2.1. *Evaluation methodology*

Environmental impacts associated with the production of yarn from hemp and flax were evaluated using Life Cycle Assessment (LCA), as detailed in Turunen and van der Werf (2006). LCA is a method to assess impacts associated with a product, by quantifying and evaluating the resources consumed and the emissions to the environment at all stages of the product's life cycle—from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product, to its reuse, recycling or final disposal (Guinée et al., 2002). In the Inventory Analysis phase, inputs from the environment (resources used) and outputs to the environment (emissions) associated with the product are listed. In the Impact Assessment phase, inputs and outputs are interpreted in terms of environmental impacts (Guinée et al., 2002).

2.2. *Goal and scope of the study*

The study aims to quantify major impacts associated with three scenarios for the production of hemp textile yarn, in order to establish reference data for environmental performance, and identify problem areas and potential for improvement. We evaluated a flax yarn production scenario for bench-marking, as the flax textile industry uses technologies similar or identical to those used for hemp, while being economically much more important than the hemp textile industry.

Impacts are expressed per 100 kg of yarn of a metric count number (Nm) of 26 (a g of 26 Nm yarn is 26 m long). The present study compares four scenarios for the production of bleached textile yarn: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD). Each of these scenarios consists of three production stages: crop production, production of long fibre, and yarn production. For each of these stages the analysis includes the use of major inputs (machines, energy carriers, chemicals, water), buildings are not included in the analysis.

2.3. *Yarn production scenarios*

For HW and HB crop production is according to a generic Central-European scenario, mainly based on data from Hungary (Iványi, personal communication, 2004), with harvest at the end of the flowering stage of the crop. For BH crop production is in Italy, according to Amaducci (2005), and for FD crop production is based on data from France, Belgium and The Netherlands. None of the crop scenarios involves irrigation. Inputs used in crop production are presented in Table 1.

Table 1 – Inputs used (in kg/ha) for field production of Central European hemp, Baby hemp and flax

	Hemp central Europe	Baby hemp	Flax
N (ammonium nitrate)	68	28	40
P_2O_5 (triple superphosphate)	30	12	30
K_2O (potassium chloride)	114	46	60
CaO	333	135	333
Seed for sowing	55	100	115
Pesticide (active ingredient)	0	4.0	2.6
Diesel	55	54	57
Agricultural machinery	17.3	15.0	15.5

For HW production of long fibre is based on traditional warm water retting according to current production practices in Hungary (Homonyik, personal communication, 2004). The crop is mown and bound in sheaves, which dry on the field. Dry sheaves are retted in open concrete retting pools, using a 28 °C mix of warm thermal water and cold well water. After retting sheaves are air-dried, dried sheaves are stored outdoors, causing a 10% loss due to spoiling. Stems are scutched using a hemp scutching machine to obtain separation into scutched long fibre, scutched short fibre and shives.

HB corresponds to an experimental process developed by Gruppo Fibranova in Italy within the HEMP-SYS project (Tofani, personal communication, 2004). The crop is mown, cut into 1 m sections, laid into a parallel swath to dry on the field and baled using a round bale press; bales are stored indoors. Stem sections are green scutched (i.e. before retting), using a flax scutching machine to obtain separation into green scutched long fibre, green scutched short fibre and shives. Green scutched long fibre is retted in open tanks filled with warm (35 °C) water, inoculated with selected bacteria to improve retting. The water is heated using wood pellets. After retting the fibre is rinsed, and dried using natural gas. The dried fibre is softened using fluted rollers to obtain long fibre for processing into yarn.

BH crop growth is terminated by herbicide spraying when the crop is 120–140 cm tall. The crop is left standing in the field to ret for 30–50 days, harvested ("pulled") using flax harvesters, laid in a parallel swath to dry, turned once and baled with a round bale press. Bales are stored indoors. Stems are scutched using a flax scutching machine to obtain separation into scutched long fibre, scutched short fibre and shives.

FD is harvested ("pulled") using flax harvesters, laid in a parallel swath to dry, turned twice and baled with a round bale press. Bales are stored indoors. Stems are scutched using a flax scutching machine to obtain separation into seed, scutched long fibre, scutched short fibre and shives.

The yarn production stage is identical for the four scenarios and consists of the following processes: hackling to produce sliver, production of rove, bleaching, wet ring spinning and winding.

Crop yield levels and amounts produced for intermediate and final products for the four scenarios are given in Table 2. These data are based on a range of sources: statistical data, literature references, industry data and expert opinion, as detailed in Turunen and van der Werf (2006).

Table 2 – Yields per ha of the intermediate and final products for the four scenarios

Products	Hemp			FD (flax dew retting)
	HW (water retting)	HB (bio-retting)	BH (babyhemp)	
Green stem	8000	8000		6000
Retted stem	6480		3250	5400
Green scutched long fibre		1000		
Green scutched short fibre		1000		
Grain yield (9% humidity)	0	0	0	600
Green scutched long fibre after retting		658		
Scutched long fibre	583		293	972
Scutched short fibre	1490		748	594
Shives	2592	3600	1300	2970
Yarn	236	213	119	512

Yields are in kg/ha of dry material at 14% humidity.

