Environmental Impact of Industrial Hemp

HAMK
HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Visamäki Campus, Construction Engineering

Autumn Semester, 2018

Gramoz Shpendi

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Degree Program
Construction Engineering
Visamäki

Author Gramoz Shpendi **Year** 2018

Subject Environmental Impact of HEMP *(Cannabis Sativa L.)*

Supervisor(s) Hannu Elväs

ABSTRACT

With the current environmental situation worldwide and greenhouse gases caused by major industries the future seems bleak and there is a need for alternative renewable raw resources to replace our non-renewable resources. Cannabis sativa L. aka Hemp is one of the potential such renewable resources that could impact the large industries and could potentially be a wonder plant to our environment.

The thesis focuses on the life cycle and environmental impact of hemp cultivation compared to other plants and its use in industries such as textile, construction, plastics, paper and biofuels.

Keywords Cannabis sativa L., Hemp, Environmental Impact

Pages 38 pages including appendices 3 pages

CONTENTS

Appendices

1 INTRODUCTION

Environmentally worldwide the situation now seems bleak and despite the recent development and surge in sustainable and environmental technologies that can recounter the environmental pollution caused by irresponsible use of earth’s resources, there are not many organic organisms that can deliver in the environmental department as much as industrial hemp, can.

The focus of the thesis is industrial hemp and will not take under consideration the environmental impact of recreational cannabis, which could be a study on itself. Therefore, through the thesis any reference to hemp is in regard to industrial hemp, if not stated otherwise.

In recent years there has been a reintroduction of hemp in the consumer market since its criminalization in the 1930s and there has been increased awareness around the difference between industrial hemp and recitational hemp, which has led to an increase in knowledge around the environmental and sustainable impact that hemp can have on different industries. The widespread use of industrial hemp can impact the energy, construction, textile, food and paper industries to name some. However, apart from hemp’s impact as a raw material, it benefits the environment from cultivating the plant are as impressive. No herbicides, fungicides and insecticides are needed to grow industrial hemp. The cultivation of hemp preserves biodiversity since it favours insect pollinators and the auxiliaries of the crops. As a high-yielding biomass crop, hemp sets a high amount of CO_2 in its straw and with its powerful root system, hemp strongly limits leaching of nitrate to groundwater and watercourses. The cultivation and use of hemp products, therefore, have a positive effect on the reduction of greenhouse gases and the environment.

The thesis is a collection of researches and studies related to hemp use and its impact on the environment. Despite increased access to industrial hemp research there seems to be a lack of updated and generalized study on the environmental impact of hemp and with resurgence of hemp in everyday life of consumers and industries, it’s important to study hemp in this regard. This research also aims at educating and enabling future interested parties in grasping the importance of industrial hemp.

To quote from the book of Jack Herer, a well-known activist and contributor to cannabis rights “ If all fossil fuels and their derivatives, as well as trees for paper and construction were banned in order to save the planet, reverse the Greenhouse Effect and stop deforestation; Then there is only one known annually renewable natural resource that is capable of providing the overall majority of the world's paper and textiles; meeting all of the world's transportation, industrial and home energy needs, while simultaneously reducing pollution, rebuilding the soil, and cleaning the atmosphere all at the same time. And that substance is the same one that did it all before, Cannabis Hemp." (Herer 1985, page 7)

2 INDUSTRIAL HEMP HISTORY

Cannabis sativa L. also known as hemp, cannabis, marijuana, weed, pot and several other names which derive due to widespread cultivation and usage, is known to be one of the first plants domesticated by humans and its fibre used in day to day life.

Hemp has accompanied humans from their earliest industrial initiatives. The oldest references of use of hemp date back to 2727 before Christ (BC) in Chinese pharmacopoeia and it is now several thousands of years since humans transformed hemp into serviceable products. Literature in different studies suggest that hemp for more than 1000 years before the time of Christ until late 19th century was our planet's largest agricultural crop and most raw material in several industries, involving a large variety of products. Palynological studies have cannabis pollen grains dating to 3450 BC in northern Italy, samples from central and northern Germany, Scandinavia, England and France have dated back between 2900 to 1700 BC. However, these discoveries do not suggest cultivation of hemp, but its wild growth. (Bouloc, Allegret, Arnaud, 2013)

In China, a formal proof of hemp existence and usage is available from archaeological discoveries or from the administrative documents preserved. Hemp makes its appearance in China very early around 8000 BC, pottery dated at 6200-4000 BC has been found depicting clothing that was shown to be made from hemp. The remains of hemp, including hemp seeds have been found in graves of nobles dating 2000 BC. Other products such as ropes and paper have been found that also date from a similar timeline. These discoveries demonstrate that the migration of people west and south brought hemp to Europe and India. (Bouloc et al., 2013)

In the Middle Ages (600 – 1600 AC) hemp was considered a strategic commodity because of its already large number of uses allowed by its quality fibre. Entering the 17th and 18th century the importance of hemp was especially in focus and regard to sails, where it was used in conjunction with flax on ropes, cables, ladders and stays that made up a ship's rigging. (Bouloc et al., 2013)

By the 19th century, statistical records of hemp production became available. These statistical records allow following the evolution of hemp production and see its production affected by the development of new technologies. The invention of waving machines and steam engines in particular affected the production of hemp. The weaving machines allowing for large quantities of cotton to be processed, put cotton in the first place for its use in textile industry and the steam engines with steel condemned use of sail power to history. However, this era saw the increase of hemp import into the first world countries such as France, Germany and Italy with the main supplier of hemp being Russia. (Bouloc et al.,2013) Figure 1 below shows the history and decile of Hemp in the past 150 years.

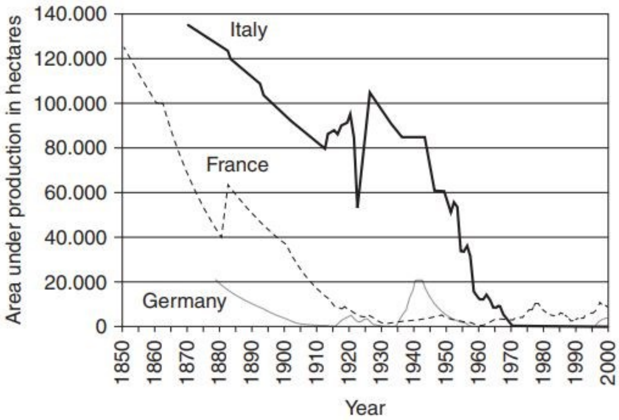

Figure 1. History and decile of hemp. (Bouloc et al., 2013) (Navo Institute, Germany)

After World War I, hemp's importance diminished year by year. Hemp was not used anymore in textile industry. However, it was still used in the production of sacking, ropes and strings. It was also still in use in paper industry for the production of certain special papers. Hemp cultivation decreased rapidly throughout the world, apart from USSR, who maintained hemp cultivation and production. Serbia, Hungary and Romania also managed to certain amount of production. However, it was the USA that during the interwar years put strong tactics against the use of hemp. With the development and rise of synthetic fibres and the introduction of the term 'marijuana', which in a derogatory form depicted hemp used only as a drug, created the 1937 Marijuana Tax Act, which imposed heavy taxes on hemp cultivation, making it uneconomical. From 1945 onwards, hemp has effectively been banned in the USA and with post World War II position as a global power, the USA imposed their view on hemp in the UN, which resulted de facto in a worldwide ban. China, India, USSR, Eastern Europe, Italy and France, however, resisted the US led initiative. (Bouloc et at.,2013)

2.1 Status of hemp worldwide

Currently around 30 countries in Europe, Asia, and America permit the cultivation of hemp. Some of these countries never banned the cultivation and production of hemp, while other countries within the past 20 years have been working in legalizing cultivation and production of hemp products. China is among the largest producers and exporters of hemp textile and related products, as well as the major supplier of such products to the USA. The European Union (EU) has an active hemp market, with most of the member nations cultivating and producing hemp. The cultivation is centred in France, United Kingdom, Romania, and Hungary. (Johnson, 2014)

Hemp Cultivation worldwide has been mostly steady or decreasing, with reported around 200,000 acres globally in 2011. However, global production has increased overall from 120 million kg in 1999 to more than 180 million kg in 2011, mostly due to increased production of hemp seed (Figure 2). Increased trends in global hemp seed production roughly track similar increase in trends in USA imports of hemp seed and oil, mostly used in hemp-based foods, supplements and body care productions. (Johnson, 2014)

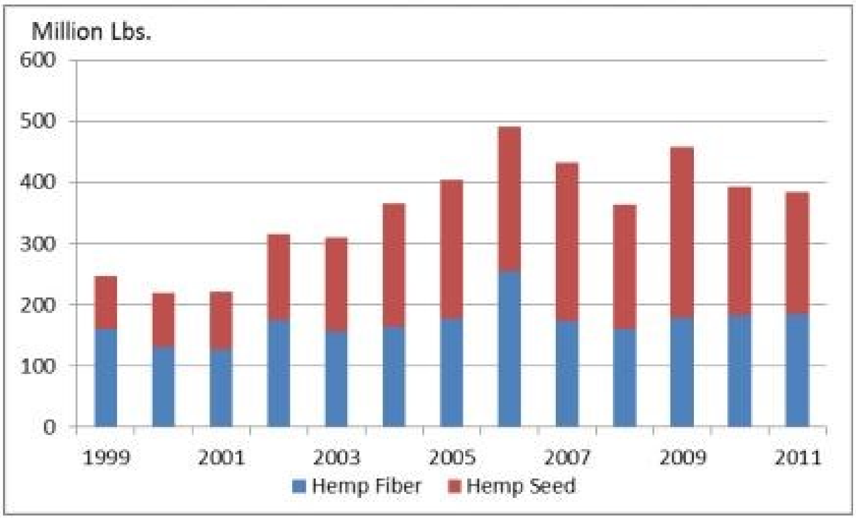

Figure 2. Hemp Fibre and Seed, Global Production (1999-2011) (FAOSTAT, http://faostat.fao.org/site/567/default.aspx#ancor.)

