MSc Program
Environmental Technology & International Affairs

A HOLISTIC APPROACH TO THE EUROPEAN BIOECONOMY AND ITS AGRICULTURAL BIOMASS SUPPLY - MULTIFUNCTIONAL HEMP AS ONE OF THE FUTURE PILLARS.

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 09.06.16

Affidavit

I, **BOB PIERRE LUCIEN LESSEL**, hereby declare

1. that I am the sole author of the present Master's Thesis, "A HOLISTIC APPROACH TO THE EUROPEAN BIOECONOMY AND ITS AGRICULTURAL BIOMASS SUPPLY - MULTIFUNCTIONAL HEMP AS ONE OF THE FUTURE PILLARS.", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

Agricultural biomass is one of the major pillars for the supply of increasingly needed renewable resources for the growing bioeconomy. However, minimal additional pressure should be put on the environment. The approach of this thesis to interlink political frameworks and their objectives with those of the bioeconomy and the traits of hemp cultivation, processing and the scope of substitution is a genuinely new one. This thesis provides further genuinely new evidence and findings in regard to the inclusion of a hemp utilization scenario in the context of a EU bioeconomy.

1. The Material Flow Analysis can help to better understand, quantify and illustrate the “Hempland” scenario. Hence, a new approach with an adequate illustration of the flows and processes is incorporated. These are part of a scenario where multifunctional hemp is grown for its specific purpose in an average EU region.

2. Water is the most important mass flow in the system. Followed, by the sequestration and release of CO2 and O2. Besides, flue gas, waste and debris are crucial in the “Hempland” scenario.

3. In a EU average region with 10 million people, where 10% of the cropland is cultivated with hemp, the first harvest can contribute to the production of 1.48 Mt/year of biocomposites. Additionally 0.16 Mt/year of animal feed, 0.35Mt/year of insulation material and 1.38 Mt/year of hempcrete would result from this region.

4. The hemp crop is able to provide the bioeconomy with crucial amounts of sustainably produced biomass in order to cover quantities of demand of various productlines in the bioeconomy, without foiling the environmental objectives of the EWFD and the CAP.

Against this background, the thesis has reveiled that the demand for composites and insulation material can be satisfied by far. About one third of the EU demand for soybean meal feed imports can be substituted. Also in regard to the respective EU concrete demand, more precisely the demand for non-load bearing concrete which was assumed to contribute 25% to the total demand for concrete, more than the half can in the long run be substituted by hempcrete.

Acknowledgements

I want to especially thank my supervisor, Prof. Dr. Paul H. Brunner, who allowed me to gain deeper understanding and knowledge of this interesting and fascinating topic. Namely, his helpful advices and suggestions have brought me on the right track to combine my interests and motivations with scientific excellence.

Furthermore, a very warm and sincere thank-you goes to my parents who tread a very exceptional and challenging path with me. Without their manifold support, affinities, convictions, education, love, values and declared intentions that they have shared with me, I would not be in the same mental and physical condition that I am in today. Thank you.

Of course, I also want to take the opportunity to acknowledge all the wonderful friends I have come across in my life and with whom I can enjoy life at its best. In this context, special acknowledgments go to those people who really helped to build up one of the most outstanding, multicultural, equitable, multilingual places in the world to grow up in, the European Union and more specifically, Luxembourg. It offered to many people and myself, great opportunities and foundations in order to face the goals and challenges in life and in a globalized world.

This paper is also written by a strong belief and based on the acknowledgment that one day, the suffering of human beings and its diverse and complex reasons will be minimized to a truthfully full extent. Hopefully, this century will know a period of peace and increased awareness where we minimize the use of harmful actions and goods which lead to any form of harm and suffering for our next and beloved ones. This thesis acknowledges experiences that others and myself have come through and which, instead of ignorance, deserve study and attention. This paper aims to acknowledge also the people contributing to a healthy environment and hence, a foundation for all of us. To all the seriously ill children I have met during the first years of my life in the children hospital of Luxembourg. All of these experiences and many others have decisively contributed to the selection of the topic for this thesis.

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List of Abbreviations/Acronyms

AEHO	Acrylated Epoxidized Hemp Oil
CAP	Common Agricultural Policy
CBD	Cannabidiol
EFSA	European Food Safety Agency
EHSO	Epoxidized Hemp Seed Oil
EIHA	European Industrial Hemp Association
EWFD	EU Water Framework Directive
MFA	Material Flow Analysis
PLA	PolyLactic Acid
WTE	Waste-To-Energy

1. Introduction

1.1 The Problem

We witness a loss of arable land, while the demand for food and non-food destined biomass increases. 9 Billion people will probably live on earth by 2050. At the same time, there is a strong political, economical and environmental will to shift from a fossil fuel based economy to a so-called bio-based economy. There are increasingly, very promising achievements and potentials, not only in terms of the established Bioeconomy, but also in regard to new bio-based products. However, the European Bioeconomy and its endeavour to sustainably move towards an allocation of renewable biological resource for European economies and its commitment to substitute fossil-based products, faces one major fundamental challenge. Provide the necessary biomass from limited land, efficiently, without further deteriorating the environment. This challenge must be closely seen in relation to the customers trust into sustainable bio-based products, like i.e. bio plastics, which is a crucial foundation for a well-functioning bio-based economy. In the introductory paper of the European Commission in regard to a "European Strategy and Action Plan towards a sustainable bio-based economy by 2020", is stated: "the main objective of this initiative is to address the technological and societal challenges in building the bio-economy in the next 10 years taking into account longer term time horizons, with increased emphasis on sustainable use of natural resources, competitiveness, socio-economic and environmental issues.“ (European Commission. 2011)

Various other EU directives, i.e. the European Water Framework Directive, and their implementation are dependent on an environmentally friendly Bioeconomy. However, negative effects on the level of organic matter in soil and soil biodiversity are to be expected. Linked to this, additional negative impacts on soil fertility and soil productivity may occur due to an increased use of forest and agricultural waste streams for bio-based materials. Moreover, a desired increase in crop productivity usually involves a increased use of fertilisers and pesticides, which additionally lead to water and soil pollution. The bio-based economy can aggravate water scarcity in many areas of the world, because it puts additional pressure on water demand. Thus, the already mentioned increase in demand for land for food and non-food crops is prone to cause more monocultures, linked to other undesirable environmental effects and pressure on natural habitats and biodiversity. (Cf. Scarlat et al. 2015) A sustainable Bioeconomy must therefore consider the amount of land required for biomass production, which strongly depends on the type of crop and the allocation of land use for co-products (e.g. for materials, feed, etc.).

It is at this point, where a highly discussed multifunctional crop, namely hemp could be of interest. Often referred to as "the" ecological and yet high yielding crop, which could provide economies with the highly needed renewable resources. In this context, it seems to be necessary to verify whether this only is a utopian idea or whether the properties and potentials of the still quite unknown hemp crop could realistically contribute to a sustainable bio-based economy in the EU. Although, many studies have been made on the possible single applications of hemp and their possible applications or ecological effects, none of them I have found, has incorporated a holistic and long-term approach where EU directives and their objectives are interrelated to the total input and output in the long run. Hence, also the extent of utilizable biomaterial, which could arise from a specific number of hectares over a period of for instance one hundred years and from a certain pilot scheme region, let us say "Hempland", would be constructive for this paper. As the Bioeconomy includes a wide variety of bio-based products and with respect to the scope of this paper, only a few possible applications, i.e bio-plastic, will in accordance with the in the next chapter described scenario, be subject to the endeavours of this paper.

1.2 Objective and Research Questions

It is the objective of this paper to find out about the long-term compatibility of environmental impact of an on hemp based Bioeconomy, with EU CAP and EWFD. This includes an elaboration of the potential long-term total input and output of a Biorefinery processing the crop constituents. And to which extent the output can satisfy the average demand of EU citizens.

1) The main research question is to what extent the inputs of cultivation are in the long run reflected in an efficient and environmentally friendly output per hectare and if they

contribute to the development of the European Bioeconomy without compromising the objectives of EU directives?

This will entail a comparative literature and research review of environmental criterions. Additionally, it will include a quantitative analysis of input data of substances with crucial importance for environmental impact. For instance fertilisers, water pressure and agrochemicals will be taken into account. Hence, I will additionally and where appropriate use the current results of the water footprint methodology according to Hoekstra. The results should be analysed in a material flow analysis to assess the long-run significance for a bio-based economy, which should not foil the objectives of the described EU directives.

2) What are the crucial inputs and outputs of a biorefinery where hemp is processed for the specified purposes of its constituents, namely biocomposites, animal feed and construction material?

The assessment from the first question will also be of relevance for the second research question, which will also be based on literature analysis and interviews with a farmer and as far as possible with researchers involved in research projects of relevance.

3) Do the total input and output of cultivation show the suitability to efficiently supply in the long run, half of the substituted demand, for the specified product lines, of average EU citizens?

For the third question I will compare literature and investigate on a quantitative basis on the average demand of EU citizens in regard to the specific product line and to conclude out of literature and the analysis of the MFA if the output of hemp cultivation can sustainably substitute half of the demand. Thus the focus should be limited on an elaboration of one utilization scenario of the hemp crop. The results are to be brought together with the demands of the EU citizens of "Hempland", in order to guarantee a comprehensible and constructive analysis of the inputs and outputs and hence of the significance for a bio-based economy located in "Hempland".