2.4. *Inventory assessment*

Our partners in the HEMP-SYS project provided data on resource use and emissions for many of the major processes making up the three production stages considered in this study. Data for energy carriers and for transport are from the BUWAL 250 database (BUWAL, 1996). For electricity the European UCPTE energy mix data from the BUWAL database are used. Values for resource use and emissions of other processes are based on literature references and several LCA databases. Details are in Turunen and van der Werf (2006).

A number of processes studied yield more than one product, e.g. scutching produces long fibre, short fibre and shives. In such a case the impacts resulting from the process have to be allocated (i.e. partitioned among) the products. We allocated impacts according to the economic value of the products, which presents a measure of the incentive for production. Economic allocation is not without problems, as the prices of natural fibres fluctuate, but was chosen over mass-based allocation, because long (and short) fibres represent only a small fraction of the stem mass, but they are the major reason for hemp cultivation.

2.5. *Impact analysis*

In the Impact Assessment phase, it is first determined which impact categories will be considered. In this study we consider: eutrophication, climate change, acidification, non-renewable energy use and land occupation, this set of impact categories is appropriate for the evaluation of agricultural products. Next, the indicator result for each impact category is determined by multiplying the aggregated resources used and the aggregated emissions of each individual substance with a characterisation factor for each impact category to which it may potentially contribute. Characterisation factors are substance-specific, quantitative representations of the additional environmental pressure per unit emission of a substance. The characterisation factors used in this study are given below for each impact category.

Eutrophication covers all potential impacts of high levels of macronutrients in the environment, in particular of N and P. As recommended by Guinée et al. (2002), eutrophication potential (EP) was calculated using the generic EP factors in kg PO_4-equivalents, NH_3: 0.35, NO_3: 0.1, NO_2: 0.13, NO_x: 0.13, PO_4: 1.

Climate change is defined here as the impact of emissions on the heat radiation absorption of the atmosphere. As recommended by Guinée et al. (2002), Global Warming Potential for a 100 year time horizon (GWP_{100}) was calculated according to the GWP_{100} factors by IPCC in kg CO_2-equivalents, CO_2: 1, N_2O: 310, CH_4: 21.

Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings). As recommended by Guinée et al. (2002), acidification potential (AP) was calculated using the average European AP factors in kg SO_2-equivalents, NH_3: 1.6, NO_2: 0.5, NO_x: 0.5, SO_2: 1.2.

Non-renewable energy use refers to the depletion of energetic resources. Energy use was calculated using the Lower Heating Values proposed in the SimaPro 1.1 method (PRé Consultants, 1997), crude oil: 42.6 MJ/kg, natural gas: 35 MJ/m^3, uranium: 451,000 MJ/kg, coal: 18 MJ/kg, lignite: 8 MJ/kg, gas from oil production 40.9 MJ/m^3.

Land occupation refers to the loss of land as a resource, in the sense of being temporarily unavailable for other purposes due to the growing of crops. This is a quantitative assessment, which does not distinguish quality of land use.

In addition to these impact categories, the amount of pesticide active substance used as well as water used in processing is assessed. Thus water used by the crop (transpiration loss) during the crop production and water used for pesticide application is not included in the assessment.

3. Results

3.1. *Eutrophication*

Eutrophication per 100 kg of yarn was lowest for FD (2.6 kg PO_4-eq.), followed by HB and HW (3.0), and highest for BH (4.9) (Table 3). The contribution of the crop production stage to eutrophication ranged 75–93%, depending on the scenario (Fig. 1). Emissions from the soil (N and P) made up about 90% of this. The remainder resulted, e.g. from the diesel combustion in the field operations. The retting effluent contributed 13% of eutrophication in HW (Fig. 1). The contribution of effluents in HB was minimal. Yarn production contributed to eutroph-

Table 3 – The environmental impacts of yarn production expressed per 100 kg of yarn for the investigated scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD)

Impact category	Hemp			FD
	HW	HB	BH	
Eutrophication (kg PO_4-eq.)	3.04	3.02	4.94	2.61
Climate change (kg CO_2-eq.)	1350	1810	1460	1360
Acidification (kg SO_2-eq.)	7.38	9.01	8.02	8.16
Non-renewable energy use (MJ)	25,500	35,800	26,500	26,100
Land occupation (m^2 year)	1160	1260	2410	1150
Pesticide use (act. subst.) (kg)	0	0	0.874	0.296
Water use (m^3)	19.9	22.1	7.63	7.23

ication through emissions due to electricity production. The relative contribution of the production of 100 kg of yarn to per capita eutrophication in Europe was 6.8–12.9%, depending on the scenario (Table 4).

3.2. Climate change

Climate change per 100 kg of yarn was lowest for HW and FD (1350 and 1360 kg CO_2-eq., respectively), followed by BH (1460), HB had the highest value (1810) (Table 3). For FD, HW and BH, the crop production stage represented 15–24% of the impact, fibre processing 6–7% and yarn production 69–78% (Fig. 2). For HB fibre processing made up 28% of the total impact, which reduced the relative contribution of yarn production to 56%. The large contribution of the fibre processing stage in this scenario was due to fibre drying. The relative contribution of the production of 100 kg of yarn to per capita climate change in Europe ranged from 9.2 to 12.4% (Table 4).