Many EU countries lifted the ban on hemp production in the 1990s and hemp acreage was reported around 26,000 acres in 2010. Most EU production is of hurds, seeds and fibres. Other countries with active hemp production and consumer market include Russia, Ukraine, Australia, New Zealand, India, Japan, Korea, Turkey, Egypt, Chile and Thailand. (Johnson, 2014). Figure 3 below shows countries cultivating hemp in 2004.

Countries Cultivating hemp in 2004			
Europe 25[3]	Area of hemp in 2004 (ha)	Other European countries	Area of hemp in 2004 (ha)
Germany	1730	Romania	2000
Austria	397	Russia	2500
Belgium	0	Serbia	200
Denmark	0	Ukraine	1000
Spain	678	**TOTAL**	
		Other European countries	**5700**
Estonia	PM	**ASIA**[4] (estimations)	
Finland	6	China	65000
France	8 427	North Korea	13000
Great Britain	1 640	South Korea	224
Holland	27	Japan	20
Hungary	539	Turkey	700
Ireland	22	**TOTAL Asia**	**78944**
Italy	885	**Australia**	
Latria	PM	Australia	**250**
Lithuania	PM	**North America**	
Poland	81	Canada	**5500**
Slavakia	PM	**South America**	
Sweden	PM	Chile (FAO)	4300
Czech Republic	500	**Africa**	
TOTAL		South Africa	PM
Europe 25	**14932**	**TOTAL WORLD**	**105756**

3. Data from the EU.
4. Data from FAO and estimations
* PM = not recorded

Figure 3 Countries Cultivating hemp in 2004 (Bouloc et al.,2013)

Interest in cultivating and producing hemp is growing across the world, and especially in Europe, in industrial hemp and in natural hemp fibres in particular.

3 HEMP BOTANY AND CULTIVATION

Hemp is an annual plant with a steam that can grow to the height of some 2-4m depending on the variety. The stem rarely branches and has a diameter that averages between 1 and 3 cm. The plant's morphological characteristics can vary according to the growing conditions. At low sowing densities, branching is likely to increase, whereas a high sowing density will favour the development of a tall plant with long, straight unbranched stems. The volume of the root system varies according to the cultivation methods used and the soil quality. On average, the root volume comprises 8-9% of the total biomass. The main root can grow to a depth of 2m, whereas the secondary roots that form the bulk of the root system reach lengths of between 10 to 60 cm. Hemp seeds are spherical in shape and measure 3-5mm in length. Figures 4 and 5 show industrial hemp grown outdoors and indoors.

Figure 4 Outdoors Industrial Hemp grown in North Carolina

Figure 5 Indoor Industrial Hemp grown in North Carolina

Hemp has excellent agronomic characteristics. As a slender and annual plant depending on its handling and agro-chemical aspects it can supply a high yield of dry matter per ha. As an annual plant hemp is sown in the spring and harvested at the end of the summer or the start of autumn. Under conditions usually encountered in Western Europe, the vegetative period lasts from 80 days to over 150 days, depending on variety. Hemp can find its place in a crop rotation system, for its ability to leave the ground free of weeds and improving soil's structure. (Bouloc et al.,2013)

The plant's cultivation and production is determined by the end purpose or use with main difference in hemp fibre or seeds. Harvesting practices differ depending on the non-textile grade fibre, textile grade fibre, or dual purpose and seeds.

4 HEMP AS A SUSTAINABILITY TOOL

The intent of sustainable development is a “humane equitable and caring global society, cognizant of the need for human dignity for all” (United Nation, 2002).

Sustainable development is formed on three interdependent components: economic development, social development and environmental protection. Social sustainability is created by systematic community participation. Economic sustainability maintains four forms of capital, human-made, natural, social, and human. Environmental sustainability tries to improve human and social welfare through the protection of raw material sources used to required needs, the focus being to produce consumption waste products that are not harmful to humans. Sustainability seeks to maintain total natural capital stock at or above the current level. This means an efficient use of resources in the present, with a plan for future resources needs.

In evaluating hemp as a sustainable development tool, we take under consideration the three above mentioned components of sustainable development: social, economic and environmental.

Since the very early development and production stages of hemp, the plant has created community participation and involvement all along. Hemp versatility and possibility of personal cultivation can have empowering effects on community and individuals. In the early 20th century hemp was known to be a part of common household, especially in everyday products created from hemp fibre.

At a time when humans are worrying about the future and questioning the impact their behaviour has on the environment, it is reassuring to know and understand that hemp can offer possibilities for the development of new and sustainable industries. With new generations becoming more environmental conscious, they find themselves in the position for making change and hemp has been noted to be able to do so. In the same aspect hemp also intrigues involvement not only in industries and technology, but also agriculture and environment, as it is a plant. This can have a positive effect on social balancing and future development of agriculture which in large has a major impact on the environment.

Another major social impact on hemp can be currently related to the development of new sustainable industries in developing countries which are highly relaying in their agriculture. It has been noted that hemp can grow under a large variety of circumstance and can supply raw material for many industries. Many of the developing countries currently are struggling with keeping their agriculture environmentally friendly and sustainable. Hemp with its characteristics offers the possibility of development of agriculture, industry and environmental technology in these developing countries without large investments, as the raw products for these developments its easy, cheap and reliable, it being hemp.

4.1 Environmental Benefits of Hemp Cultivation

Hemp has demonstrated several agronomic and environmental strengths. With its versatile and widespread use, hemp can have a large environmental impact considering the plants sustainability and life-cycle. As a plant hemp covers the ground quickly and smothers majority of weeds without the requirement of herbicides or pesticides. It requires a moderate amount of nitrogen fertilization, since its roots are deep and can use the mineralized nitrogen deposited in the soil. Hemp is very resistant to drought and in practice, hemp cultivated for straw does not need to be irrigated. Only the crops cultivated for straw and seed are occasionally irrigated. When harvested hemp leaves the ground clean, relatively dry and loosened for some depth. Hemp is an excellent crop to follow and can improve the cultivation of the following crops. (Gorchs and Lloveras, 2003).

In 2002, the European Union financed a study called HEMP-SYS (Amaducci, 2003) with the objective to promote the development of competitive, innovative and long-lasting hemp fabric industry. The project intended the development of an improved production chain to produce high-quality hemp fabric that was ecologically sustainable, coupled with an integrated quality control system for the stems, fibres and thread. To do this, the project had to evaluate the environmental impact of the various products used in the production of hemp textile, in which context the impact of hemp production in the field was studied by means of life cycle analysis (LCA). (Bouloc and van der Werf, 2013)

The main impact of hemp cultivation is quantified and compared to those of seven other annual crops. The effects of modified farming practices and the amount of nitrate lost throught washing were explored for hemp. The environmental impact of the eight annuals crops has been estimated by an LCA, allowing the study of the potential impact of the cultivation by quantifying and evaluating the resources used and the environmental emission at each stage of the life cycle. (Guinee et al., 2002)

The environmental problems that were taken under consideration during the study were eutrophication, climate change, acidification, terrestrial pollution, energy use and the use of cultivated land. Eutrophication includes all that may result from the introduction of excessive levels of nitrogen and phosphate fertilizers into the environment. Climate change is defined as the impact of emission on the atmosphere’s ability to absorb radiated heat. Acidifying substances can have a wide range of effects on the ground, water, living organisms, ecosystems and buildings. Terrestrial pollution covers the impact of toxic substance on terrestrial ecosystems. Energy use related to the use and using up of non-renewable energy resources. The use of cultivated land concerns the temporary non-availability of cultivated land as a resource with it is being used for production of the crop. (Bouloc and van der Werf, 2013)

The value representing the impact indicator for each category of environmental problem is calculated by multiplying each type of resources used and each type of substance emitted by a characterization factor for each of the categories of problem which the resource and substance can contribute. The impact is expressed in equivalent kg of PO_4 for eutrophication, equivalent kg of CO_2 for climate change, equivalent kg of SO_2 for acidification, equivalent kg of 1,4-dichlorobenzene for terrestrial pollution, in MJ for energy use and in m^2/year for land use for cultivation. (van der Werf, 2004)

The study concerned itself with hemp production from a non-combined crop and seven other annual crops in France. The inputs and yields for the eight crops are summarised in Table 1.

Table 1 Input, yields and emission for hemp and seven other annual crops. (Bouloc and van der Werf, 2013)

	Hemp	Sunflower	Rape	Peas	Wheat	Maize	Potato	Sugarbeet
Inputs								
N (ammonium nitrate)	75	85	110	0	130	100	170	220
P_2O_5 (triple superphosphate)	38	32	41	46	64	51	80	101
K_2O (potassium chlorate)	113	21	30	95	90	30	293	180
CaO	333	167	167	333	333	333	0	333
Seed	55	5	2.5	200	120	20	2,000	2.5
Pesticide (active ingredient)	0	1.0	2.9	3.2	2.9	3.5	5.5	3.7
Diesel	65	79	81	87	101	91	165	137
Natural gas (for drying the seed)	0	0	0	0	0	167	0	0
Agricultural machinery	16.4	23.0	23.3	26.9	28.7	21.3	29.0	34.2
Grain yield dry matter	–	2,100	2,970	4,110	5,910	6,440	–	–
Straw yield dry matter	6,720	–	–	1,410	3,870	–	–	–
Dry matter yield	–	–	–	–	–	–	10,000	11,540
Followed by an intermediate crop (%)[a]	0	0	0	0	50	0	0	0
Following crop	Wheat	Wheat	Wheat	Wheat	Maize	Wheat	Wheat	Wheat
NO_3-N emitted	40	40	40	70	40	40	40	40

Note: [a]Indicates the percentage of cases in which we believe an intermediary crop was sown between the harvesting of the crop and the sowing of the following crop.

In the case of hemp modification in farming practices such as use of pig slurry and no-tilling was taken under consideration, together with a more optimistic hypothesis regarding nitrogen losses in the form of nitrates (20 kg/ha instead of the common 40kg).