To summarize, the methods should allow a precise analysis of the objective whether hemp, in regard to the more elaborately explored purposes, is a suitable crop for the major problem of the bioeconomy and bring clarification. Thus this thesis and the application of methods aim at delivering data and assessments relevant to assess strategies currently in place to reduce the pressures on environment resulting from the agricultural biomass supply for the Bioeconomy.

The main hypothesis is that hemp constitutes a viable plant crop in the context of the environmental challenges for the further development of an agricultural European Bioeconomy without foiling the Water Framework Directive and the EU Directive of Common Agriculture Policy. For this I will do a comparative literature analysis and as this undertaking is related to the regional level, I will use as a system for the MFA of this paper a fictional region called "Hempland".

2. Overview of EU Bioeconomy

Most actors generally support the definition of the bio-based economy provided in the Commission's background paper. It encompasses the position papers received from organisation that are directly or indirectly linked to the bio-based economy:

"[...] More precisely, a bio-based economy integrates the full range of natural and renewable biological resources — land and sea resources, biodiversity and biological materials (plant, animal and microbial), through to the processing and the consumption of these bio-resources. The bio-economy encompasses the agriculture, forestry, fisheries, food and biotechnology sectors, as well as a wide range of industrial sectors ([6]), ranging from the production of energy and chemicals to building and transport. It comprises a broad range of generic and specific technological solutions (already available or still to be developed) which could be applied across these sectors to enable growth and sustainable development, for example in terms of food security and requirements for industrial material for future generations" (European Commission. 2011)

Within the scope of this paper, the range of natural and renewable biological resources will be limited to land resources and biological materials. Thus the undertaking of this paper is excluding raw materials for the bioeconomy, which are sourced from the forestry or fisheries sectors. Another alternative, more flexible definition in view of possible future developments for the Bioeconomy has been recommended by several organisations. Therein has been concluded that a public goods-oriented bio-based economy should be based on: "production paradigms that rely on biological processes and, as with natural ecosystems, use natural inputs, expend minimum amounts of energy and do not produce waste as all materials discarded by one process are inputs for another process and are reused in the ecosystem (…)" (ibid.)

The potential risks, which have been mentioned in this executive summary and be highlighted, are the risks, that "could arise at the level of food, agriculture and the environment, particularly if policies are developed and implemented in a disintegrated way. Risks include competition between food supply and biomass production, (…) over-exploitation of natural resources and loss of biodiversity, and loss in consumer trust." (ibid.) It is emphasized how important additional integration between policies is in order to avoid contradictions in policy goals and to guarantee a level playing field for all actors. A new agricultural raw material policy and the creation of an enabling policy setting are claimed in this request. More specifically to exert the needs of the bio-based economy with regard to future updates of major EU policies. (Cf. ibid.) With respect to this, this thesis will within its realms of possibilities try to contribute incentives to a mitigation of these potential risks for the EU Bioeconomy. Particularly by addressing objectives of EU directives in chapter 4.2 to 4.4, which would be affected by a further consideration of hemp as a viable biomass and by fully taking into account the adverse competition between food supply and biomass production. This competition is moreover characterised by its manifold environmental significance. Since it is clear that " (…) agriculture is expected to remain the largest water-consuming sector, natural resources such as water and fertile soil tend to be exposed to over-exploitation." (ibid)

Although the bio-based economy is still in its infancy, a exponential growth is expected as a consequence of the drive towards more sustainable production processes, the in the long term higher prices for fossil resources, and the necessity to reduce the emission of greenhouse gases. If properly developed, the carbon-negative bio-based economy has the potential to play a key role in mitigating climate change. But, this will require an entire innovation chain that covers the integration of both fundamental and applied research. (Cf. Vanholme et al. 2013) Also is the long-term goal set by the European Commission and its achievement to develop a competitive, resource efficient and low carbon economy by 2050 strongly depending on the Bioeconomy, which is expected to play an important role in the low carbon economy. (Cf. Scarlat et al. 2015) Beside the EUs many well-established traditional bio-based industries, which range from agriculture, food, feed, fibre and forest-based industries, there are additionally new sectors emerging, such as biomaterials and green chemistry. This is expeted to lead to an increased competition for natural resources, in particular for water and land resources with potential negative impact on the environment, land use patterns and biodiversity (Cf. Scarlat et al. 2015) As has been asserted during the literature research of this paper, the general opinion of stakeholders is that the transition toward a bioeconomy will of course also depend amongst others on the advancement in technology and achievements of a breakthrough in terms of technical performances and cost effectiveness. But, and this is to be set into the context of this thesis, it will most importantly depend on the availability of sustainable biomass.

When fostering the Bioeconomy, it seems moreover evident that major improvements in resource efficiency in the use of resources can be gained through a "cascading utilisation." (Ibid.) This is due to the fact, as has been argued by the Nova Institute, that "bio-based materials have a higher input-output efficiency than biofuels. Therefore material use (…) of renewable resources should come before energy use. " This simple but strong statement is part of the reason why the scenario of hemp biomass utilization in this thesis will prioritize bio-based materials and consider the energy use of the biomass as a last possible application. Biorefineries play in this context a major role as a production facility for a broad range of bio-based end products. Moreover, they create production systems, which drastically reduce the necessary input and resulting waste, as it is reused. (cf. ibid.) Additionally, the idea of solving the land-scarcity by integrating on the same land parcel food and non-food activities has to be considered. More about the significance of this aspect to this thesis can be found in some of the subsequent chapter and it will also be reflected in the MFA of "Hempland".

A strong EU Bioeconomy would furthermore substantially contribute to "change Europe from being a net oil importer to exporter of technology and bio-based products." (ibid) A significant aspect in the context of bio-based products, as such a development would help to progressively replace conventional oil derivatives like for instance plastic.

The use of agricultural crops in the EU looks as follows:

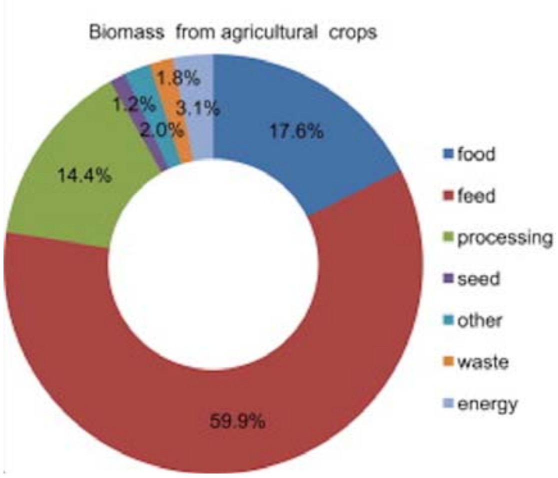

Figure 1: Use for agricultural crops in the EU (Scarlat et al. 2015.)

To emphasize this figure and for the purpose to integrate into this thesis an as realistic approach as possible, the scenario of hemp biomass utilization will include one product line, described in chapter 5.2 and 6.2, where animal feed is produced in the form of highly nutritious presscake. In this context it seems evident that „to develop a carbon-negative and sustainable bio-based economy, it is important to maximize the biomass yield per unit land. This obviously starts with the selection of the most appropriate biomass crops, which depends largely on the geographical location of the field. Ideally, these crops are able to produce substantial amounts of biomass over a short period of time, with minimal requirements for nutrient and water input.“ (Vanholme et al., 2013) This assessment goes into the same direction as the one, which has been made by the European Commission in the context of the identification of barriers and challenges for the bioeconomy. These evaluations are also shared by many of the participants in the survey and meetings in workshops. The first primoridal challenge, which has been identified, is the future gap between demand and supply.

„The demand for biomass is increasing. The FAO foresees a rising demand for food and feed, bioenergy and bio-based products. To avoid extensive use of non-sustainable biomass and loss of social and economic strength in communities all over the world a new design of biomass production systems is needed.

The additional land available is – under current use and harvests – not enough to meet the increasing demand towards 2050. It follows that biomass should be used much more efficiently and that more intensive use of land and of biomass is needed, however without overexploitation. Good examples can help to realize a smart design of *agricultural systems that can be intensive as well as sustainable. New sources of biomass can be found in side streams, new crops (including algae), and new biomass production systems (Short Rotation Crops, Short Rotation Forest crops). Cascading of biomass can enable a more efficient use of available resources.“* (European Commission. 2014)

The endeavours to interlink these exigencies, is what will be further reviewed in the context of a short rotation hemp crop used for the purposes of a developing bioeconomy.
In the next chapter, some of the various potential applications of the hemp crop as a mean for the as previously mentionned efforts to shift towards a sustainable bioeconomy will be further elaborated.

3. Potential hemp applications in the Bioeconomy

Consequently, an illustration of the scope of applications made out of hemp, against the background of a recent revival for specific applications and the efforts to encounter the before mentioned challenges, will be undertaken. Hence, this chapter will give a general description of the main constituents of the hemp crop and the applications they are currently used for in the EU.