3.3. Acidification

Acidification per 100 kg of yarn was lowest for HW (7.4 kg SO_2-eq.), followed closely by BH (8.0) and FD (8.2). It was highest for HB (9.0) (Table 3). Acidification was largely (62–79%) due to yarn production in all scenarios (Fig. 3). Fibre processing was responsible for 8.5–9.7% of the impact in all scenarios except HB. Drying increased the contribution of fibre processing to 24% in this case. The contribution of crop production was highest for BH (19%) and lowest for FD (10%). The relative contribution of the production of 100 kg of yarn to per capita acidification in Europe was 8.8–10.7% (Table 4).

3.4. Non-renewable energy use

Non-renewable energy use per 100 kg of yarn was highest in HB (35,800 MJ) and similar for the other three scenarios (around 26,000 MJ) (Table 3). Energy use resulted mainly from yarn production: 85–88% in all scenarios, except for HB, where it was 63% (Fig. 4). The yarn production stage was less important in

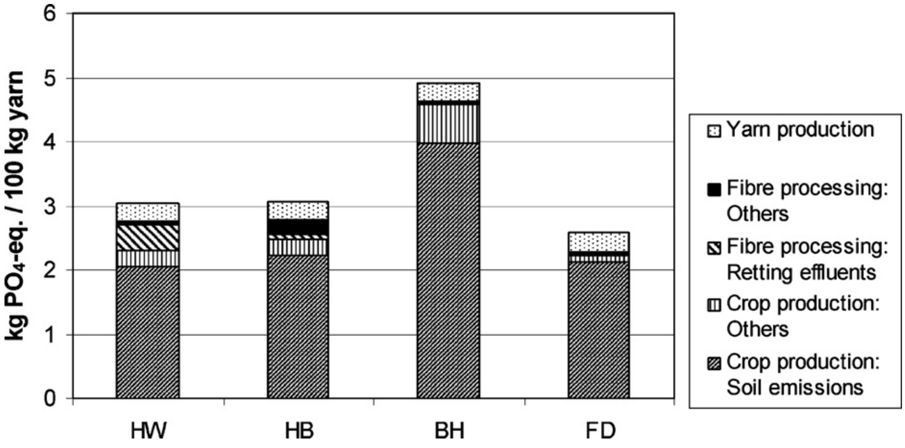

Fig. 1 – Contribution (in kg PO_4-eq.) of the different stages of the production of 100 kg of yarn to eutrophication, according to the scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD). Unit processes within stages are shown separately if they contribute 10% or more to the total impact for one or several of the scenarios. "Others" refers, for the specific production stage, to the impacts from unit processes, other than those mentioned separately.

Table 4 – Normalised impacts, i.e. the contribution of the production of 100 kg of yarn according to the investigated scenarios (hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD)) to per capita environmental impacts in Western Europe

Impact category	Normalisation value	Reference for normalisation value	Contribution (%)			
			HW	HB	BH	FD
Eutrophication (kg PO_4-eq.)	38.4	Huijbregts et al. (2001)	7.9	7.9	12.9	6.8
Climate change (kg CO_2-eq.)	14,600	Huijbregts et al. (2001)	9.2	12.4	10.0	9.3
Acidification (kg SO_2-eq.)	84.2	Huijbregts et al. (2001)	8.8	10.7	9.5	9.7
Non-renewable energy use (MJ)	154,000	PRé Consultants (1997)	16.6	23.2	17.2	16.9
Land occupation (m^2 year)	10,100	Huijbregts et al. (2001)	11.5	12.5	23.9	11.4