Table 2 Inputs, yield and emission for three different scenarios of hemp production. (Bouloc and van der Werf, 2013)

	Pig slurry	No-till	Reduced washout
Inputs			
Pig slurry	20,000		
N (ammonium nitrate)	0	75	75
P_2O_5 (triple superphosphate)	0	38	38
K_2O (potassium chlorate)	51	113	113
CaO	333	333	333
Seed	55	55	55
Pesticide (active ingredient)	0	0	0
Diesel	72	39	65
Agricultural machinery	18.8	11.6	16.4
Straw yield dry matter	6,720	6,720	6,720
Followed by an intermediate crop (%)[a]	0	0	0
Following crop	Wheat	Wheat	Wheat
NO_3-N emitted	40	40	20

Note: [a]Indicates the percentage of cases in which we believe an intermediary crop was sown between the harvesting of the crop and the sowing of the following crop.

The study took under consideration the impact resulting from field production, including harvesting, transport to the processing unit and drying of the product (this only applies to maize). The impacts resulting from the production and sourcing of key inputs (agricultural machinery, diesel, fertilizer, pesticides and seeds) have been taken into consideration using the method proposed by Nemecek and Heil (2001). The data for energy contributions and transport are derived from the BUWAL 250 database (BUWAL, 1996). Buildings have not been included as their contribution to the impact of annual crops is negligible: 0–2% (van Zeijts and Reus, 1996). (Bouloc and van der Werf, 2013)

The impact of the cultivation of the eight different annual crops on the considered environmental problems is compared in Table 3.

Table 3 The environmental impact arising from the production of 1 ha of hemp compared to seven other annual crops. (Bouloc and van der Werf, 2013)

Impact category	Unit	Hemp	Sunflower	Rape	Peas	Wheat	Maize	Potato	Sugarbeet
Eutrophication	kg eq-PO_4	20.5	20.2	20.6	34.4	21.9	21.0	23.8	24.1
Climate change	kg eq-CO_2	2,330	2,300	2,700	2,890	3,370	3,280	4,120	4,900
Acidification	kg eq-SO_2	9.8	10.8	12.8	8.3	16.3	13.6	22.4	24.5
Land pollution	kg eq-1,4-DCB	2.3	1.8	2.5	0.1	4.0	3.0	4.9	6.7
Energy use	MJ	11,400	11,900	13,800	11,800	18,100	23,000	25,600	26,300
Land surface used	m^2/year	10,200	10,000	10,000	10,500	10,200	10,100	10,400	10,200

Note: kg eq = kg equivalent.

Take under consideration the results the impact is variably low for hemp and sunflower, but relatively high for potato and sugarbeet.

Since in the case of hemp four different production scenarios were taken under consideration, the impact of its production is different by scenario relatively.

In certain areas, organic fertilizers are available at a very low cost and their use can reduce production costs dramatically. The substitution of a mineral fertilizer with pig slurry reduces the climate change impact by –24% and energy use by –32%, but increases eutrophication (+16%), acidification (+140%) and terrestrial pollution (+1720%). No-till farming is interesting because it reduces erosion, production costs and hours of work required. No-till farming reduces the climate change impact (–6%), acidification (–13%) and energy use (–16%). The amount of nitrate washed out will be lower where the nitrate residue in the ground at the time of harvesting is low and when the period between harvesting and planting of the following crop is short. A reduction in washout of 40–20 kg N/ha reduces eutrophication (–43%) and climate change (–10%). The environmental impact arising from 1 ha of hemp production according to four different production scenarios is seen below in Table 4. The reference scenario is that defined in Table 1, the other three are defined in Table 2. (Bouloc and van der Werf, 2013)

Table 4 The environmental impact arising from 1 ha of hemp production according to four different production scenarios.

Impact category	Units	Reference	Pig slurry	No-till	Reduced washout
Eutrophication	kg eq-PO_4	20.5	23.7	20.2	11.6
Climate change	kg eq-CO_2	2,330	1,770	2,200	2,090
Acidification	kg eq-SO_2	9.8	23.5	8.5	9.8
Terrestrial ecotoxicity	kg eq-1,4-DCB	2.3	41.9	2.3	2.3
Energy use	MJ	11,400	7,760	9,520	11,400
Surface used	m^2/year	10,200	10,200	10,200	10,200

Note: kg eq = kg equivalent.

Through this study relative to the other crops examined, hemp and sunflower showed to be the crops requiring the lowest amount of inputs and the lowest environmental impact upon cultivation.

4.2 Hemp and Climate Change

Hemp has the potential to make an important contribution to the protection of the environment and to reversing of greenhouse gases, which is the leading cause of climate change. Hemp yielding in 1 ha(hectare) land gives about:

- 1ha of hemp can produce nearly 12 ton of dry matter, with humidity level of 15%
- exported straw at about 6 ton

- hemp seed around 1.2 ton
- root system and leave around 3.5 ton

Hemp contains approximately 45% of the atmospheric carbon taken during photosynthesis. Considering that the carbon stored in hemp parts must have a life expectancy more than the annual life cycle, we must take into account only the straw destined for use in products with long life expectancy. Therefore, hemp straw produced by 1 ha of land can stock approximately 3.06 ton of carbon. (Bouloc et al.,2013). Carbon is stored for a long time where straw is used in production of materials with long life expectancy. The modern uses of hemp straw and its derivatives thus fix carbon for a long time, in cases such as the following:

- Hemp wool has life expectancy of 20 years
- Panels made from hemp fibre used in car door manufacturing last on average 7 years
- Hemp cement lasts over 30 years
- Plastics made using hemp fibre can be expected to last on average 7 years, etc.

It is clear that the use of hemp in long-lived materials can contribute to a reduction in the greenhouse effect. In such a case we can also acknowledge the possibility of mitigation of climate change through hemp. This highlights the need for further study of the potential of cultivation of hemp and its use in different sectors of industry. Hemp's potential to be further developed and used as the main source for production of long-lasting products in a variety of industries is one of the main methods in mitigating climate change. On the contrary from most of the current used raw products in industries such as plastics, textile, construction, paper, cosmetics, energy, animal, hemp can be more environmental in several aspects.

4.3 Agriculture, deforestation, and environment

The many agricultural benefits of growing hemp are well established. Hemp cultivation requires very limited amounts of pesticide. Few insect pests are known to exist in hemp crops and fungal diseases are rare. Since hemp plants shade the ground quickly after sowing, they can outgrow weeds, a trait especially helpful for organic farmers. Hemp has a broad climate range and has been cultivated successfully from as far north as Iceland to warmer, more tropical regions. Being an annual crop, hemp functions very well in crop rotations. And as noted above, hemp is a drought-resistant crop which will augment climate change adaptation. The environmental impacts of increased hemp production over cotton would be tremendously positive. Cotton simply takes more water, more fertilizer, more herbicides and more pesticides to grow. (Johnston, 2016)

Hemp has long been known as a potential substitute resource for paper sourced from trees. According to studies, substituting hemp for trees results in longer lasting paper products produced with a significantly less environmental impact.

Using hemp in place of timber as a source of paper could radically reduce deforestation. One acre of hemp produces four times as much pulp as an acre of timber. Hemp also grows on almost any land and in any region, so it could be grown throughout the US, unlike the trees which are used for paper and which have a fairly limited habitat. Hemp can also be grown on unproductive land and between seasons and can even be used to enrich soil which has become leached of minerals. [citation] Hemp can also be grown without the pesticides that are necessary for cultivation of other textiles and paper products, such as cotton which requires large amounts of pesticides and today is the most polluting of all agricultural industries. Cotton production, in fact, accounts for half the pesticide use in the US, and that product is one of the major products for which hemp could be substituted. (Johnston, 2016)

Producing Hemp for copy paper, boxes, toilet paper, and books, can have a positive impact on deforestation. Forests hold thousands of species of animals and plants that are becoming endangered due to deforestation. On top of that, trees act as Mother Nature’s ‘lungs’.

- On average, one acre of Hemp can produce two to four times more paper than one tree.

- Hemp matures 90-120 days. For trees, it takes 20 years to mature.

- Paper produced from Hemp can be recycled a little over two times more than timber paper.

- Paper manufacturing needs many harmful chemicals for bleaching. Hemp can be simply whitened with hydrogen peroxide.

- Trees remove emissions out of the air—just like Hemp. Let’s leave the trees standing and grow fields of Hemp like never before! (Johnston, 2016)

Hemp paper is superior to timber not only because of sustainability, but also because it is much more durable and lasts many decades longer. The characteristics of hemp which make it particularly appealing for making paper are as follows:

- Hemp fibres are long (makes for stronger paper which can be recycled more times than wood paper)

- Hemp contains high levels of cellulose (57-77% – more cellulose makes for more pulp)

- Hemp has low (3%) lignin content (this is what makes wood-pulp paper turn yellow over time).

- One acre of hemp can produce as much usable fibre as four acres of trees. Hemp can be harvested every 100 days. Trees take decades to harvest. (Johnston, 2016)

Hemp production can therefore benefit rare, threatened and endangered species that rely on forest habitat. Furthermore, old-growth forests are valuable carbon sinks. Thus, substituting hemp for tree-based paper will have consequential benefits with respect to climate change mitigation.

5 HEMP AS ORGANIC ENVIRONMENTAL TECHNOLOGY

5.1 Textile Industry

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 characterized by high water requirements and use of substantial amounts of fertilizers 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.

Using other natural crops for the production of textiles may decrease the impact on the environment given the lower water requirements of many other fibre crops. One of these is hemp, which was already used in the distant past. The water footprint (WF) of industrial hemp, based on earlier studies, is less than one third of the WF of cotton (10,000 l/kg vs. 2,719 l/kg). (Avernik, 2015)

Cotton is the most important natural fibre used in textile industries worldwide, contributing 36 per cent of apparel fibres in 2008. The global average water footprint of cotton fabric is approximately 10,000 litre/kg (Hoekstra, 2013). Global average footprint of different raw materials in the textile industry can be seen in the Table 5.