But first, it is essential to make clear, that there are beside hemp many other highly effective means and sources of biomass. They can and will all together contribute to the development of a sustainable Bioeconomy. The flax crop, its applications and properties are for example often compared to those of hemp. However, it was decided to concentrate on hemp cultivation and the applications for the whole plant use, as it seemed to have even more environmentally friendly traits, which will also be briefly outlined in chapter 4.1. Within the limits of this paper, the potential hemp applications must be seen in front of changing backgrounds where optimal input-output scenarios and research for the diverse end-uses are still in process. Generally speaking, hemp is a plant lignocellulosic biomass, which is an abundant renewable resource that can provide biopolymers, fibers, chemicals and energy. (Cf. Andre et al. 2016)

The following figure should help to illustrate and get an overview of some of the various possible applications for the hemp crop.

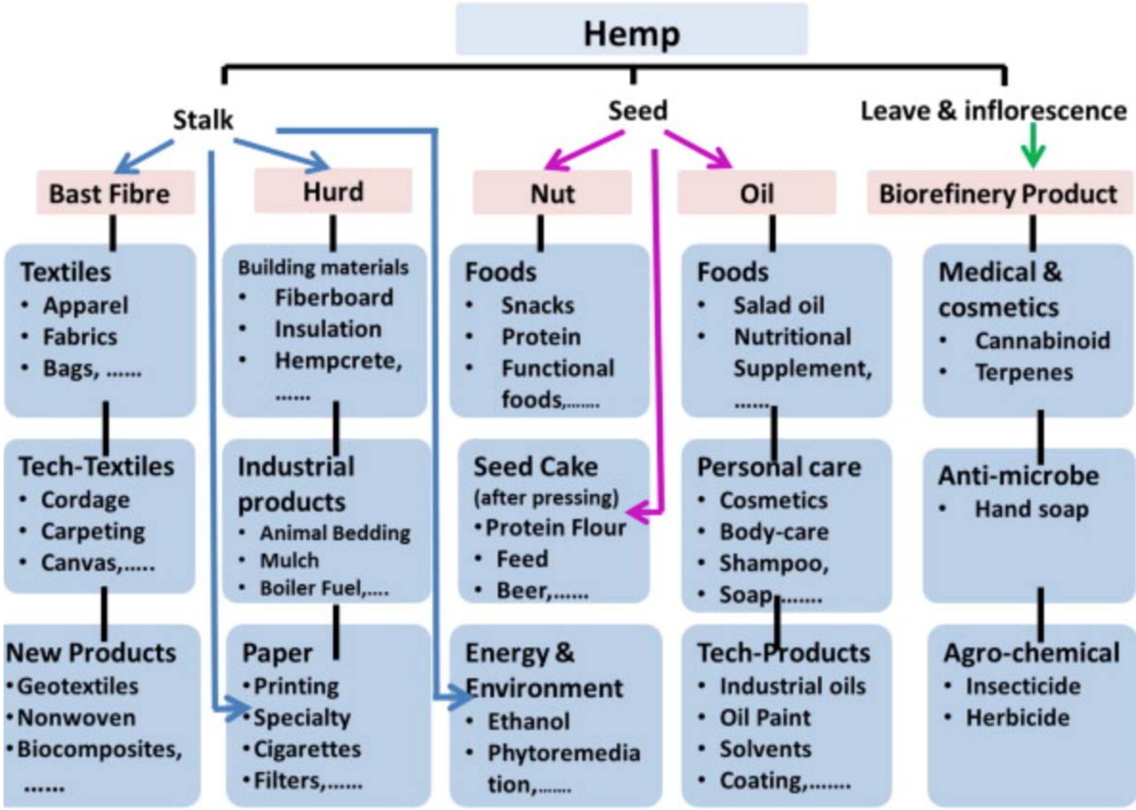

Figure 2: Various applications for hemp constituents. (Salentijn, et al. 2015)

Hemp cultivation areas in Europe have expanded from 8,000 ha in 2011 to almost 25,000 ha in 2016. This means a triple increase in 5 years, entailed by the growing demand for different raw materials obtained from this outstanding multi-purpose crop. (Cf. EIHA. 2016.)

The wood processing industries are moreover partly contributing to this trend as it is looking for alternatives. Timber prices are increasing and the availability is in decline. This is mainly because of the increasing demand from the energy sector. (Cf. Carus et al. 2008)

In general it must be said, that there are many promosing applications for the hemp crop. However, there are many which are only about to be fully explored and developped.[1]

[1] More information on applications for hemp lignin can be found in annex I

3.1 Fibre applications

Beside textile production, composites are an extremely promosing application for hemp fibres. These can be a viable substitution fibre for any fibre-reinforced-plastics, where currently glassfibre, carbonfibre or other synthetic fibres are incorporated. Thus, this product line will be further reviewed in chapter 5.1. The hemp crop can provide high biomass quantities in a short time. “The stem of this fiber crop supplies both cellulosic and woody fibers: the core is indeed lignified, while the cortex harbors long cellulose-rich fibers, known as bast fibers.” (Andre et al. 2016) The automotive industry already uses the fibre in its pressed form for manufacturing parts such as door panels and dashboards.[2] And the industry is particularly keen on using hemp bast fibers to produce bioplastics, as this material is stronger than polypropylene plastic and lighter in weight. (Cf. Andre et al. 2016) Beyond the mentioned applications, hemp fibers are also attractive in the light of their natural antibacterial property. “Hemp bast fibers have been indeed described as antibacterial and their use for the manufacture of an antibacterial finishing agent, surgical devices or functionalized textiles.“ (Andre et al. 2016)

The following graphic represents the applications for European hemp fibre from the harvest in 2010, which accumulaed in a total of 26,000 metric tonnes. (EIHA 2014)

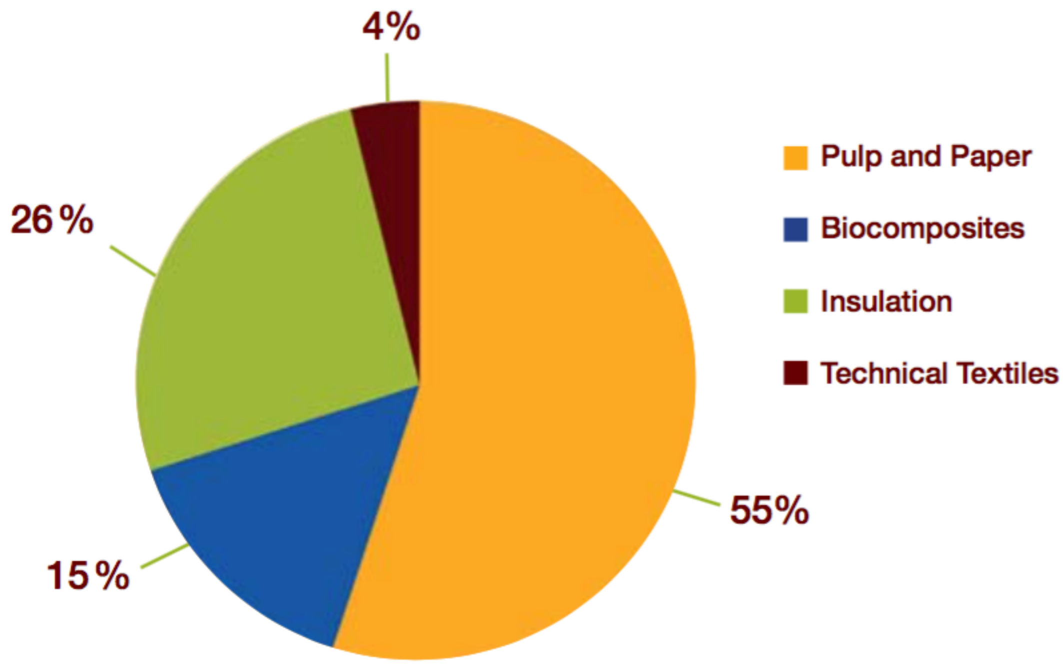

Figure 3: Applications for European hemp fibre from the harvest in 2010. (EIHA 2014)

[2] More information on the processes of manufacturing for fibre reinforced thermoplastic composites can be found in annex II

3.2 Shiv applications

Shives results as a byproduct from the separation of the fibre from the stem. For a long period they have been mainly used a bedding material for animals, like i.e horses. Beyond its use for energy production by incineration, this thesis will again concentrate on the material before energy approach and look at the utilization in the building and construction sector. This graphic represents the applications for European hemp shive from harvest in 2010, in total 44,000 metric tonnes. (Cf. EIHA 2014)