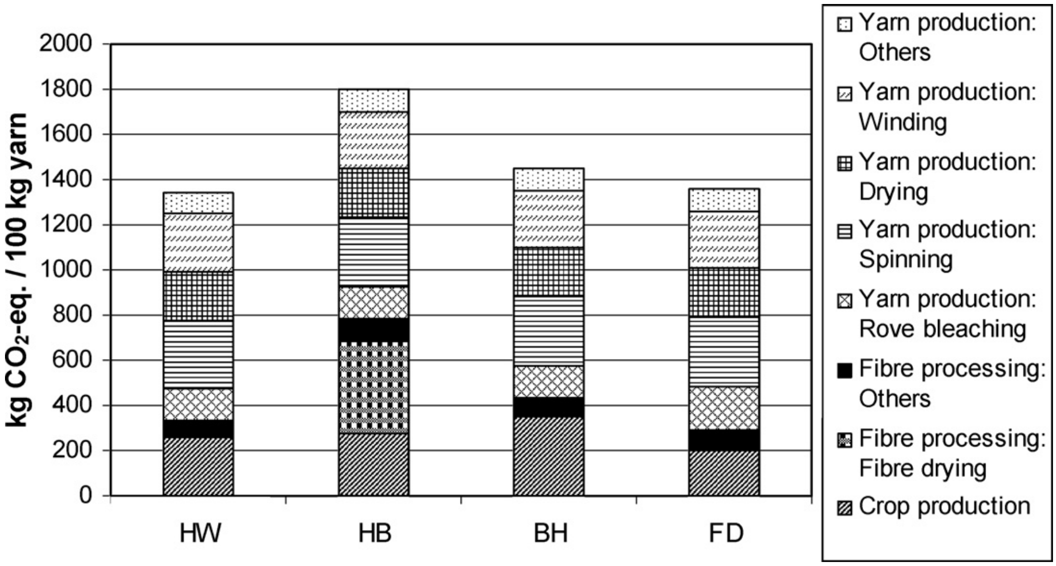

Fig. 2 – Contribution (in kg CO_2-eq.) of different stages of the production of 100 kg of yarn to climate change, according to the scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD). Unit processes within stages are shown separately if they contribute 10% or more to the total impact for one or several of the scenarios. "Others" refers, for the specific production stage, to the impacts from unit processes, other than those mentioned separately.

HB due to higher energy use in fibre processing (33% of total), largely due to drying. In the other scenarios the contribution of fibre processing was 6–7%, while in all scenarios energy use in crop production contributed only 4–8%.

The yarn production stage, which contributed, by far, most to energy use (as well to climate change and acidification), was essentially the same for the four scenarios. Its large contribution overshadowed the differences in the previous stages of the production chain. Fig. 5, where the impacts of the yarn production stage were excluded, allows a better examination of the significance of the various other sub-processes. Apart from fibre drying, the retting in tanks (essentially the heating of retting water) increases the energy use in the bio-retting scenario. The effect of softening is negligible.

In all scenarios the 400-km transport of long fibre from the fibre processing to the yarn-processing site contributed very little to energy use in comparison with the other processes. The relative contribution of the production of 100 kg of yarn to per capita energy use in Europe ranged from 16.6 to 23.2% (Table 4).

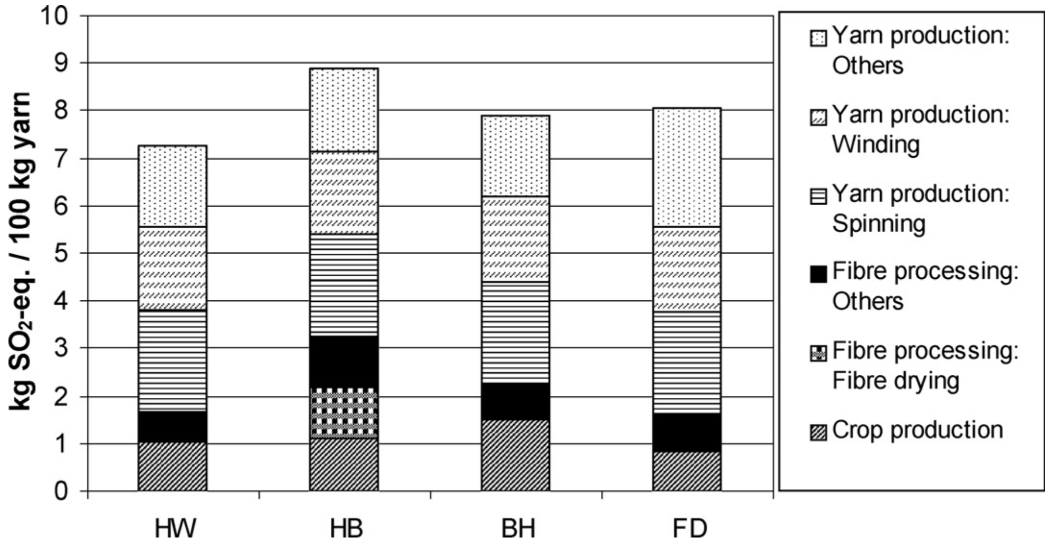

Fig. 3 – Contribution (in kg SO_2-eq.) of different stages of the production of 100 kg of yarn to acidification, according to the scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD). Unit processes within stages are shown separately if they contribute 10% or more to the total impact for one or several of the scenarios. "Others" refers, for the specific production stage, to impacts from unit processes, other than those mentioned separately.