Table 5 The global average water footprint of different raw material of textile (Hoekstra, 2013)

Product	Global average water footprint (litre/kg)			
	Green	Blue	Grey	Total
Abaca fibre	21,529	273	851	22,653
Cotton lint	5,163	2,955	996	9,114
Sisal fibre	6,791	787	246	7,824
Agave fibre	6,434	9	106	6,549
Ramie fibre	3,712	201	595	4,508
Flax fibre	2,866	481	436	3,783
Hemp fibre	2,026	0	693	2,719
Jute fibre	2,356	33	217	2,606

Comparing hemp water footprint with cotton as one of the most demanded textile fibres it can be clearly seen as to the fact that cotton water footprint is four times higher.

Hemp requires no pesticides, crowds out weeds without herbicides, controls erosion of the topsoil and sequestrates carbon, making it an eco-friendly plant for the production of textile.

Hemp's characteristics as a textile make it a desirable choice in many applications:

- Hemp is stronger and more durable than any other natural fabric, including linen, which almost matches hemp's abrasion resistance and tensile strength. The result is that hemp has a longer lifespan than other natural fabrics. Products made from hemp will outlast their competitors by many years.

- Not only is hemp strong, but it also holds its shape, stretching less than any other natural fibre. This prevents hemp fabric used in upholstery, demountable panels, acoustic panelling or as wallcovering from stretching out or becoming distorted with use.

- Hemp fabric withstands, even benefits from, commercial laundering. Its inherent lustre and light reflective qualities are enhanced by washing; it becomes finer and more luxurious with use. Hemp also possesses excellent soil-release properties because it sheds a microscopic layer each time it is laundered. This eliminates soiling and exposes a fresh surface. In effect, this means that hemp retains its sleek sheen every time it is washed, that it never dulls, and that it releases stains more easily than other fabrics.

- Hemp may be known for its durability, but its comfort and style are second to none. The more hemp is used, the softer it gets: it wears in, not out, thriving on regular use and machine washing without suffering fabric degradation. Hemp actually becomes softer, more resilient and more lustrous as a result of washing.

- Hemp's superior absorbency, due to its porous nature, means that it is very breathable and quick drying. Hemp can absorb up to 20% its own weight while still feeling dry to the touch (vs. polyester, which can absorb a maximum of 6%). This is important in the case of any fabric that is in contact with human skin, such as sheets, as perspiration is rapidly absorbed. It feels cooler in summer yet during cool weather, air which is trapped in the fibres is warmed by the body, making it naturally warm.

- Hemp's absorbency allows it to accept dyes readily and retain colour better than other natural fibres, including cotton.

- Hemp has a high resistance to ultraviolet light; it will not fade or disintegrate from sunlight as quickly as other natural fibres.

- Hemp fibre is highly resistant to rotting, and its resistance to mildew, mold and salt water led to its premier use in marine fittings: the majority of all twine, rope, ship's sails, rigging and nets up to the late 19th century were made from hemp. The word canvas itself is derived from cannabis.

- Finally, any product made of hemp is fully biodegradable and easily recyclable. (Goldstein, Earth Protex)

In 2009 MADE-BY released the first draft of the Environmental Benchmark for Fibres (Appendix 1), created in conjunction with internationally acclaimed environmental research company Brown & Wilmanns Environmental LLC. This benchmark was further updated in July in 2011 to include recycled wool (Class A) and mechanically and chemically recycled polyesters differentiated to represent the contrasting environmental impact of the recycling technologies used. In December 2013, three new fibres were included - CRAiLAR Flax, elastane, and Monocel (bamboo product). (MADE-BY, 2013). The impact parameters taken under account in the benchmark included greenhouse gases, human toxicity, eco-toxicity, energy input, water input and land use.

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). 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. (Turunen and van der Werf, 2006)

The study of impacts of production of hemp and flax were focused on the issues of eutrophication, climate change, acidification, non-renewable energy and land use. The results are presented both in quantity of toxics released that effect the mentioned issues (Table 6) and normalised impacts according to per capita environmental impacts in Wester Europe (Appendix 2).

Table 6 The environmental impacts of yarn production expressed per 100kg of yarn for investigated scenarios: hemp water retting (HW), hemp bio-retting (HB), babyhemp (BH) and flax dew retting (FD) (Turunen and van der Werf, 2006)

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

The studies presented and conducted are a sign of superiority of hemp compared to the commonly used cotton and synthetic material; however, an emphasis should be put on further development of technologies for the production of hemp yarn and textile since they lack far behind in comparison to the popular materials.

5.2 **Construction Industry**

Construction industry is a large contributor to consumption of both energy and natural resources and well known for its impact on air, water and soil. Construction of buildings and roads are responsible for nearly half of the raw materials and energy consumed across the plant; therefore, impacting the depletion of finite resources and emission of greenhouse gases. The emphasis should be now put on the development of more sustainable technologies and eco-design. As mentioned, the physio-chemical and mechanical properties of hemp make it a lucrative raw material to be used in the construction industry. Nowadays, in building hemp can be found in insulation mats, concretes and bio-composites. However, the range of products is just growing.

Except for hemp seed, the bast fibres and the woody core of the hemp stalk used to produce hurds are the two main raw materials which can be used in the construction industry.

The fibres are used to produce insulating materials, replacing synthetic fibres and contributing to the mechanical strength which hemp fibres have to offer. Fibre Reinforced Concrete is another application in which a composite concrete material consists of a hydraulic cement matrix reinforced with fibre.

The hurds are used for their two main characteristics: low density and properties as an insulator. Other properties include elasticity and permeability. The primary use of hurds is in production of superlight concretes or “hempcrete”, mortars and as space-occupying insulation agents that can be packed into cavities and under floors. Hemp hurds are extensively used in hemp lime products, lime being used as a binding element. Recent literature on hemp fibre reinforced concrete and hemp hurds composite demonstrates that mechanical properties of these composites have been tested on lab-scale specimens: for compressive strength, flexural strength, and flexural toughness. The mechanical properties have been found to be strongly dependent on the binder used and on the addition of fillers and aggregates. Use of hemp shives and fibres in construction industry can be seen in Figure 6.

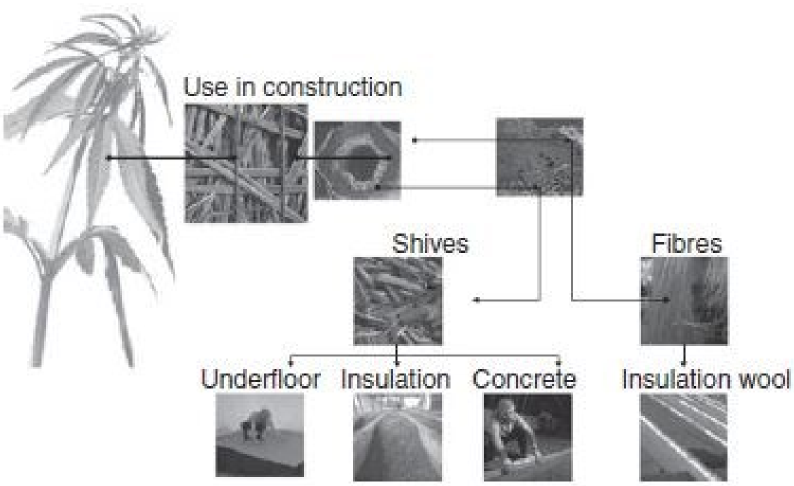

Figure 6 From plant to building – hemp in construction industry (Arnaud, Boyeux, Hustache, 2013)

Recent studies in polymer composites reinforced with hemp fibres have attracted interest producing high performance polymer-based materials with specific mechanical properties.

Focusing on the environmental issues of the hemp-based materials, several studies were found and many are still expected to be conducted in the future as the number of research and applications of hemp in the construction industry are growing.

5.2.1 Thermo-acoustic insulation mats

One of the most widespread ways to use hemp fibres is to manufacture mats to be employed in buildings with thermo-acoustic insulation functions. A considerable number of authors have worked on the assessment of both energy and environmental performances of these products. LCA performed by Luca Zampori, 2013, of the production (technical fibre and woody core) and use of hemp for the evaluation of the impact generated by the manufacturing of a hemp mat with a thermal conductivity of 0.044 W/m* K. (Ingrao et al., 2015)

The study included assessment of both the inventory flows and the environmental burdens associated with the cultivation of 1 ha of land and of the sustainability of two walls where the insulating performances were guaranteed alternatively by hemp-based or rockwool insulating panels. The authors used mass allocation considering that hemp cultivation delivers the following three co-products: woody core; fibre; and, dust. According to the authors, 1 ton of 18 dried hemp yields 70% for the woody fraction, to 25% fibres and up to 5% dust particles. Therefore, it can be said that fibres are responsible for 25% of the damage due to cultivation of 1 ha of hemp land: this aspect was considered by the authors for implementation of the panel production and, in turn, of the life-cycle of the walls. Interestingly, the following three indicators were used by the authors for assessing the environmental burdens associated with the production of hemp (in the amount required for mat manufacturing) and with the two designed walls: Greenhouse Gas Protocol (GGP); Cumulative Energy Demand (CED); and, Ecoindicator99. (Ingrao et al., 2015)

The study highlighted that, for all the before mentioned impact indicators, hemp fibre production is the most impacting process in the production of the manufactured panel and, in turn, of the life-cycle of the designed walls. With regard to this latter phase, it was found that the highest contribution in terms of 100-year Global Warming Potential (GWP-100) comes from the fertilisation phase in terms of both production and management of the fertilisers required. CED calculation results show that hemp usage results in more renewable energy. Moreover, from the application of the Ecoindicator99 method it appeared that hemp fibre production affects the non-renewable energy resource stock due to the high consumptions of fossil fuels associated with the agricultural activities involved and to the retrieval and transportation of all the input materials required. This aspect was stressed by Fassi and Maina, 2009, who evidenced that, in terms of primary energy, hemp fibre with a total energy consumption of 15 MJ/kg uses less energy than mineral and synthetic materials, but more energy than other natural materials. This is mostly due to input material production and supply which accounts for almost 64% with a primary energy consumption value equal to 9.63 MJ/kg. (Ingrao et al., 2015)

Zampori, 2013, concluded that hemp-fibre mats are valid alternatives to conventional materials and are feasible for the application in the green-building sector. A comparison between a hemp and a rock-wool mat showed that the former is far less impacting than the second. This was attributed to the CO_2-uptake associated with hemp-plant photosynthesis, thereby enabling GWP100 credits that offset the GWP-100 burdens of the mat production. (Ingrao et al., 2015)

Another interesting comparison was carried out by Menconi and Grohmann, 2014, who developed a thermal simulation model integrated in an LCCA-based approach aimed at identifying the best choice of insulating material to retrofit the roofs of an extensive sheep farm building. The study showed that all of the considered insulating materials work well for increasing the period of time in which a temperature of comfort is maintained so as not to exceed the critical value for animal welfare. By analysing their entire life-cycles, the best materials were found to be glass wool, sheep wool, and hemp fibre whilst the polyurethane ranked last because of its high primary energy input though it presents the best response in terms of temperature control. Hemp fibre was confirmed to be one of the less energy demanding and GHG emitting materials. (Ingrao et al., 2015)

The application of hemp fibre in such construction materials, however, requires carefully executed production, construction and maintenance as to avoid a potential risk for microbial activity and contamination.