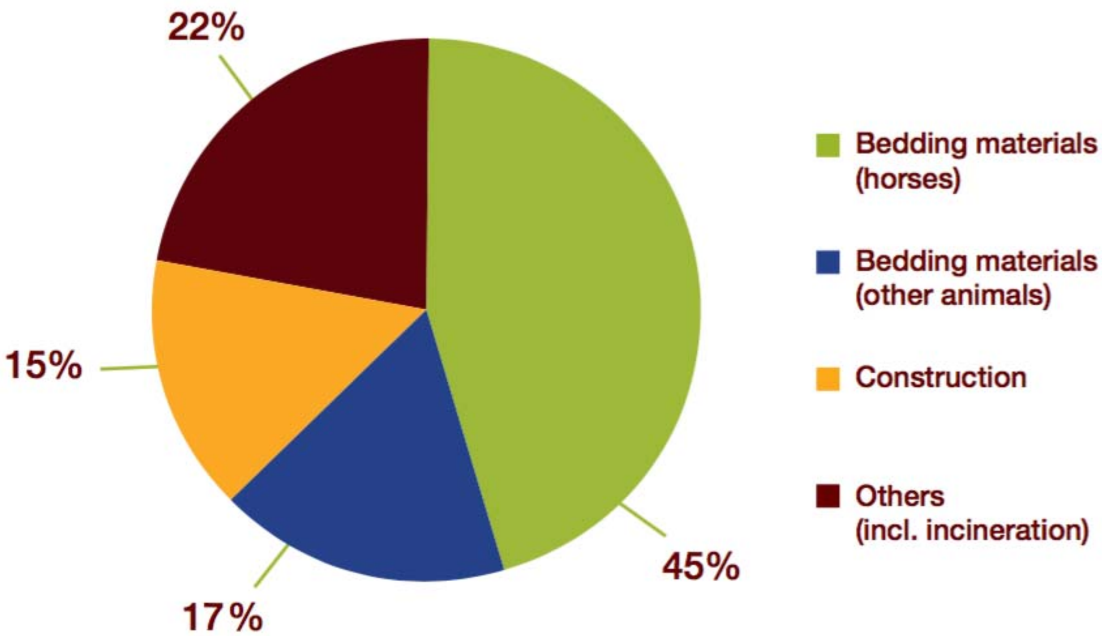

Figure 4: Applications for European hemp shive from the harvest in 2010. (EIHA 2014)

3.3 Seed applications

The whole hemp plant, its seeds and derived seed meal following oil extraction, can be and are to a certain extent already used as feed materials in the EU countries. According to the European Food Safety Agency: „Four essentially different types of feed materials may be derived from the hemp plant: hemp seed (full-fat), hemp seed meal/cake (after lipid removal, mainly cake from mechanical pressing), hemp seed oil and whole hemp plant (which may include hemp hurds, fresh or dried). Further products are hemp flour (ground dried hemp leaves) and hemp protein isolate (from seeds).” (EFSA. 2011.) The second type has given rise to the incorporation of hemp seed meal/cake to the hemp utilization scenario of this thesis, which will be further elaborated in chapter 5.2

Moreover it has been found, that hemp seeds are with a 95% share used predominantly, in animal nutrition, mainly for non-food producing birds, while the remaining 5 % are being used as food. Hemp seed oil, produced by cold pressing the seeds, is used as food and in cosmetic formulations for body care. (Cf. EFSA. 2011.) The following figure shows the applications for European Hemp Seeds from harvest 2010, which amount to a total of 6,000 metric tonnes (Cf. Carus et al. 2013)

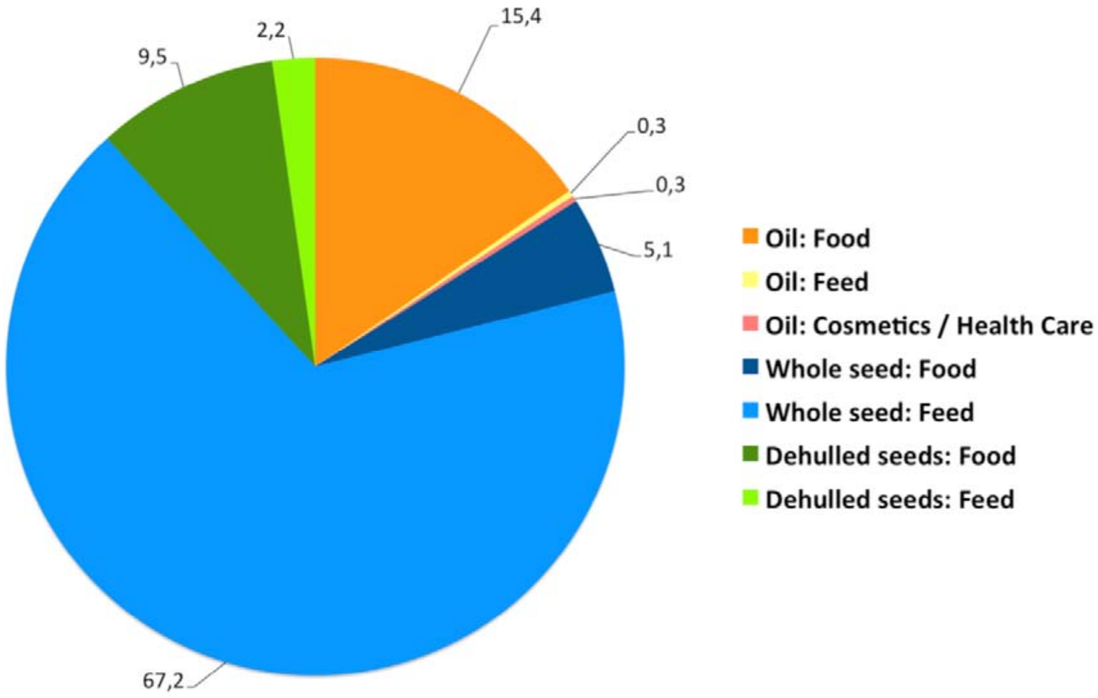

Figure 5: Applications for European Hemp seed from the harvest in 2010 (Carus et al. 2013)

3.4 Flower applications

Last but not least, hemp can be grown for its flowers and be processed into medicine in various forms, like i.e CBD (Cannabidiol) drops, foods, or simply into tea etc. Up-to-date research has revealed that not only diverse health shops in Austria and other EU countries offer the CBD drops, but also with increasing demand pharmacies. The choice had for the objectives of this thesis to be made to either additonally gain seed or flower from the hemp cultivation or even both.

Although the EU hemp cultivation is currently about to be rescuciated due to a strongly growing market for CBD drops, which incorporate medically valuable ingredients, it was decided for diverse reasons to not further investigate this scope. One is that the focus should be on product lines with more accessible data, which are considered to contribute certain material inputs for the decided on productlines and thus also have rather ascertainable environmental considerations. Moreover, has the current situation to be seen as a direct consequence of the restrictive judicial situation and lack of supply of potent medical hemp products. A considerable lack of data would also be expected for the realm of the investigations. How to compare the output of CBD drops of Hempland with the EU demand for comparable medicines etc.? Thus, although in reality there is an increasing amount of hemp grown in the EU for the supply op CBD products and also in respect to the limits of this paper, only the other main constitutents of the hemp crop, namely fibre, shive, fibre and the residue of dust will be considered.

4. Challenges:

This chapter is named this way, as one of the objectives of this thesis is to investigate some of the main factors, which could help to understand if our scenario for a hemp incorporating bioeconomy is foiling or not the EU Water Framework Directive (EWFD) and Common Agricultural Policy (CAP). In order to do this adequately, an ecological consideration is indispensable as well as a hereto-linked elaboration of some crucial objectives of EU Directives and their meaning for this thesis and the results of the MFA.

4.1 Ecological consideration:

This chapter is of great importance to this thesis. It should help to understand why hemp was chosen as a crop for a potentially sustainable supply of biomass to the bio-based economy. There are various crops with good fibre or seed yields, but this often goes along with devastating ecological burdens which are no more, they never were, acceptable. This chapter should enable the reader to understand the effects, which the cultivation of hemp can have on the environment where it is grown. For the purpose of this thesis, it is of primordial importance to clarify how hemp differentiates in this aspect from other widely grown crops used in the bioeconomy.

As we can see from the next table, hemp has an overall very favourably low impact on environment.

	Nutrient depletion	Pesticides	Erosion	Soil compaction	Water consumption	Biodiversity	Agro-biodiversity
Permanent pasture	A	A	A	A	A	A	A
Short rotation coppice (poplar, willow)	A	A	A	A	B	A/B	A
Winter grains	A	A	A	A	A	B	B
Linseed	A	B	A/B	A	A	A/B	A
Hemp	A	A	A/B	A	B	B	A
Alfalfa	B	A	A	A/B	A/B	A/B	A
Grass	B	B	B	A/B	A	B/C	A
Switchgrass	?	?	A	A	A	B	A
Mustard	A/B	B	A/B	A	B	B	A
Sorghum	A	B/C	A	A	A/C	B	B
Wheat	A	B	A	A	B	B/C	C
Sunflower	A/B	B	B/C	A	B	A/B	B
Rapeseed	B/C	C	B	A	0	B/C	A/B
Sugarbeet	B/C	B	C	C	A/C	B	B
Maize	C	C	C	B	A/B	C	B/C
Potato	B/C	B	C	C	C	B/C	C

Table 1: Environmental effects of hemp, linseed and different major crops
Source: Adapted from EEA 2007; A = Lowest impact on environment, B = Medium impact, C = Worst impact on environment, 0 = not applicable, ? = insufficient database

Figure 6: Environmental effects of hemp and different major crops (Carus, Piotrowski. 2011)

4.1.1 Land usage and crop rotation

One of the most important ecological advantages consists in the quick up growth of the seedlings. Combined with a rapid closure of plant series its growth leads to an extraordinary strong suppression of weeds. Potent other plants can't withstand the high competition pressure from hemp. This only is possible when two given conditions are fulfilled. A good crop growth linked to a sufficient supply of water and nutrients, and good soil conditions, which consist of avoiding dammed-up water and soil compaction. Secondly, the hemp crop needs a certain sowing strength. If these conditions are fulfilled, no herbicides are necessary for a successful harvest. Even more, hemp is a crop, that is not only incompatible with the use of herbicides as it reacts sensitively to the usage of it, but it also reacts with a slowed down growth on arrears from the previous year. Thus it sets an incentive for the farmer to be cautious when making use of herbicides in his crop rotation. Another positive side effect comes from the fact that the hemp crop supresses the weeds in a way that they can't flourish and hence are less impeding with the crop sequence. (Cf. Carus et al. 1996) As hemp has a high self-compatibility, the risk to be used in monoculture is relatively high. This is however strongly not advised, due a risk of increased pest contamination and lack of nutrients. It would also foil the good crop rotations effects and thus hinder an optimal usage of hemp properties. All in all, the cultivation of hemp is an exciting crop for organic farming, notably in regard to its good properties in a crop rotation with most crop plants like i.e.: Potatoes, winter wheat and sugar beet. In that regard, it should only be made sure that hemp is well positioned after well-suited crops like legumes in the crop sequence. (Cf. Carus et al. 1996) Additionally, it should be said that for the aims of this thesis, including the MFA, a monoculture of hemp is clearly seen as a unfavourable agricultural practice to counteract the negative effects which large-scale monocultural cultivation today often have on the environment. Furthermore, a cultivation on land-set-aside linked to drinking water protection zones, could be envisaged, also in regard to the land surface considered for the MFA of "Hempland". However, unfortunately no adequate data was available.