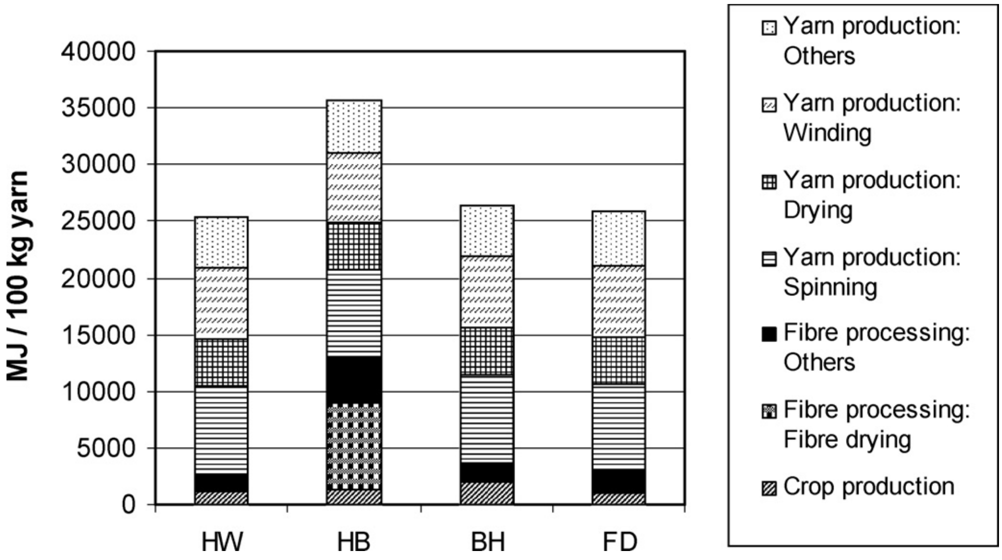

Fig. 4 – Contribution (in MJ) of different stages of the production of 100 kg of yarn to non-renewable energy use, according to the scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD). Unit processes within stages are shown separately if they contribute 10% or more to the total impact for one or several of the scenarios. “Others” refers, for the specific production stage, to the impacts from unit processes, other than those mentioned separately.

3.5. *Land occupation, pesticide use, water use*

FD and HW had the smallest land occupation per 100 kg of yarn (1150 and 1160 m^2 year, respectively), followed closely by HB (1260) (Table 3). Land occupation for BH was more than double (2410). The relative contribution of the production of 100 kg of yarn to per capita land occupation in Europe ranged from 11.4 to 23.9% (Table 4).

Pesticide use was zero for HW and HB, 0.296 kg of pesticide active substance were used in FD and 0.874 kg in BH (Table 3). Expressed per hectare, this corresponded to 2.58 kg for FD and 4 kg for BH.

Water use was similar for FD and BH (7.2 and 7.6 m^3, respectively), and for HW and HB (19.1 and 22.1 m^3, respectively) (Table 3). Rove bleaching accounted for all of water use in BH and FD. In HW and HB rove bleaching used the same volume (i.e. 7.6 m^3), while the rest was consumed in retting. In HB, water use was 36% for retting and 64% for rinsing.

3.6. *Scenario variations*

The sensitivity of the results of HW, HB and FD to changes in some key parameters was explored by comparing variations of these scenarios to their respective original scenarios. For HW

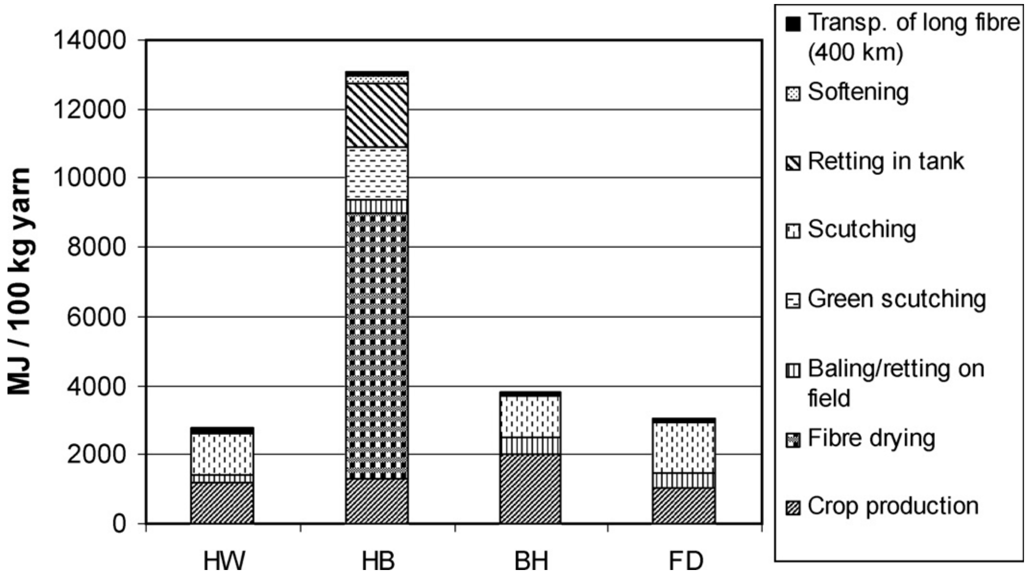

Fig. 5 – Contribution (in MJ) of unit processes of the crop production and fibre processing stages of the production of 100 kg of yarn to non-renewable energy use, according to the scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD).