5.2.2 Composites

Pervaiz and Sain, 2003, investigated mechanical properties and environmental performance of mat thermoplastics made of 21 finished natural fibre (NMT) and compared the obtained results with mat thermoplastics made of glass fibre (GMT). The performed analysis highlighted that natural fibres, such as hemp, have a great potential to act as a sustainable 'sink' for CO2 and that their use enables saving of non-renewable energy resources. For this reason, hemp fibres should be preferred to glass thus allowing more eco-friendly composites to be produced. (Ingrao et al., 2015)

Table 7 Overall energy consumption schedule for natural fibre and glass fibre (Pervaiz and Sain, 2003)

Quantity (1 metric ton)	NMT (65% fiber)	MJ	GMT (30% fiber)	MJ
(a) Materials				
	Hemp cultivation	1340	Glass fiber production	14 500
	PP production	35 350	PP production	70 700
	Total	36 690	Total	85 200
(b) Production				
	Composite	11 200	Composite	11 200
(c) Incineration				
PP incineration				
	Energy required	117	Energy required	234
	Energy released	−7630	Energy released	−15 260
Hemp fiber incineration			*Glass fiber incineration*	
	Energy required	1108	Energy required	516
	Energy released	−10 650		
	Net	−17 055	Net	−14 510
(d) Balance				
	Gross energy required	49 115	Gross energy required	97 150
	Energy released	−18 222	Energy released	−15 260
	Net energy required	30 800	Net energy required	81 890

The environmental benefits of hemp fibre for the production of bio-composites were further highlighted by many authors who tested the use of hemp fibre as a reinforcement for the production of composites made of several polymer materials, such as, polypropylene (PP) and polyethylene (PE). Bourmaud, 2011, conducted a study with the aim of environmentally exploring the changes of the main characteristics of a recycled PP/hemp composite produced using PP coming from various industrial wastes after multiple injection mouldings. The assessment highlighted an overall reduction of the estimated impacts for acidification and for nonrenewable energy consumption mainly. This emphasises the environmental feasibility of using a recycled matrix to bond hemp fibres in order to produce polymer/vegetal fibre compounds. The addition of hemp fibre to composites made of High Density PE (HDPE) was tested by Lu and Oza, 2013. They investigated the effect of silane and sodium hydroxide (NaOH) treatment of hemp fibres on the thermal and thermo-mechanical properties of composites produced by adding hemp fibres to the HDPE matrix. (Ingrao et al., 2015)

A different polymeric paste was considered by La Rosa ,2013. They tested both environmental and economic cost of a hybrid composite produced by hand lay-up of glass woven fabrics and natural fibre mats with an epoxy vinyl ester resin. They concluded that the use of hemp mats in glass-fibre reinforced thermosets allows for increased environmental sustainability and increased economic convenience compared to conventional glass-fibre alternatives. (Ingrao et al., 2015)

5.2.3 Concretes

Hemp hurds can be utilised to produce concrete, known as “hemp concrete or hempcrete”, a bio-aggregate based material in which hemp hurds are pasted together with lime-based binders. It should be observed whilst concrete made of hemp hurds is used for its thermal insulating properties and not for bearing loads, the possible exploitation of hemp-fibre tensile strength has been recently investigated with the aim of producing Fibre Reinforced Concrete. Hemp concrete is generally suitable to form building envelopes by casting between, or spraying against, temporary or permanent shuttering in situ, or by pre-fabrication of building blocks or panels. It is being increasingly recommended by eco-builders because of its low environmental impact associated with the use of a renewable raw material (hemp). Being vegetal, it enables, in turn, carbon sequestration during plant growth. It is characterised by very good thermo-acoustic properties and, also, by good levels of transpirability and hygroscopicity that make it a good regulator of the indoor moisture content contributing, so, to better indoor air quality. (Arrigoni, Melia, Pelosato, Ruggieri, Sabbadini, Dotelli, 2017)

Hempcrete block is an innovative building product incorporating a large fraction of biomass, with a good performance in thermal and hygrometric regulation. The base of the binder can be hydrated lime, natural hydraulic lime or a mixture of the two. In some cases, a small fraction of cement and/or pozzolanic binder is added to speed up the hardening process and improve the mechanical resistance. Hydrated lime is made from pure limestone and sets through the absorption of CO_2 during the carbonation process. Hydraulic lime is made from limestone with clay impurities (silicates and aluminates) and sets through reaction with water. These processes transform the mixtures into final products that are solid but light, durable and with good insulation performances. Hemp, as any crop, is considered a carbon negative material, because during its growth it absorbs CO_2 from the atmosphere. In addition, the CO_2 captured from the air via carbonation will be stored into the hempcrete block throughout its lifetime and may further improve its environmental profile. (Arrigoni et al., 2017)

When used in constructions, hempcrete mixtures can easily absorb or release water vapour from the air and have a good vapour permeability. These features allow a better control of thermohygrometric conditions in the indoor environment, decrease the risk of vapour condensation and increase thermal comfort. Thanks to the action of lime, hemp shives slowly mineralize, becoming inert and reducing the risks of rot and mould formation (Evrard, 2005).

The performances and properties of hempcrete materials depend on the binder, on the quality and length of the hemp shives and on their proportions in the mixtures. Different mixtures produce building materials with different functions. In frame structures, hempcrete mixtures can be used as filling materials in infill walls. If density is increased, the hempcrete mixture allows the production of roof or floor insulation materials; on the other hand, if density is reduced, insulating indoor and outdoor plasters can be produced. The same mixture of hemp and lime can be used to produce prefabricated panels. (Arrigoni, Melia, Petosato, Ruggieri, 2017)

Hempcrete block is an interesting product that can be very easily installed, generally requiring mortar to be applied between the blocks. Hempcrete block walls can be left without any covering or can be covered with finishing plasters, using the same mixture in different proportions. Blocks can be manufactured on the construction site or through an industrial process. Industrial blocks usually have more regular dimensions and a higher quality thanks to an automated manufacturing process and to the employment of more complex mixtures. It is normally assumed by architects and designers that industrial blocks have also better thermo-acoustic performances, but it is difficult to find references on this issue since the performances of blocks constructed on site are difficult to measure. (Arrigoni et al., 2017)

In the study by Arrigoni et al., 2017 conducted on LCA of natural building materials with a focus on hempcrete blocks the environmental performances of non-load bearing wall made of hempcrete were assessed. The study encompassed the whole life cycle but the end of life, due to a lack of reliable data for the stage. During the study the production phase of the raw materials was identified as the main source of environmental impacts, but the transport of raw material and mixture of the product can affect the results considerably.

LCA analysis of hempcrete blocks produced by Arrigoni et al., 2017, encompassed all production stages except the end-of-life, presenting information to the current state-of-the-art on the employment of hempcrete as a strategy to mitigate environmental impacts. In particular, light was cast on a relevant point regarding the emission balance of lime- and cement based binders undergoing carbonation, i.e. the conversion of calcium hydroxide ($Ca(OH)_2$) present in the binder into calcium carbonate (CaCO3) through the reaction with the carbon dioxide (CO_2) present in the air (Ashraf, 2016). Carbonation increases the mechanical resistance of the bio-composite material and, by absorbing CO_2 during the process, may be relevant for the environmental balance of this product (Grist , 2015).

In the present study, carbonation of hempcrete was experimentally assessed via X-ray Powder Diffraction. XRPD outcomes were thus integrated in the environmental profile analysis of the material, assessed via LCA. In this way, the possible benefits in terms of GHG emissions balance could be highlighted. Two binders were investigated, both employed in current manufacturing practices: the first one was a mixture of dolomite lime and cement; the second was made of dolomite lime only. (Arrigoni et al, 2017)

The impact assessment was carried out using the environmental impact categories recommended by the European standard (CEN, 2012): abiotic depletion (ADP), fossil fuels depletion (ADP fossil), global warming over a time interval of 100 y (GWP), ozone depletion (ODP), acidification (AP), eutrophication (EP), photochemical ozone creation (POCP). Characterisation factors are those proposed by the Institute of Environmental Studies of the University of Leiden for the method CML-IA Baseline (version 3.04) (Leiden University, 2016). Additionally, environmental impacts were assessed in terms of Cumulative Energy Demand (CED, version 1.09) (Frischknecht et al., 2015) and with the Greenhouse Gas Protocol method (GGP, version 1.02) (World Resources Institute, 2012). (Arrigoni et al., 2017). Figure 10 shows the results of environmental impact per 1m2 hempcrete wall on the categories recommended by the European standard (CEN, 2012).