4.1.2 Soil

When talking about eutrophication and soil erosion, hemp has here as well rather positive characteristics. This is due to its high canopy grade, which is the area of ground covered by the plant. This circumstance and the deep root penetration have further ecological benefits. An increased proportion of shadow, a good crumbliness of the soil, a better aeration, a favourable water balance and in general an improved soil fauna. The consistently reported increase in yields of the following crop, in this case winter wheat, is mainly to be related to the improved soil structure and the sustainable suppression of weeds. A further finding comes from the company "Hempflax" in the Netherlands, which indicated that hemp fields better dry and warm up during spring then other fields and thus allow an earlier cultivation. Regarding fertilization, hemp requires very moderate nitrogen, phosphor and potassium fertilization when compared to other widely used agricultural crops.

For an ecological assessment it is in this context most important to look at the environmental impacts resulting from the nitrogen seepage. The up to 2 meters long roots of hemp, allow it to obtain its nutrients from low-lying layers, which remained

from the previous crops. This fact minimizes the danger of nitrogen seepage considerably. (Cf. Carus et al. 1996)
The hemp crop was furthermore identified by the European Environmental Agency as the crop with the lowest impact on environment in the categories of „Nutrient leaching to ground and surface water“, as well as „Pesticide pollution of soils and water“ (EEA 2007) Moreover, the roots, leafs and other parts of the plant are conserved in the soil and constitute a considerable amount of organic material left over for the consequent crop. Concerning fertilization in general and more specifically the potassium fertilitzation one has to be careful in regard to current investigations.

It has been stated in clear words by researchers from Ireland who only focussed on the potassium fertilitzation that „many more trials carried out over successive years on a variety of sites would be needed to develop robust potassium fertilization advice for hemp.“ And continues: „There was no response to applied potassium. Similarly, soil potassium levels over the range used in this study did not influence hemp yields. (…) The results of this study suggest that the potassium requirements of hemp may be lower than previously assumed (ITC, 2007) and lower than the potassium requirements of other crops. (…) Given the absence of a yield response in this trial on sites with moderate to high levels of soil potassium (...) as well as the fact that the crop will take up more potassium than is needed if excess levels of the element are available, our results suggest that the optimal potassium fertilization strategy for hemp grown on these soils may be to replace off-takes after the hemp crop has been harvested. “ (Finnan and Burke. 2013)

The pest management for hemp is characterized by the matter of fact that it is a plant with a low susceptibility of diseases or pests. Hence, agrochemicals are normally not needed to efficiently grow hemp. (Cf. Carus et al. 1996)

4.1.3 Biodiversity:

Another constitutive element of a realistic ecological assessment consists of the accompanying encroachment of agricultural land and the related biodiversity. They are very important criteria for a well-adjusted analysis. For this, two different scenarios of the land used by the hemp cultivation are differentiated. It is crucial whether the cultivation takes place on set-aside areas or extra for the cultivation provided areas. (Cf. Carus et al. 1996) This differentiation is of special interest as hemp is recommended, notably by the EIHA, to be eligible for the "greening measures" of the CAP of the EU. The raised question in this context is if „due to the ecological benefits of hemp cultivation (low fertilizer and no pesticides) – could hemp cultivation count as an ecological focus area or permanent grassland (like alfalfa)?" (EIHA. 2012) This justified question and the regulating framework will be further treated in chapter 4.3. In general, as we can see from the next figure, hemp is a biodiversity-friendly crop.

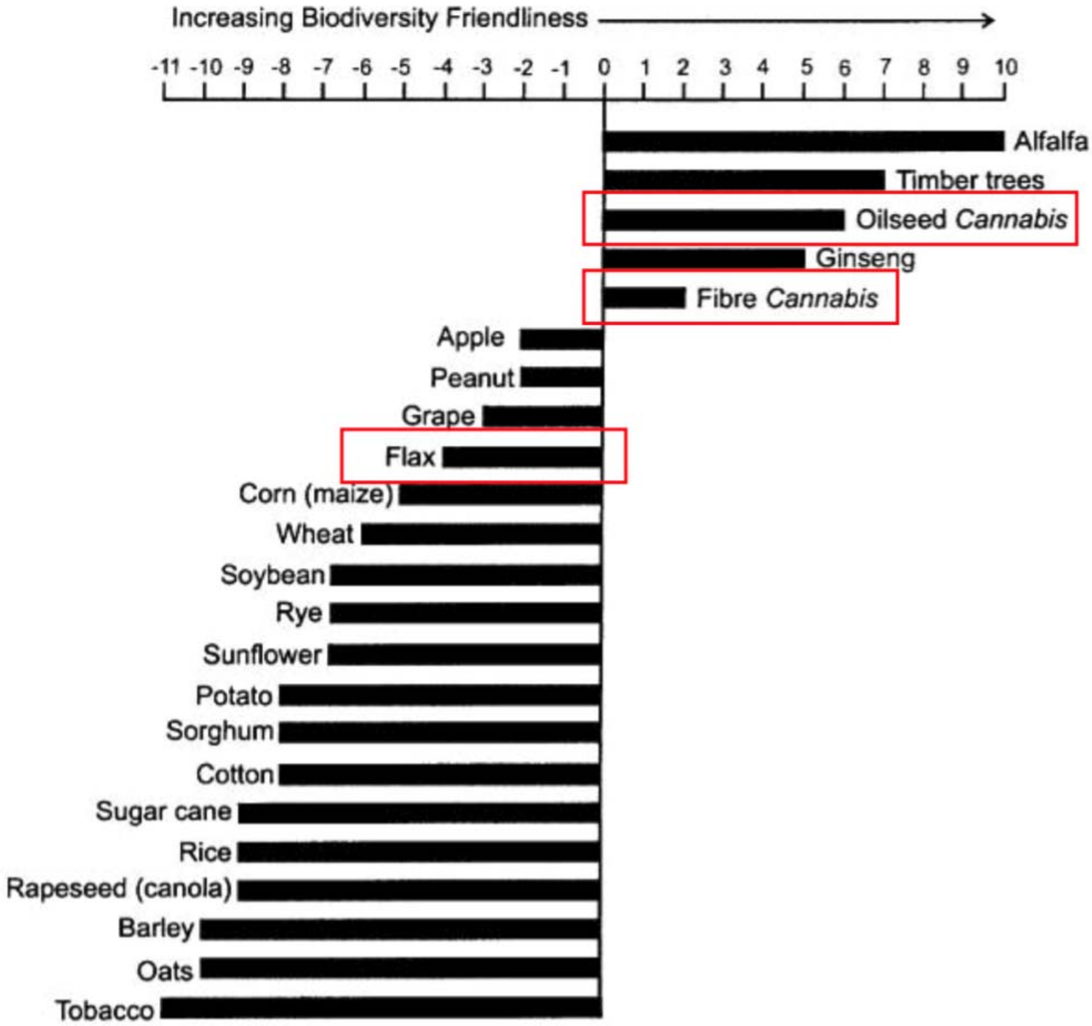

Figure 7: Biodiversity friendliness of selected major crops (Carus, Piotrowski. 2011)

The biodiversity is as a matter of course threated of a decline if new long-term allocation are occurring. However, it has been retained by the study of Carus that hemp cultivation on set-aside areas would, if they would elsewise only grass it, come along with marginal determinable changes. Thus the cultivation on set-aside areas has explicit advantages. An interesting side note is that there are different scenarios that have been investigated in order to identify effects of substitution, like for instance in the case of hemp fibre substituting cotton fibre for textile production or hemp seeds meal for soybean meal. In this context, it has been clarified that especially for the substitution of cotton, areas reserved in overseas could be used for other purposes while additional areas in Germany would be needed, but to a lesser extent then it has been the case in the substituted areas in overseas. A potential for a general land relief has been ascertained for certain scenarios. Notably for cotton, the eutrophication is much higher then for hemp. (Cf. Carus et al. 1996) In this context, it has in chapter 6 for crucial recommendations for future research projects, been suggested to review these potential land reliefs when substituting cotton or others crops.