Table 5 – Impacts for the hemp water-retting scenario and its variants per 100 kg yarn: the effect of crop yield, nitrate leaching and use of gas for heating retting water

	Eutrophication (kg PO_4-eq.)	Climate change (kg CO_2-eq.)	Acidification (kg SO_2-eq.)	Non-ren. energy use (MJ)	Land occupation (m^2 year)
HW, hemp water retting	3.04	1350	7.38	25,500	1160
HW1, crop yield + 25%	2.58 (−15.1%)	1300 (−3.7%)	7.18 (−2.7%)	5,200 (−1.2%)	927 (−20.1%)
HW2, crop yield − 25%	3.80 (+25.0%)	1440 (+6.7%)	7.72 (+4.6%)	25,900 (+1.6%)	1540 (+32.8%)
HW3, NO_3 emissions − 50%	2.07 (−31.9%)	1330 (−1.5%)	=	=	=
HW4 + gas heating	3.07 (+1.0%)	1620 (+20.0%)	7.73 (+4.7%)	30,100 (+18.0%)	=

Pesticide use and water use are not shown, as the scenario alterations did not affect them. Symbol “=” means that the value is equal to that of the reference scenario.

Table 6 – Impacts for the hemp bio-retting scenario and its variants per 100 kg yarn: the effect of using gas instead of wood for water heating, energy use for drying, and using wood instead of gas for fibre drying

	Eutrophication (kg PO_4-eq.)	Climate change (kg CO_2-eq.)	Acidification (kg SO_2-eq.)	Non-ren. energy use (MJ)	Land occupation (m^2 year)
HB, hemp bio-retting	3.02	1810	9.01	35,800	1260
HB1, gas instead of wood for water heating	2.99 (−1.0%)	1920 (+6.1%)	8.94 (−0.8%)	=	=
HB2, no energy for drying	2.95 (−2.3%)	1400 (−22.7%)	7.91 (−12.2%)	28,000 (−21.5%)	=
HB3 = HB1 + HB2	2.92 (−3.3%)	1520 (−16.0%)	7.85 (−12.9%)	28,100 (−21.5%)	=
HB4, wood instead of gas for fibre drying	3.10 (+2.6%)	1510 (−16.6%)	9.18 (+1.9%)	35,600 (−0.6%)	=

Pesticide use and water use are not shown, as the scenario alterations had no effect on them. Symbol “=” means that the value is equal to that of the reference scenario.

a 25% change in the assumed crop yield of 8 tonnes/ha had a major effect on eutrophication and land occupation, while the effect on other impact categories was small (HW1 and HW2, Table 5). The effect of decreasing the nitrate field emissions by 50% was investigated, as in certain pedo-climatic conditions (e.g. in Hungary) nitrate leaching is significantly lower than the assumed 40 kg/ha of nitrogen, which is based on the French climate and soil conditions. Eutrophication is observed to be very sensitive to nitrate emissions, whereas the other impacts are barely affected (HW3). The last modification to the reference scenario concerns the use of fossil energy for heating the retting water, since hot thermal water is not available in most places. This would cause a major increase in both climate change (+20%) and energy use (+18%), but would hardly affect eutrophication or acidification (HW4).

For HB some modifications to fibre processing were explored, in order to evaluate possibilities for improving its environmental profile. First, the substitution of the renewable energy source (wood pellets) by natural gas for heating the retting water caused a modest increase of climate change (HB1, Table 6). This is mainly caused by the fact that the non-fossil CO_2 emissions resulting from the use of wood pellets do not contribute to climate change, whereas the fossil CO_2 resulting from natural gas does. If no energy was used in fibre drying, energy use and climate change would be reduced by over 20%, i.e. drying accounts for 20% of these impacts over the yarn production chain (HB2). Effect on acidification is less. A combination of the two previous modifications would yield impacts similar to those of the no-energy variant (HB3). Substitution of gas by a renewable energy source in fibre drying would significantly reduce climate change, but would hardly affect the other impacts (HB4).

Economic allocation of impacts is often debated on the grounds that market prices fluctuate and thus introduce uncertainty. The effect of different prices for scutching co-products was tested for FD, as the relative prices of flax co-products differed significantly from those of hemp. If flax co-products had the same prices as hemp co-products, all

Table 7 – Impacts for the flax dew-retting scenario and its variants per 100 kg yarn

	Eutrophication (kg PO_4-eq.)	Climate change (kg CO_2-eq.)	Acidification (kg SO_2-eq.)	Energy use (MJ)	Land occupation (m^2 year)	Pesticide use (kg act. subst.)
FD Flax dew retting	2.61	1360	8.16	26100	1150	0.296
FD1 Hemp prices at scutching	1.99 (−24%)	1280 (−6%)	7.72 (−5%)	25300 (−3%)	833 (−28%)	0.215 (−27%)
FD2 Hemp prices at scutching, except shives	2.36 (−10%)	1330 (−2%)	7.99 (−2%)	25800 (−1%)	1020 (−11%)	0.263 (−11%)

Water use is not shown, as the scenario alterations did not affect it. Prices (per kg) used in the flax scenario and resulting allocation factors: long fibre €1.80 (86.8%), short fibre €0.35 (10.3%), shives €0.02 (3.0%). FD1 prices and allocation factors: long fibre €1.75 (62.1%), short fibre €0.75 (16.2%), shives €0.20 (21.7%). FD2 prices and allocation factors: long fibre €1.75 (77.1%), short fibre €0.75 (20.2%), shives €0.02 (2.7%).

impacts of the flax scenario would decrease (FD1, Table 7). The effect was major on eutrophication, land occupation and pesticide use, whereas climate change, acidification and energy use were affected only modestly. If flax long and short fibre (but not flax shives) had the same prices as the corresponding hemp co-products, then the impacts of the flax scenario would decrease but to a lesser extent (FD2).