Several alternative cases were generated by varying one or more basic assumptions regarding the binder mixture, the transport distances, the binder-to hemp mass ratio of the blocks and the allocation factors.

Appendix 3). Figure 7 below shows the life cycle impact of 1m2 of hempcrete wall. Figure 8 shows the cumulative energy demand of 1m2 of hempcrete wall.

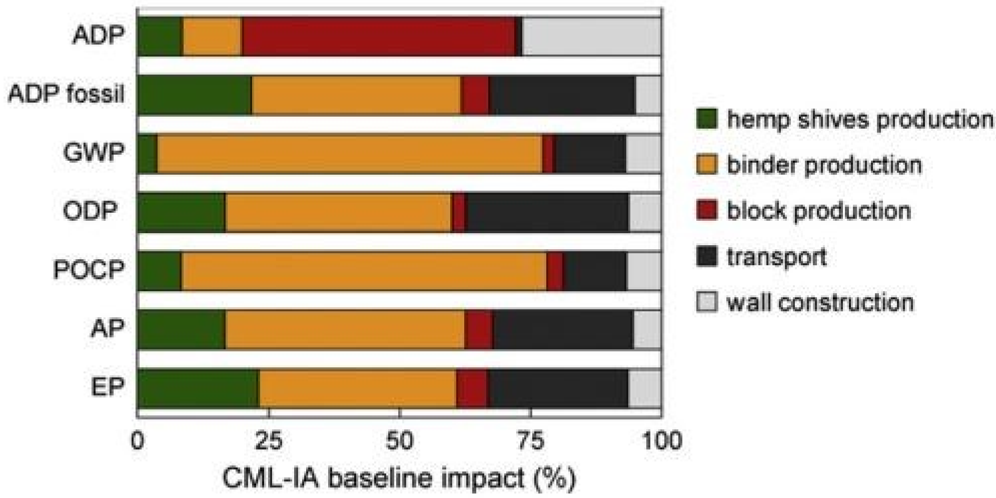

Figure 7 Life cycle impact assessment of 1 m2 of hempcrete wall. Percentage contribution of the different unit processes to CML-IA baseline impact categories. (Arrigoni et al., 2017).

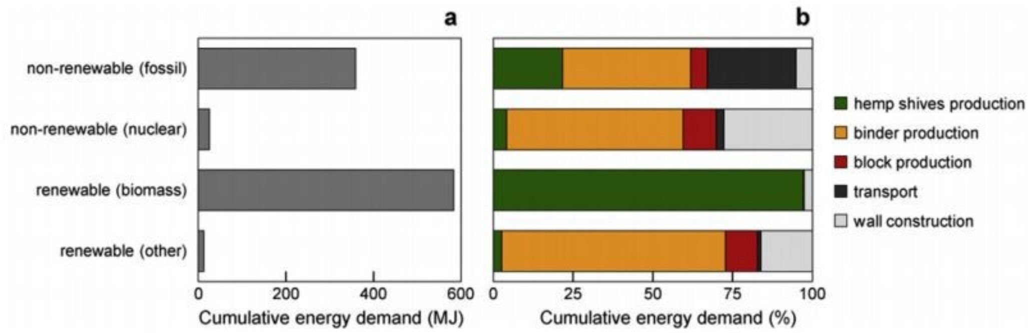

Figure 8 Cumulative energy demand of 1 m2 of wall made of hempcrete blocks. (a) Breakdown by energy component. (b) Percent contribution of each unit process. (Arrigoni et al., 2017).

The budget of greenhouse gas emission associated with functional unit of Greenhouse Gas Protocol is reported in the Figure 9. Non-biogenic (fossil emission and CO2 uptake represented the two major terms of the budged. The main source of fossil emissions was the calcination of lime. In contrast, CO2 uptake was the result of photosynthetic and carbonation processes.

Impact category	Unit	1. Hemp shives production	2. Binder production	4. Block production	3+5. Transport	6. Wall construction	7. Use phase	1-7. Total
Fossil	kg CO_2 eq	1.75	35.40	1.02	6.52	3.32	–	48.02
Biogenic	kg CO_2 eq	0.01	0.18	0.03	0.01	0.10	–	0.34
Land use	kg CO_2 eq	0.00	0.00	0.00	0.00	0.00	–	0.00
Uptake	kg CO_2 eq	58.0	0.04	0.04	0.01	1.51	0.53 (14.45)	59.60

Figure 9 Greenhouse gas emissions and CO2 uptake of 1 m2 of wall made of hempcrete blocks calculated using the Greenhouse Gas Protocol. (Arrigoni et al., 2017).

Impact category	Unit	A	B	C	D1	D2	E	F	G	H
ADP	mg Sb eq	1.75	1.61	15,101.48	1.75	36,321.24	1.74	1.78	1.73	1.73
ADP fossil	MJ	358.73	359.44	348.08	401.90	389.78	332.52	396.19	337.03	343.82
GWP	kg CO_2 eq	48.04	47.88	45.88	50.87	49.08	46.33	58.41	42.03	47.70
CO_2 uptake	kg CO_2 eq	74.04	73.29	80.08	74.04	82.36	74.03	68.61	77.19	74.04
ODP	mg CFC-11 eq	3.93	4.09	3.97	4.46	4.70	3.61	4.42	3.65	3.80
POCP	g C_2H_4 eq	6.84	7.48	6.63	7.20	7.53	6.62	8.18	6.06	6.73
AP	g SO_2 eq	81.33	74.28	79.82	90.79	143.02	75.35	91.80	75.26	78.74
EP	g PO_4^{3-} eq	15.82	13.12	14.43	17.66	13.94	14.65	17.36	14.94	15.13

Figure 10 Results per 1m2 of hempcrete wall relative to the seven impact categories recommended by EN 15804; for completeness, CO2 uptake, including both biogenic uptake and the amount from full binder carbonation, is listed separately. (Arrigoni et al., 2017).

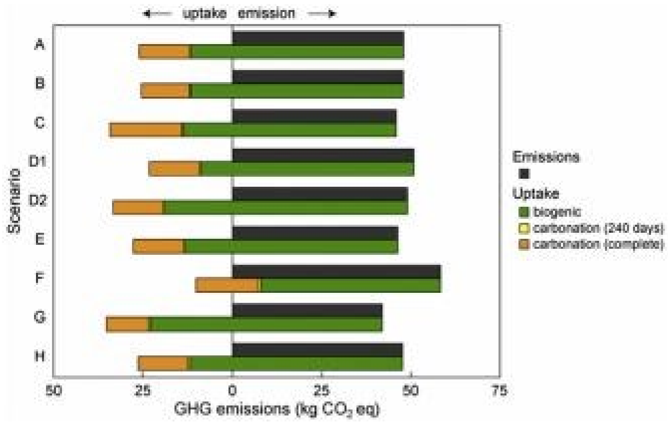

Figure 11 Greenhouse gas emissions and CO2 uptake of 1 m2 of wall made of hempcrete blocks under different scenarios mentioned in Figure 10 (Arrigoni et al., 2017).

In both samples, the amount of carbonates in the blocks increased with the sample age. The carbonation rate strongly depended on the sampling depth: in the sample composed only of dolomite lime the amount of carbonates increased rapidly in the outermost layer (0e2 cm) from about 15% (by mass) of the binder at 30 d to about 50% after 240 d, mainly at the expense of Ca(OH)2 that showed an opposite trend. In the second layer (2e4 cm), the amount of carbonates increased significantly only after 150 d of ageing, while in the innermost layers the carbonation was very limited: an increase in carbonates could be detected at a depth of 4e6 cm only after 8 months, while it was still negligible below 6 cm depth at any age. The base case sample, containing both dolomite lime and cement, showed a similar behaviour both in time and in depth, except that the amount of carbonates was higher in absolute terms due to the higher initial content of carbonates in the binder. Overall, assuming 1 face exposed to air, the amount of CO2 captured after 240 d was estimated to be 7 g per kg of binder for the sample containing just dolomite lime and 12 g per kg of binder for the block containing also cement. (Arrigoni et al.,2017).

5.3 Plastic Industry

In recent years there has been increased research on combining of natural materials into plastics, motivated highly by the need to protect the environment and reduce the use of non-renewable resources. However, the creation of composite materials containing natural fibres can only be achieved industrially by creating a complete, structured production from the farmer to the plastics manufacturer with the necessities on control of production of the raw materials and its processing.

In the view of these difficulties, hemp producers created, in 2001, the company AFT Plasturgie, with the specific objective of creating and developing a procedure that would allow an economically viable production of modified polymer containing natural fibre. (Moungin,2013)

As plant-derived fibres are the most common natural fibres used to reinforce plastics fibres such as wood, hemp and flax which are easily produced in Europe are consequently the three most used fibres.

The main constituent of plant fibres is cellulose, a polymer with entire blocks in crystalline form. The different constituents are not distributed homogeneously within the complex microstructure of the fibre. The elementary fibres of hemp and cellulose have a length varying between approximately 5 and 60mm. They have a density of 1.4 g/cc. (Moungin,2013)

Hemp provides fibres comparable to those of other technical fibres with several preferences over other plants:

- Hemp prices are stable and not effected currently by susceptible changes in fashion

- Hemp plant is not destroyed by parasites or disease and more than often does not require any chemical treatment

- Hemp grows under a large variety of conditions and needs a low amount of nitrogen fertilizers

- Hemp cultivation and transformation is well practiced in the EU and hemp can be used to produce several co-products

Figure 12 below shows various applications of hemp in plastic production.

Figure 12 Various application on hemp in production of plastics in car, packaging, construction and technical products. (Moungin, 2013)

The use of hemp as a reinforcing material in plastics does, however, require the close control of the production and treatment of the plant.

The amount of reinforcement that can be achieved using hemp exceeds 70% by weight, but for the transformation of compounds to proceed without problems the amount of hemp must be less than 40%.