4.1.4 Water

Holistically seen, the effects of hemp cultivation on water resources are characterized by the absence of agrochemicals, like pesticdes and herbicides, a moderate fertilization requirement and a low leaching of nitrate. In general, the water consumption of hemp plants is highest for the first six weeks of growth. Afterwards it is widely drought resistant. (Cf. Carus et al. 1996) However, it is evident that for such research studies where the water consumption is taken into account, this will vary greatly according to the geographical location, associated rainfall patterns, soil etc. The same is true for nitrate leaching. In the United Kingdom, it has been shown that the hemp crop requires precipitation in the form of rainfall of about 500-700 mm per growing season. And the water requirement to produce 1kg of dry matter is of 300-500 L per growing season. (Cf. Cherrett et al. 2005.)
According to the water footprint methodology of Hoekstra, the global average water footprint of certain hemp goods will also be taken into account. The footprint is divided into a green, blue and grey water footprint. „The blue water footprint refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.“ (Mekonnen and Hoekstra. 2010)

For the further proceeding of this thesis and the use of natural hemp fibre, the statement by Mekonnen in his main report seems to be signifcant: „The water footprint of cotton fibres is substantially larger than the water footprints of sisal and flax fibres, which are again larger than the water footprints of jute and hemp fibres." (Mekonnen and Hoekstra. 2010) In regard to the leaching of nitrate into surface and groundwater it can additionally be said that Nitrate leaching is of about 20kg/ha. It has furthermore been suggested to optimise nitrogen fertilisation and to reduce the period between harvest and the establishment of the next, favourably catch crop. These measures constitute the principal recommendations to reduce NO3 leaching (Cf. Van der Werf. 2004). As fertilisation was optimised in Van der Werfs scenarios, a rapid establishment of the next crop or of a catch crop seems the most promising measure to reduce nitrate emissions. Accordingly, breeding efforts are susceptible of contributing to a reduction of the environmental impacts of hemp production, „in particular by carrying out breeding programmes under conditions of reduced inputs. Our results have shown that it would be of particular interest to focus on conditions combining lower nitrogen fertilisation levels (limiting nitrate leaching) and reduced soil tillage." (Van der Werf. 2004) To conclude this chapter, it seems important to link the elaborated ecological consideration with the underestimated image value of hemp for the bioeconomy. In regard to the important sustainable image, the bioeconomy has and wants to exploit and strengthen; one should not underestimate the public opinion of hemp crop as an ecological plant. This marketing, but also political aspect could also be of interest for future poltical decisision, research topics, argumentation lines and "green" products.

Finally, the elaborated main environmental impacts of hemp cultivation are suggested to be interpreted against the background of the next chapter, where is tried to establish an interlinkage between the EWFD, the CAP and a possible increase in hemp cultivation for the demands of the EU Bioeconomy. Finally, the MFA will contribute further data and acknowlodgments to the endeavours of this thesis.

4.2 Necessity for political and legal frameworks

In the realm of this paper, those political and legal frameworks, which could be decisive to foster a more sustainable EU bioeconomy, will be further elaborated. Sustainable in the sense of an efficitently growing bioeconomy, which won't make the future generations worse off then the todays. Thus, we will in general not recur to solely economically biased political frameworks in the context of the bioeconomy. The primer consideration of environmentally biased political and legal frameworks is to be seen as a prerequisite for a subsequent sustainable economic success of the bioeconomy.

Notably the EWFD and the CAP. Whereas the latter one has as one of the main objective to foster a competitive agriculture, it is of importance to this paper as its policies are decisive for an adequate understanding and support for hemp-based materials in the bioeconomy. The approach of interlinking political frameworks and their objectives with those of the bioeconomy and the traits of hemp cultivation and processing is genuinely new.

The EU's political and legal frameworks are increasingly important guidelines setting incentives to bias the involved stakeholders. Contributing to the endeavour of making everybody better of in regard to the treated matter. Hence, the inherent guidelines and bias are decisive when choosing the most adequate tools, to reach the targets. In this case the biomass supply for the bioeconomy with the utilization of hemp is to a certain extent analysed and looked on. As a consequence, it is believed that in the near future frameworks will be created "for the design of appropriate public policy oriented to development and promotion of the aforementioned materials and technologies." (Ingrao et al. 2015) Hence, "this aspect could also include adjustment of the current EU-policy in order to provide subsidies to producers and users of hemp-based materials, so as to enable enhancement and differentiation of their applications in the industry." (Ibid.)

A major incentive to include a chapter which is destined for legal and political frameworks was due to the currently unsustainable and these frameworks opposing developments, which take place under the realm of the Renewable Energy Directive and the massive cultivation of energy plants like i.e maize and rapeseed for energy uses and increasingly also for bio-based products. This thesis may contribute to a better understanding of a possible alternative way of how to better bias agriculture. As the status quo is definitely foiling the EWFD and CAP, it seemed obvious to consider a development of the bioeconomy which moves away from these patterns where there is no fair and binding level playing field between crop selection for primary energy usage and primary material usage. According to the report of the VDI, the association of german engineers, there are several primer problems when it comes to the extension of energy plant cultivation for bio-energy. First of all, the changing landscapes and the therewith deterioration of biodiversity. Secondly, the loss of arable lands for the production of food and so an increased concurrence for land. And last but not least, the overutilization of corn, which is in proportionally higher amounts polluting, by it's high risk of erosion for the soils and need for fertilizer and pesticides, the water reserves. (Cf.

BIOGAS. 2007) Hence, foiling to a greater or lesser extent the ambitious aims of the EWFD and CAP. During literature research, these considerations have been stated in many of the scientific papers.

The incorporation of the EU WFD AND CAP should help to understand and interlink the independencies between the future crop selection for the supply of diverse bio-based products and the objectives of these political frameworks. The bioeconomy touches policies, which intersect with other societal goals, like those specified in the WFD and the CAP, creating the possibility of co-benefits or adverse side effects. If well managed, these intersections can strengthen the basis to put a more sustainable bioeconomy into effect. Mitigation efforts can excert a positive or negative influence on the accomplishement of other societal goals. It may imbed the protection of the environment, hence water protection, human health, food security, local environmental quality, livelihoods, biodiversity, equitable sustainable development and so on. (Cf. IPCC. 2014) This multi-objective perspective may be difficult to thoroughly capture, but can help to raise a sustained and wide-ranging awareness of interlinked goals in the realm of diverse areas of interest, and provide for adequate policies.

This is also the reason why EU policies of interest to this topic are approached in this thesis. Already a few years ago the Nova Institute has emphasized how important a sound legal and political framework is for adequate hemp cultivation. Notably the renewable energy policy, which restrains a level playing field with biomass sources for industrial materials, has been named. (Cf. Carus. 2014) It seems obvious that in order to get to a level playing field in this regard, one needs to highlight the advantages and win-win situations when also including the WFD and CAP. Only a holistic incorporation of the legal and political cornerstones can reveal the adequate current and future stance towards hemp utilization in the bioeconomy.

While preparing this thesis, it has become manifest that several EU frameworks, which aim at protecting the environment, would in multiple and sustainable ways benefit of an adequate exploitation of the bioeconomy. The brief description of the EWFD and the CAP should help to understand the interlinkages between the EU bioeconomy, the EU legal frameworks and “Hempland”, which have a direct influence on the bioeconomy and vice-versa. It seems evident, that only a bioeconomy, which is to the least possible extent foiling these frameworks, can in the long term provide the sustainable biomass the stakeholders demand. The understanding of the objectives and their reach should provide further incentives for the exploitation of high yielding crops, which reflect these legal frameworks ambitious commitments to environmental protection. Also, one should bear in mind that EU Directives are legal acts, which oblige the Member States to achieve a particular result without dictating the means of achieving that result. This fact is one of the essences of this thesis and has lead to the choice of procedure and the line of argumentation, as it provides further legitimacy for the endeavours incorporated.

4.3 EU Water Framework Directive

One of the most ambitious legal frameworks when it comes to the protection of water resources is the EWFD. There are national policies and policies of the European Union which are available. Many reasons and consequences for water pollution are in most cases not limited to nation states. Therefore, EU policies that call all the EU member states to account are increasingly becoming inevitable and significant for a sustained shift of water policies into the right direction. The EWFD, which was adopted in the year 2000, can be interpreted as the result of the consternation and need for cooperation within the EU and its member states. „The EU water framework directive addressed for the first time in a comprehensive manner all the challenges faced by EU waters, making it clear that water management is much more than just water distribution and treatment. It involves land-use and management that affect both water quality and quantity; it requires coordination with spatial planning by the Member States and integration into funding priorities." (European Commission. 2012)

The EWFD will also „require Member States to establish pollution reduction programmes addressing pesticides in the framework of the River Basin Management Plans, which must include measures such as buffer strips or the use of particular technical equipment to reduce spray drift. Member States will have to strongly reduce or ban the use of pesticides in the specific safeguard zones according to Article 7(3) of Directive 2000/60/EC." (European Commission. 2007)

Additionally, they conclued a interlinkage of the main causes of negative impacts on water status. „These include climate change; land use; economic activities such as energy production, industry, agriculture (...). Pressure from these causes takes the form of pollutant emissions, water over-use (water stress), physical changes to water bodies and extreme events such as floods and drought, which are set to increase unless action is taken. As a result, the ecological and chemical status of EU waters is threatened, more parts of the EU are at risk of water scarcity, and the water ecosystems — on whose services our societies depend — may become more vulnerable to extreme events such as floods and droughts. It is essential to address these challenges to preserve our resource base for life, nature and the economy and protect human health.“ (ibid.)