4. Discussion

4.1. *Hemp bio-retting relative to hemp warm water retting*

HB had higher impacts than HW for all impacts except eutrophication and pesticide use. The higher impacts for climate change and acidification are related to the higher energy use in fibre processing, which, in turn, is mainly due to the retting process. HB involves heating the retting water and drying of the retted fibre, whereas in HW naturally warm water is used and stems dry on the field. For climate change, the scenarios differed due to the fibre drying process only. Heating of retting water did not contribute to this impact, due to the renewable energy source (wood chips) used. Had a non-renewable source (e.g. gas), been used, the climate change impact would have further increased by 6%.

The yield percentages of long fibre were slightly lower in HB than in HW: the yarn yield in HB was 90% of that of HW. As a consequence, even with identical inputs, impacts (expressed in terms of the final product, yarn) would be higher for HB. This is illustrated by the results in the land occupation category, in which HB has a slightly higher impact, although the crop production stage, which is the only contributor to land occupation, was identical for the two scenarios.

Crop production, in particular nitrate leaching, was the main contributor to eutrophication. Identical results in this category for the two scenarios are a consequence of the shared crop production stage. The above-mentioned effect of differences in yield is counterbalanced by the somewhat higher emissions due to the retting liquor in HW.

The slightly higher water use in HB goes against one of the main goals of this method: to reduce water consumption by green decorticating the stems, thus minimising the bulk of retted material. However, the rinsing step in this scenario increased water consumption. Without rinsing, water use would come down to 13 m^3/100 kg of yarn, which is significantly less than the 20 m^3 of HW.

4.2. *Babyhemp relative to hemp warm water retting*

BH had higher values than HW for all impacts except water use, due to its lower yield: 3.25 tonnes/ha of retted stem versus 6.5 tonnes/ha for HW. For BH herbicide use was 0.9 kg of active substance per 100 kg of yarn, for HW no herbicide was used. For BH water use was 38% of that of HW, since no water was used in retting, but only in bleaching.

4.3. *Hemp bio-retting relative to babyhemp*

HB had higher values for energy use, climate change, acidification and water use. The main reason is its more energy intensive fibre processing stage. BH had higher impacts for eutrophication and land occupation, due to its lower yield. Pesticide use was also higher for BH.

4.4. *Flax dew retting relative to hemp warm water retting*

FD was similar to HW for all impacts except eutrophication, water use and pesticide use. Eutrophication was slightly lower, because FD does not involve effluents. FD water use was lower, as water was used only in rove bleaching. Pesticide use for FD (0.296 kg) was higher than for HW (0 kg). FD yarn yield per hectare was double compared to that of HW. This was surprising, since higher yield is often given as one of the major advantages of hemp over flax. However, scutching of HW yields a long to short fibre ratio of 28–72%, whereas for scutching of FD this ratio is 62–38%. This higher long fibre extraction rate largely compensated the 25% lower green stem yield of flax.

The flax yield of 6 tonnes/ha used in this study can be debated, but so can the hemp yield of 8 tonnes/ha. Of the many yield levels found in the literature, we tried to find realistic comparable values for the two crops. For hemp, the sensitivity analysis of the results to yield level revealed that impacts dominated by the crop production stage, such as eutrophication and land occupation, were almost proportionally affected by changes in per ha yield. Other impact categories were less sensitive to changes in yield.

The scenario variations concerning prices of flax scutching co-products illustrate that at current prices economic returns are largely generated by the flax long fibre and, as a result, the environmental impacts are allocated mostly to it. For hemp, economic value of the co-products and, consequently, the environmental impacts are more evenly distributed. The hemp prices applied to flax allocated a greater share of the impacts to the other co-products and decreased the impacts for flax long fibre. The scutching price alteration affected mainly the impacts dominated by the crop production stage, i.e. eutrophication, land occupation and pesticide use, because the impacts caused by post-scutching processes are not affected by this allocation.

5. Environmental “hot spots” of the hemp scenarios

5.1. *In general*

A normalisation of the results indicates the areas that need most attention. The normalisation revealed that the production of hemp and flax yarn contributed more to energy use than to other impacts. Energy use, in turn, was dominated by yarn production, mainly due to electricity. The impacts energy use, climate change and acidification are strongly interrelated, as energy demand is largely met by fossil fuels, the combustion of which results in the emissions of carbon dioxide and sulphur oxides. The former is the most well known greenhouse gas, while the latter contributes to acidification. Consequently, yarn production contributes most to climate change and acidification. For the four scenarios, total energy consumption of yarn production is three times higher than comparable literature values for cotton spinning (Turunen and van der Werf, 2006). This seems to result mainly from differences in the cotton and bast fibre spinning technology.