Reinforcement of polymers such as PVC with 30% natural fibres produces final products with significant improvements such as:

- Thermal performance improvement where a piece of PP exposed to 150C for 400h shows virtually no deformation
- Water absorption which is a well-known future of natural fibres in this case absorbing approximately 7% when submerged. The cycle can be reproduced without affecting the compound
- Ability to store bacterial liquid in pallets made from high density PE reinforced with 20% hemp and the release it over a period of 8 months, thus killing any bacteria coming into contact with the product
- Hemp fibres are not oriented with the flow ,therefore they produce moulded plastic that possesses isotropic mechanical properties
- Hemp properties as a sound and thermal insulator can be used to improve these characteristics in the plastic to which it is added
- 15-20% weight improvement compared to glass fibre (Moungin, 2013)

The act of reinforcing polymers such as PVC with 30% natural fibres produces final products with a fossil fuel consumption that is only 70%. (Moungin,2013)

The environmental and ecological impact, therefore, is significant, especially considering the properties listed above, including the ability of hemp as a carbon sink. Hemp has the ability to store 0.79 kg of CO_2/kg and can release 10 MJ/ kg of energy when incinerated at the end of its life. Table 8 and 9 below show production of industrial hemp compared to glass fibre and polymer.

Table 8 Production of 1 kg of fibres. (Moungin,2013)

	Hemp	Glass fibre
Energy consumption	3.4 MJ	48.3 MJ
CO_2 emissions	0.64 kg	20.4 kg
SO_2 emissions	1.2 g	8.8 g
NO_2 emissions	0.95 g	2.9 g
Biochemical oxygen demand	0.265 mg	1.75 mg
Chemical oxygen demand	3.23 g	0.02 g

Table 9 Substitution of 1 kg of natural fibre to 1 kg of polymer

	Hemp	Polypropylene
Energy comsumption	3.4 MJ	101.1 MJ
CO_2 emissions	0.64 kg	3.11 kg
SO_2 emissions	1.2 g	22.2 g
NO_2 emissions	0.95 g	2.9 g
Biochemical oxygen demand	0.265 mg	38.37 mg
Chemical oxygen demand	3.23 g	1.14 g

Essential contributions of hemp reinforced polymers to the environment can be summarized with a low cost, significant reduction in duration of production cycle, energy saving, completely recyclable, non-toxic, reduced use of fossil duel use, active plastic and, no residues left following incineration at the end of the product's life.

5.4 **Paper Industry**

Hemp has long been known as a potential substitute resource for paper resourced from tree and according to studies substitution for hemp results in longer lasting paper produced with lower environmental impacts.

The most common papers that can generally be produced by especially long fibre such as hemp fibre are cigarette paper, filter paper, coffee filter, tea bags, speciality non-woven, insulating paper, greaseproof papers, security paper and various speciality art papers. The use of hemp is concentrated mainly on bast fibres, while the woody core of the plant is generally considered as waste, apart from in cigarette paper production, where all the fibre in the hemp stem is used. Table 10 below shows comparison of hemp and tree pulp in paper making process.

Table 10 Hemp and Tree Pulp Paper Making Processes (The Sustainability of Tree Paper vs. Hemp Paper, 1998)

Source: Trees from naturally standing forests or tree plantations. Methods used for logging include: primarily clear cutting and also selective cutting, shelterwood cutting, and patch cutting.	Source: Hemp seed is sown in a well drained, sandy loam soil with a pH above 6.0. A pH of 7.0 to 7.5 is preferred. Hemp is harvested 60 to 90 days from the seed date. The plant grows approximately 10 tons per acre in approximately 4 months.
Cleaning: All non-fibrous components need to be removed and remaining fibers must be cleaned of dirt, rocks, and other contaminants.	Harvesting: Hemp is harvested using sickle-bar mowers and hay swathers that cut the hemp stock and prepare it for retting.
Fiberizing: The elementary fibers are taken apart by either chemically removing the glue that holds them together, or by mechanically tearing the fiber structure apart. This results in material known as pulp.	Retting: Is the process of beginning to separate the bast fibers from the hurds or other plant tissues (http://www.gov.on.ca/omafra/english/crops/fax/hemppr od.htm) **pg7***. Dew retting occurs in the field where the stalks are spread on the ground so that dew, rain, sun and bacteria dissolve and wash away the chlorophyll and most of the gums , leaving only the fibrous bark and wood remaining. Retting may also be controlled unnaturally by using water and/or chemicals. This process occurs over a 12 to 18 days and the swaths need to be turned once or twice during this periods to ensure even retting.
Cutting: Fibers must be cut to the right size to give a homogeneous paper sheet.	Binding: Hemp is bound into bundles when the woody core breaks away easily and is then baled for the paper mills.
Classification: Fibers suitable for use are separated from ones that are too short, too long, too dirty etc.	Cooking: Hurds are cooked to reduce the fibrous raw material to a residue of cellulose pulp by means of a chemical and heat process. Water is added (5 to 10 times the fiber weight) along with chemicals to remove the lignin and pectin from the fibers. The fibers are cooked until they are separated form each other.
Bleaching: The suitable fibers may be bleached to higher "whiteness"	Beating: Fibers are cut to a proper length and given the required surface roughness for better bonding capacity.
Refining: Fiber surfaces are "roughened". The greater the surface roughness of a fiber, the better it adheres to other fibers in the paper sheet. Thus, increasing the strength of the paper sheet.	Bleaching: Bleaching is added during the beating process or transferred to separate tanks. Bleaching often involves chlorine compounds but can also use oxygen and hydrogen peroxide, which generate wastewater that can be recycled back into the process.
Dilution: Fibers are laid out evenly into a homogenous sheet. Pulp is then diluted with large amounts of water.	Pressing: Once bleached, the pulp is ready to be pressed by the paper machine.
Formation: The fiber-water slurry is poured on a fine mesh wire. Water will fall through the wire, leaving the fibers to settle into a flat sheet.	
Drying; The wet sheet is dried by subsequent pressing and steam heating processes.	

In the comparison between hemp paper and tree paper, the benefits of hemp use in production are:

- 1 acre of Hemp can produce as much paper as 4-10 acres of trees over a 20-year cycle
- Hemp stalks grow in 4 months, whereas trees take 20-80 years
- Hemp has a higher concentration of cellulose than wood, the principal ingredient in paper
- Trees are made up of only 30% cellulose, requiring the use of toxic chemical to remove the other 70%. Hemp on the other hand is made up of 85% cellulose
- Hemp has 15 % lower lignin content than wood, a component that must be removed from the pulp before production of paper

- Hemp due to its long and strong fibres is more durable and can be recycled more times than wood paper (Johnston, 2016)

Apart from the differences in paper production and quality, an important reason of shift towards hemp-based paper instead of tree based is the importance of trees and forests to our environment. The destruction of forest for the production of paper has a great implication upon the atmosphere as large forests are major producers of oxygen and absorb carbon dioxide, playing the role of air filters. The excessive use of trees in paper production can lead in deforestation which has a devastating effect on the surrounding land and soil.

5.5 **Biofuel Industry**

Fossil fuels are a major issue contributing negatively to the environment and our reliance on them is a major problem.

Biofuel is a fuel produced through contemporary biological processes such as agricultural and anaerobic degustation, rather by geological processes. While biofuels have long been an attractive alternative, numerous problems with attempts such as ethanol and biodiesel have emerged. One problem is the need to avoid converting farms away from food production because of limited land resources; another is the failure of ethanol to deliver and its consequential problems associated with monocrop corn plantations and pollution. Industrial hemp has the potential to avoid these problems and serve as a feasible and critical part of our transition out of fossil fuel economy.

There are two basic ways to create hemp biofuel: hemp ethanol/methanol, and hemp biodiesel. Biodiesel is produced by pressing of hemp seeds to extract their oils and fats. Ethanol is traditionally made from wheat-based crops such as corn and barley, and then used as an additive on gasoline. Hemp can be made into ethanol by various forms of fermentation. Using hemp as the main source of ethanol, instead of food crops like wheat and corn has clear advantages. Table 11 below shows the comparison on biodiesel yield per acer between different crops and hemp.

Table 11 Biodiesel yield per acer from selected crops (Brown, 2006)

Crop	Fuel Yield (gallons/ha)
Oil Palm	508
Coconut	230
Rapeseed	102
Peanut	90
Sunflower	82
Soybean	56
Hemp	207

Table 5.5.1 Biodiesel yield per Acer from selected crops (Brown, 2006)

Hemp biofuels present a carbon neutral replacement to fossil fuels. During the three-month cycle of growth, the plant ingests carbon dioxide. Hemp seed has a clear advantage over palm seed oil as a source of biodiesel fuel, since the production of palm oil has a large impact on the destruction of rain forest and wildlife. In comparison with other crops hemp yield is much larger in the production of biodiesel fuels and hemp cultivation is the least impactful on the environment.

6 CONCLUSION AND FURTHER ADVANCMENTS

Hemp has been a part of the common individual's life a relatively long period of time. However, over a period of 50 years between its criminalization period and today there seems to be a lost connection between the individual and the potentially first mass produced agricultural plant. Often mistaken and regarded for its psychoactive and medical abilities, industrial hemp is demonized in countries that could strongly benefit from its cultivation.

Throughout the studies read and reviewed for the thesis topic it became evident that there is potentially no such plant as the single most valuable and all good plans. However, hemp does come close, as it impacts some of the main and the larges industries. Industries such as textile, construction, plastics, paper and fuels are known to highly impact the environment and are the main contributors of greenhouse gases. Hemp has been able to prove more than often that its use in such industries can benefit not only the environment, but also the industry itself with the creation of superior products compared to the already existing ones. However, it is clear that there exists a need for further exploration of use of hemp in such industries and especially in the construction industry for its natural fibres. More importantly than the use in industries, hemp cultivation and production can be seen to benefit the environment.

Currently there is a need of advancing of technologies used in the production of hemp and use of it in industry. Most of the technologies used in processing of hemp are still outdated and since its resurgence there has been little to no improvement, as there seems to be a lack of interest by big time industries to invest in an ecological future. The governments have not been of much help either as they have been lacking in pushing for more sustainable solution to our use of non-renewable resources and have been inactive in education of common population in benefits of industrial hemp and its distinction from cannabis.