It incorporates a EU wide important confession on the necessity to ameliorate the European water conditions. The EWFD asserts: “Unless stronger action is taken, 47% of EU surface waters will not have good ecological status by 2015. About 25% of ground waters have poor chemical status due to human activities. The chemical status of 40% of surface waters is unknown, showing that monitoring is inadequate in many Member States.“ (European Commission. 2014)

The EWFD, which refers to several facts, is in this regard also pointing to the necessity of EU wide action "because river basins and pollution cross borders.” (ibid.) The Directive is clearly stating: “*Europe's water is under pressure. Economic activities, population growth and urbanization are increasing pressures on freshwater throughout Europe.“ Furthermore it is emphasized that „water management is linked to many policies: Integration is the only way forward for sustainable water use. Water is involved in a huge range of economic activities, and therefore in the policies applied to regulate them. For example: agriculture, land-use and development, (...) and more. These economic activities depend – like all of us – on healthy aquatic and water-dependent ecosystems, which provide food and water, are essential to maintain human health, and help regulate the climate.“* (ibid) Moreover should the good water management be integrated into all of these areas, and the Water framework directive takes account of all aspects of water use and consumption. (Cf. ibid.)

The European Commission has in that regard in 2012 published a Blueprint to Safeguard Europe's Water Resources in which is stated: „Water is a local issue but it is also a global problem interlinked with many issues such as food security, desertification, climate change, impact of natural and man-made disasters etc., which all have significant economic, social and security dimensions.“ (European Commission. 2012)

In the EWFD, the environmental objectives are defined in the core article, Article 4.1. It introduces the principle of preventing any further deterioration of status. „The aim is long-term sustainable water management based on a high level of protection of the aquatic environment. ” (European Commission. 2009a) The "environmental objectives" of the water framework directive are mainly set out in Article 4.1. „The main environmental objectives in the Directive are manifold and include the following elements (for details see Article 4.1, (a) surface waters, (b) groundwaters and (c) protected areas):

- No deterioration of status for surface and groundwaters and the protection, enhancement and restoration of all water bodies;
- Achievement of good status by 2015, i.e. good ecological status (or Potential) and good chemical status for surface waters and good chemical and good quantitative status for groundwaters;
- Progressive reduction of pollution of priority substances and phase-out of priority hazardous substances in surface waters and prevention and limitation of input of pollutants in groundwaters;
- Reversal of any significant, upward trend of pollutants in groundwaters;
- Achievement of Standards and objectives set for protected areas in Community legislation.“ (European Commision. 2009a.)

“The Water framework directive is furthermore complemented by other, more specific, EU laws:

- The Environmental Quality Standards Directive (2008)
- The Floods Directive (2007)
- The Groundwater Directive (2006)
- The Drinking Water Directive (1998)
- The Urban Wastewater Directive (1991)
- The Nitrates Directive (1991)” (European Commission. 2014)

The latter Nitrates Directive is an integral part of the EWFD and is one of the key instruments in the protection of waters against agricultural pressures. The Nitrates Directive aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by supporting the use of good farming practices. (Cf. European Commission. 2015)

In order to implement this directive some guidelines can be specified. Amongst others:

1. "Establishment of Codes of Good Agricultural Practice to be implemented by farmers on a voluntary basis. (…) Crop rotations (…)
2. Establishment of action programmes to be implemented by farmers within "Nitrate Vulnerable Zones" on a compulsory basis" (European Commission. 2015)

Complementary to the EWFD, the EU also sets rules for the sustainable use of pesticides to reduce the risks and impacts of pesticide use on people's health and the environment in Directive 2009/128/EC. (Cf. European Parliament and European Council. 2009) Some of the main actions for sustainable use of pesticides, and which are of further interest for this thesis, are:

- **"**National Action Plans- EU countries adopt them setting objectives and timetables to reduce risks and impacts of pesticide use;
- Minimising or banning - EU countries minimise or ban the use of pesticides in critical areas for environmental and health reasons;
- Integrated pest management - Promotion of low pesticide-input management including non-chemical methods." (European Parliament and European Council. 2009)

In Annex III, the general principles of integrated pest management are listed. Among them:

- „The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:

- Crop rotation,

- Use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material

- Use of balanced fertilisation, liming and irrigation/drainage practices (...)" (Ibid.)

The mention of crop rotation is of particular interest to this thesis as has been further elaborated in chapter 4.1.3. Moreover, there are different instruments, which are directly linked to the Water Framework Directive and to the integrated Groundwater Directive. They are part of a set of measures that needed to be operational in order to achieve “good environmental status” objective by the end of 2015. The instruments have in common that they all seek to prevent or limit pollutant inputs into groundwater. (Cf., European Commission. 2008) Regarding groundwater in the context of the EWFD, it is presumed that the case of groundwater is somewhat different. In relation to groundwater the presumption is broadly characterized by the fact that it should not be polluted at all. Furthermore has the EFWD introduced a strong approach for a general protection, which *“is essentially a precautionary one. It comprises a prohibition on direct discharges to groundwater, and (to cover indirect discharges) (…), and to reverse any antropogenically induced upward pollution trend. Taken together, these should ensure the protection of groundwater from all contamination, according to the principle of minimum anthropogenic impact.“* (European Commission. 2016a)

A statment in a research from Piotrowski and Carus, about the role of possible support instruments for industrial hemp in the framework of the CAP brings both directives together and hence serves as a fitting transition.

„Beyond the mandatory “greening” component of direct payments, the EU considers further instruments in order to reach its goals of the 2020 Biodiversity protection strategy. According to a press release of May 2011 (EurActiv 2011) these include:

- *Incorporationg the Water Framework Directive (WFD) within the scope of cross-compliance in order to improve the state of aquatic ecosystems in rural areas, meaning that fulfilling the requirements of the WFD would count as cross-compliance.“*

These „greening“ measures and their role for the objectives of this thesis will be further elaborated in the subsequent chapter. (Piotrowski and Carus. 2011)

4.4 Common Agricultural Policy

In the year 2013, a reform of the CAP for the period of 2014-2020 has been adopted. This new policy continues along this reform path, moving from product to producer support and now to a more land-based approach. (Cf. European Commission. 2013)
This is in response to the challenges facing the sector, many of which are driven by factors that are external to agriculture. These have been identified as *“economic (including food security and globalisation, a declining rate of productivity growth, price*

volatility, pressures on production costs due to high input prices and the deteriorating position of farmers in the food supply chain), environmental (relating to resource efficiency, soil and water quality and threats to habitats and biodiversity) and territorial (where rural areas are faced with demographic, economic and social developments including depopulation and relocation of businesses)". (Ibid.)

As it is the role of the CAP to provide a policy framework that supports and encourages producers to address these challenges while remaining coherent with other EU policies, this translates into three long-term CAP objectives: "viable food production, sustainable management of natural resources and climate action and balanced territorial development." (Ibid.)

In order to achieve these long-term goals, the existing CAP instruments were adapted. Hence, the reform focused on its sustainability over the long term and the operational objectives of delivering more effective policy instruments, designed to improve the competitiveness of the agricultural sector. Briefly said, the EU agriculture needs to attain higher levels of production of quality and safe food, while preserving the natural resources that agricultural productivity depends upon. (Cf. European Commission 2013) Moreover is the focus of the second pillar on sustainability clearly visible as at least 30% of the budget of each Rural Development programme is dedicated for voluntary measures, which are advantageous for the environment and climate change. (Cf. European commission. 2013) This is to be strongly related to the ecological considerations, which have been undertaken in chapter 4.1.

In the context of the CAP reform, farmers should be stronger rewarded for the services they deliver to the wider public in the form of i.e landscapes, farmland biodiversity and climate stability albeit they have no market value. This is the reason for the already mentionned greening measure, which is a new policy instrument of the first pillar. It is directed to the provision of environmental public goods, which depicts a major change in the policy framework. (Cf. European Commission. 2013) Furthermore it is has been retained, that, agriculture has to improve its environmental performance through more sustainable production methods given the pressure on natural resources. (Cf. Ibid.) The combined and complementary effects of various instruments should achieve this improved sustainability. "On top of this, from 2015 onwards, the CAP introduces a new policy instrument in Pillar 1, the Green Direct Payment." (European commission. 2013)

These payments encompass 30% of the national direct payment envelope and reward farmers for respecting three obligatory agricultural practices, namely crop diversification, maintenance of permanent grassland and ecological focus areas. They have also the advantage of introducing practices that are beneficial for the environment and climate on most of the utilised agricultural areas, as the green direct payment is compulsory. (Cf. European commission 2013). This moreover unveils what potential of support by the CAP and of harmony with its objectives there exists in environmental and also financial terms, when considerung hemp cultivation. This gains even more importance and interest as „within a more restricted budgetary framework, it is crucial that scarce resources are distributed in a way that maximises the attainment of the CAP's objectives.“ (European commission 2013) Hence in the new CAP, as from 2015 onwards, the payment of the income support is coupled with greening actions, hemp can be used in practice to increase rotation. (Grow2Build. 2015) There seems not much ground to reason why Hemp should not be eligible for the green direct payment and more generally the fulfilment of the CAPs objectives.