For eutrophication, the crop production phase was the biggest contributor. The eutrophying emissions resulting from hemp and flax growing are, however, by no means exceptional. In fact, hemp has been identified as a low-impact crop relative to other annual crops (van der Werf, 2004). Some emissions via leaching from agricultural land seem inevitable. But to minimise the impact, any measures leading to a reduction in nitrate leaching are highly interesting, as a 50% reduction of the amount of NO_3 leached reduced eutrophication by 32% over the yarn production chain. For the crop production phase alone, a reduction of eutrophication of 43% was reported (van der Werf, 2004). In general, the optimisation of nitrogen fertilisation and the reduction of the period between harvest and the establishment of the next (catch) crop are the principal measures recommended to reduce NO_3 leaching (Gustafson et al., 2000). However, fertilisation was optimised in our scenarios, therefore a rapid establishment of the next crop or of a catch crop seems the most promising measure to reduce nitrate emissions and eutrophication.

5.2. *Hemp warm water retting*

In the literature, water retting is often considered to be “bad” for the environment, due to the emissions from the retting water effluent. However, in this study the contribution of the retting liquor (after wastewater treatment) to eutrophication was small compared to the impact of the crop production stage. The situation would obviously be different without a wastewater treatment process. It should be also remembered that LCA is a global analysis and while globally the emissions of eutrophying substances from retting may not be significant, they might, however, have a considerable local impact at the recipient water body.

This scenario included the availability of free thermal water, which is not generally the case. If retting water were heated by gas, energy use and climate change would increase by around 20%, so the availability of thermal water is a real advantage. The effect of 400 km transport (of long fibre) had a negligible impact on energy use. Thus, from the environmental point of view, even fairly long transport distances may be justified, if “free” warm water can be exploited. Economical constraints might of course be different. Thermal water is not available in many places, but waste heat of process cooling waters might be available.

5.3. *Bio-retting*

High energy input in the fibre processing stage is the most critical issue of the bio-retting scenario. Especially drying of the fibre after retting stands out as an energy intensive process, so more energy efficient options for drying are worth exploring. Using a renewable energy source for drying could reduce climate change. In the fibre processing stage, heating of retting water also adds to the environmental impacts. Use of a renewable energy source (wood pellets) is an appropriate choice with regards to climate change. The possibility of reducing retting duration from 72 h to, for example, 48 h is worth exploring, as it would reduce energy use for maintaining the water temperature. A reduced water-fibre ratio at retting would also decrease the energy use in retting. The rinsing water is not heated, but possibilities for reducing water use in this process should be investigated, as lower water use is an aim in itself.

6. Conclusions and perspectives

LCA methodology was used to evaluate the environmental impacts of three hemp yarn production scenarios and a flax yarn production scenario. The comparison of traditional warm water retting based hemp processing with its two newly proposed alternatives and with flax revealed that, overall, neither of the alternatives was unambiguously better than the reference. The environmental impacts of the hemp reference scenario and the flax scenario were very similar, except for pesticide use (higher for flax) and water use (higher for hemp).

A reduction of the environmental impacts associated with the production of hemp yarn should give priority to reduction of energy use in the fibre processing and yarn production stages and to reduction of eutrophication in the crop production phase.

If yields can be improved, not only in agriculture, but in every processing step, without increasing inputs, impacts per kilogram of final product will decline and benefits (environmental and economic) will increase. Hemp breeders have been concentrating on developing varieties with increased fibre content. It seems, however, that less than 30% of the total amount of fibre is recovered as long fibre, so an additional goal should be to maximise the yield of long fibre. The optimisation of fibre processing should also be an important goal. The West-European flax sector has worked intensively for the last 20 years to maximise the yield of long fibre and they now harvest the fruits of this development.

Technological developments seem crucial for the development of the hemp textile industry in Europe. Contemporarily, significant amounts of hemp long fibres are only produced in Eastern Europe, mainly Hungary and Romania, where the labour costs are low. The level of mechanisation of the current production methods, which correspond largely to the hemp water-retting scenario, is low and the technology is not directly transferable to Western Europe. In the long run it will probably encounter problems in Eastern Europe too. Therefore, technological development, in particular aiming at the reduction of labour requirements, is essential for the successful production of hemp textiles in Europe. In this respect, the hemp bio-retting scenario investigated here seems to offer a promising potential to develop into a method combining a low labour requirement and a satisfactory environmental profile.

Each investigated production scenario is associated with an “environmental profile”, which was assessed in this study. What has not been done is to consider the actual fibre/yarn quality along with the environmental impacts. Besides the environmental sustainability of an agro-industrial production system, the fibre quality is indeed an important aspect, since it is the foundation of any successful spinning operation. Throughout this study we have assumed that the different scenarios yield long fibre of similar quality, but this can be questioned. Fibre quality is a focal issue within the HEMP-SYS project and it would be very interesting and "enlightening" to combine the LCA results with the analysis of fibre quality obtained from different scenarios. It would bring us one step closer to finding the most sustainable fibre scenario—remembering that the concept of sustainability has three dimensions: environmental, social and economic.

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