Another rather important issue is the fact that post criminalization of hemp that was strongly led by the USA, many of the second and third world countries have resisted the reintroduction of hemp in their agriculture, while on the other hand the USA has been pushing for legalization of cannabis for industrial and recreational use throughout its all states. With the current unstable climate and season of farming, the third world countries seem to be in need for a stable and a capable plant to grow under more differentiating conditions; this is where hemp comes in. Such countries are in need of projects and organizations that would help introduce hemp within its populations and development of new industries.

The need for education regarding hemp and its potential is viable and should be take upon by all environmental enthusiasts. Hemp might not solve all the problems of the future; however, it does present a large number of solutions for such problems. The steps to a more ecological future are formed by many steps and the global legalization and use of hemp.

REFERENCES

Arrigoni A., Melia P., Pelosato R., Ruggieri G., Sabbadini S., Dotelli G., (2017). Life cycle assessment of natural building materials: the role of carbonation, mixture components and transport in the environmental impact of hempcrete blocks. Retrieved 15 October, 2018 from https://www.researchgate.net/publication/313961941_Life_cycle_assessment_of_natural_building_materials_the_role_of_carbonation_mixture_components_and_transport_in_the_environmental_impacts_of_hempcrete_block

Andy Kerr (1998). The Environmental Benefits of Using Hemp. Retrieved September 25, 2018 from http://www.andykerr.net/hemp-environmental-benefits/

Amberznectarz (2016). Hemp production around the World. Retrieved October 10, 2018 from https://hempedification.wordpress.com/2016/08/27/hemp-production-around-the-world/

Averink J. (2015). Global Water Footprint of Industrial Hemp Textile. Retrieved October 10, 2018 from https://essay.utwente.nl/68219/1/Averink,%20J.%200198501%20openbaar.pdf

Bouloc P., Allegret S., & Arnaud L. (2013). Hemp: Industrial Production and Uses.

Carus M. (2017). The European Hemp Industry. Retrieved September 10, 2018 from http://eiha.org/media/2017/12/17-03_European_Hemp_Industry.pdf

Challa L. (n.d.) Impact of Textiles and Clothing Industry on Environment. Retrieved October 25, 2018 from https://www.fibre2fashion.com/industry-article/1709/impact-of-textiles-and-clothing-industry-on-environment?page=17

Design Life-Cycle (n.d.). Hemp Textiles. Retrieved October 17, 2018 from http://www.designlife-cycle.com/hemp-textiles/

Founders Hemp (n.d.). History of Hemp. Retrieved October 15, 2018 from https://foundershemp.com/history-of-hemp/

Goldstein Y. (n.d.). Characteristics of hemp. Retrieved 10 September, 2018 from https://oecotextiles.wordpress.com/2010/06/02/characteristics-of-hemp/

Hemp (n.d.). History of Hemp. Retrieved September 30, 2018 from http://www.hemp.com/history-of-hemp/

Hemp University (n.d.). Countries growing hemp. Retrieved September 10, 2018 from http://www.hempuniversity.com/hemp-university/growing-hemp/countries-growing-hemp/

Herer J. (1985). The Emperor Wears No Clothes.

Hoekstra A. (2013). The water footprint of modern consumer society.

Ingrao C. et al. (2015). Energy and environmental assessment of industrial hemp for building applications: A review. Retrieved 10 October, 2018 from https://www.researchgate.net/publication/278683961_Energy_and_environmental_assessment_of_industrial_hemp_for_building_applications_A_review

Innovation in Textile (n.d.). Reintroduction of industrial hemp is in full swing. Retrieved October 10, 2018 from https://www.innovationintextiles.com/reintroduction-of-industrial-hemp-is-in-full-swing/

Johnston S. (2016). The Environmental Benefits of Industrial Hemp.

Jordan J. (2014). Hemp vs. Trees. Retrieved 25 September, 2018 from https://gdblogs.shu.ac.uk/b1028760/2014/04/27/hemp-vs-trees/

Luginbuhl A. (2001). Industrial Hemp (Cannabis sativa L): The Geography of a Controversial Plant. Retrieved September 22, 2018 from http://scholarworks.csun.edu/bitstream/handle/10211.2/2738/CAgeographer2001_p1-14.pdf?sequence=1

Made-By (2013). Environmental Benchmark for Fibres. Retrieved September 15, 2018 from http://www.made-by.org/wp-content/uploads/2014/03/Benchmark_environmental_condensed_240118.pdf

Martino J. (2013). Hemp Vs. Cotton: The Ultimate Showdown. Retrieved October 5, 2018 from https://www.collective-evolution.com/2013/07/17/hemp-vs-cotton-the-ultimate-showdown/

Mougin G. (2013). Hemp and Plastics.

McDonald D. (2016). Hemp Vs. Deforestation: An argument that promotes future hemp farming. Retrieved September 5, 2018 from https://improvesocietytoday.wordpress.com/2016/08/09/hemp-vs-deforestation-an-argument-that-promotes-future-hemp-farming/

Ministry of Hemp (n.d.). Hemp Paper. Retrieved 30 October, 2018 from https://ministryofhemp.com/made-from-hemp/paper/

Ministry of Hemp (n.d.). Where is Hemp grown?. Retrieved September 30, 2018 from https://ministryofhemp.com/hemp/countries/

Nunti-Sunya (n.d.). 10,000 Years of Hemp. Retrieved September 25, 2018 from http://www.nuntisunya.com/en/history-of-hemp/

Nunti-Sunya (n.d.). How does using hemp benefit our environment? Retrieved September 30, 2018 from http://www.nuntisunya.com/en/hemp-environmental-sustainable-benefits/

O Ecotextiles (n.d.). Hemp vs. Linen. Retrieved October 25, 2018 from https://oecotextiles.wordpress.com/2016/08/31/hemp-vs-linen/

Pickering E. (2018). Hemp Biofuel could ease our dependence on fossil fuels. Retrieved October 30, 2018 from https://ministryofhemp.com/blog/hemp-biofuel/

Randall T. & Chair T. (2014). Industrial Hemp: Opportunities and Challenges for Washington. Retrieved September 30, 2018 from http://ses.wsu.edu/wp-content/uploads/2015/02/WP2014-10.pdf

Simplifi Fabric (n.d.). What is Hemp Fabric?. Retrieved October 27, 2018 from https://www.simplififabric.com/pages/hemp

Small E. & Marcus D. (2002). Hemp: A new crop with new uses in North America. Retrieved September 30, 2018 from https://www.hort.purdue.edu/newcrop/ncnu02/v5-284.html

Turunen & Van der Werf (2006). The production Chain of Hemp and Flax Textile Yarn and Its Environmental Impacts. Retrieved 10 October, 2018 from https://www.researchgate.net/publication/241746015_The_Production_Chain_of_Hemp_and_Flax_Textile_Yarn_and_Its_Environmental_Impacts

Van Bakel, Stout J., Cote A., Tallon C., Sharpe A., Hugher T., & Page J. (2011). The draft genom and transcriptome of Cannabis sativa

Van Eynde H. (2015). Comparative Life Cycle Assessment of hemp and cotton fibres used in Chinese textile manufacturing. Retrieved October 24, 2018 from https://www.scriptiebank.be/sites/default/files/VanEyndeHannes_KUL_Eindwerk.pdf

Vincent-Welling K. (2013). LCA Analysis: Hemp versus Cotton. Retrieved October 27, 2018 from https://users.humboldt.edu/kvincent-welling/

APPENDIX

Environmental Benchmark for Fibres by MADE-BY (2013) Appendix 1

www.made-by.org

MADE-BY ENVIRONMENTAL BENCHMARK FOR FIBRES

CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	UNCLASSIFIED
Mechanically Recycled Nylon	Chemically Recycled Nylon	Conventional Flax (Linen)	Modal® (Lenzing Viscose Product)	Bamboo Viscose	Acetate
Mechanically Recycled Polyester	Chemically Recycled Polyester	Conventional Hemp	Poly-acrylic	Conventional Cotton	Alpaca Wool
Organic Flax (Linen)	CRAiLAR® Flax	PLA	Virgin Polyester	Generic Viscose	Cashmere Wool
Organic Hemp	In Conversion Cotton	Ramie		Rayon	Leather
Recycled Cotton	Monocel® (Bamboo Lyocell Product)			Spandex (Elastane)	Mohair Wool
Recycled Wool	Organic Cotton			Virgin Nylon	Natural Bamboo
	TENCEL® (Lenzing Lyocell Product)			Wool	Organic Wool
					Silk

More Sustainable → Less Sustainable

bwe This Benchmark was made in cooperation with Brown and Wilmanns Environmental, LLC. For further information on this Benchmark see www.made-by.org/benchmarks

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 (Turunen, van der Werf, 2006) Appendix 2

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

Parameters varied in the scenarios considered. (Arrigoni, Melia, Petosato, Ruggieri, 2017). Appendix 3

Scenario	Binder mixture components (% by mass)					Transport distances		Hempcrete blocks		Allocation method
	Dolomitic lime (%)	Hydrated lime (%)	Hydraulic lime (%)	Portland cement (%)	Pozzolan (%)	Hemp (km)	Binder (km)	Binder-to-hemp mass ratio (kg/kg)	Density (kg/m^3)	
A	80	–	–	20	–	245	320	1.3	330	Mass
B	100	–	–	–	–	245	320	1.3	330	Mass
C	–	75	15	–	10	245	320	1.3	330	Mass
D1	80	–	–	20	–	750	320	1.3	330	Mass
D2	80	–	–	20	–	750	320	1.3	330	Mass
E	80	–	–	20	–	245	40	1.3	330	Mass
F	80	–	–	20	–	245	320	2.0	360	Mass
G	80	–	–	20	–	245	320	1.0	312	Mass
H	80	–	–	20	–	245	320	1.3	330	Economic