5. Scenario of a biorefinery based on hemp utilization

Not only the environmental impact, which results from the hemp crop cultivation is of crucial importance for its contribution to the sustainable development of a EU bioeconomy. At least as important are its outputs and the here-to linked applicable amounts of renewable resources, which can be processed into valuable goods. For the aim of an adequate illustration of these, a scenario of a biorefinery, which is based on the processing of the main hemp constituents, will be implemented.

This chapter aims to properly reflect and encompass an as concrete as possible scenario of processing of the here used hemp constitutents. An important task, as there is a broad range of feasible scenarios with different applications for the hemp crop. It must be emphasized that the current and future market potential, as well as overall environmental aspects have been decisive for the selection. In order to get an impression of where the future could take us, one estimate for the EU market in this context may be of interest. It suggests that up to 30% of oil-based chemicals and materials would be replaced with bio-based ones by 2030. (Cf. Scarlat et al. 2015)

In our case, the biorefinery will be a factory where the hemp constituents will be processed and refined into adequate forms for a further processing into the subsequent product lines. Beside the commonly known applications and the here further reviewed ones for the hemp crop, there are promising future scenarios for biorefineries where, to only name one example, the "lignin" could be used. This is important to know, as lignocellulose is a rich and sustainable source of chemicals, fermentable sugars, and biopolymers that can lessen our dependence on petroleum-derived products. (cf. Guerriero. 2016) Thus future biorefineries where hemp is processed may incorporate even more sophisticated processes for industrial applications, as the hemp crop is rich in Lignocellulose. Unfortunately, processing of "lignin" and other promising chemical constituents of the hemp crop, can due to data lack and the only very recent scientific researches not adequately be treated in this thesis. [3]

In respect to the limits of this thesis however, not all kinds of processing for our scneario that would be the case for a whole crop processing can be taken into account. Only the major, most promising and more accessible ones will be treated. Hence, for diverse reasons, this paper will focus on a more reachable and accessable scenario of hemp utlization in a biorefinery. Therefore priority will be given to a biorefinery, which processes biocomposites, animal feed and construction material. These will be further elaborated in the three subsequent chapters. Firstly, the biocomposites product line will be further illustrated, as it is deemed crucial for a sustainable bioeconomy. The transition towards the latter, "needs a revolutionary change in the use of raw materials, it needs to overcome today's dependency on fossil fuels and to bring about a shift towards bio-based products based on agricultural (…) resources. Within the energy supply sector, it's solar and wind power, within the materials sector, it's Bio-based Plastics and Composites." (Biowerkstoff Report. 2010) Crucial informations and where possible also anecdotes, should contribute to an adequate understanding of the specific productlines and their scope. In this context, it should be pointed at the new approach and findings that this thesis hence provides. No previous research study has investigated into such a specific scenario and the characteristics of such a undertaking, where the processing of biocomposites, animal feed and construction material is reviewed from such a rather holistic perspective. Usually research studies aim at more specifically one of the possible productlines.

[3] More information on applications for hemp lignin can be found in annex I

5.1 Biocomposites

Firstly, it is of interest to clarify what hemp can contribute to this productline. Biocomposites are compound materials with at least one biogenic component.

There are three types of Biocomposites:

- Composites made of natural fibres and traditional polymers and matrix materials.
- Composites made of synthetic fibres and biopolymers.
- Composites made of natural fibres and biopolymers (Cf. Wikipedia)

The latter ones will be further investigated and be part of the scenario.

This is due to the fact that *„plant biomass is indeed an important feedstock for the supply of raw material, e.g. cellulosic and woody fibres that can be used for the creation of "green" composites. Plant-sourced biocomposites designed by employing plant fibres as reinforcement and substitutes of glass fibres, are gaining a lot of attention because these are renewable, cheaper and do not raise health-related issues (irritation of skin/respiratory system). In this respect fast growing nonwoody species, like fibre crops are gaining considerable importance as these can provide a high amount of biomass in a relatively short period of time."* (Guerriero. 2016)

Biocomposites, also sometimes referred to as natural fibre reinforced plastics constitute a promising material group, for injection moulding and extrusion. For ecological, technical and economic reasons they are able to replace both glass fibre, reinforced plastics and non-reinforced plastics such as PC/ABS. (Cf. Biowerkstoff report. P.55. 2010) The lightweight biocomposites are said to have a huge market potential in all the sector where material weight is crucial and hence help to save energy and increase transport capacities. This currently includes especially the aerospace, shipbuilding, railed vehicles and automotive sector. (Cf. p. 222. Carus et al. 2008) In the field of biocomposites, it is highlighted that hemp fibres should be preferred to glass ones. This is mainly because: *„(1) their production results in lower environmental impacts compared to glass fibre production; (2) hemp-based composites have higher fibre content for equivalent performance, which reduces the amount of more polluting base polymers; and (3) lower weight of hemp-fibre based composites improves fuel efficiency and reduces emissions during the use phase of the component. The use of hemp fibres for bio-composite applications, as for concrete and insulation mat, act as 'sink' for* *atmospheric CO_2 due to the amount of CO_2 that is up-taken by photosynthesis during plant growth."* (Ingrao et al. 2015)

Today, fibre composites consist mostly of a petrochemically derived polymer resin matrix reinforced with synthetic fibres such as glass, carbon and aramid. (Cf. Manthey 2011) For structural applications, the mostly used matrices are based on thermosetting resins, such as polyesters, phenolics, epoxies and polyimides. (EUCIA) However, there are strong incentives to change this. An ever-increasing environmental awareness to their use within the fibre composite industry is propelling the development of bioresins based on renewable natural materials. „Bioresins are an emerging sustainable material often derived from plant oils and due to their biological origin represent a sustainable, low environmental impact option to existing petrochemically derived resins. They may be reinforced with natural or synthetic fibres thereby creating a class of materials termed, natural fibre composites or biocomposites." (Manthey 2011)

Innovative bio-based materials, like bio-Based Plastics and Composites, can be, and are used already to a great extent by industry, "especially by the automotive, packaging and building industries. Estimates give a figure of about 500,000 tonnes a year and a two-digit growth in the European Union." (Biowerkstoff Report. 2010) Yet, only relatively few producers and users have the knowledge of the technical, economic and ecological capabilities and most of the companies who are interested in "green materials" consider it problematic to obtain suitable materials and suppliers. (Cf. Ibid.) This partly contributed to the decision to incorporate biocomposites into the scenario of this thesis. Rather new biocomposites where hemp fibres are embedded in a biopolymer matrix made of hemp oil. Hemp seed oil based bioresins or epoxies, as the one studied in Mantheys study, offer a potential alternative to petrochemical based polymer resins and are biodegradable.

„Epoxies are high performance oligomers that contain epoxide groups and have traditionally been widely used in aerospace and marine applications. However, epoxies are increasingly being considered as the high-performance option for fibre composite matrix systems for use within civil engineering. In terms of processing, epoxies are characterised as having low shrinkage thereby enabling the production of large composite parts without distortion. Moreover, they have high mechanical properties, high temperature resistance, good resistance to chemical attacks and offer excellent fibre-matrix adhesion properties necessary for durability and structural performance."

(Manthey. 2011)

Obviously, in terms of an environmental perspective it is indispensable to produce composites in which both the fibre reinforcement and matrix are derived from natural resources. Thus, fostering sustainability. Accordingly, natural materials such as plant based bioresin and fibres have favourably low environmental impacts as they are of natural origin. They therefore constitute a suitable renewable resource from which to produce biocomposites. (Cf. Manthey. 2011)
In this context, a specific research project from Austria should be distinguished, as it contributed in a decisive way to the selection of the biocomposite productline in this thesis and clearly depicts the range of biocomposites. The endeavours of the hemp project, by the "Kompetenzzentrum Holz" in Linz, are based on the fact that conventional Windturbines and their up to 80 m long rotor blades are reinforced with glass fibres and are mixed with conventional polymers, hence plastic. This is not ecological in regard to the disposal after the usual lifetime of 20-25 years. In general, it seems inadquate when a technology objective is to save petroleum, but then needs it for the construction of the own equipment.
The hemp plant offers all the raw material, which is needed for the fabrication of a lightweight material, like in this case for the construction of wind turbines rotor blades. This lightweight construction composite or fibre-reinforced composite mostly consists of two components: A fibre, which arranges for stability, and a matrix made of resin, which gives a component any arbitrary shape. In the case of this new ecological biocomposite, hemp fibre will replace glass or carbon fibre and the resin made from hemp oil should replace the function of synthetic resins. Beside, the principle for production remains the same. (Cf. BMVIT 2016)

The endeavour to use hemp oil as a matrix for biocomposites has furthermore been approved in a study where „novel acrylated epoxidized hemp oil (AEHO) based bioresins were successfully synthesised, characterized and applied to biocomposites" (Manthey et al. 2012) Accordingly, „hemp oil based bioresins, specifically epoxidized hemp oil (EHO) and acrylated epoxidized hemp oil (AEHO) were synthesised and characterised and proposed as a potential replacement to their equivalent synthetic polymer resins (epoxy and acrylated resins) and also as an alternative to other commercially available bioresins." (Manthey. 2011) [4] The author concludes in his

[4] More information on EHSO can be found in annex III

dissertation, that „AEHO should be used instead of petrochemical based resins because the final properties are very similar in both type of composites and the environmental impact would be reduced“ (Manthey. 2011) Mechanical performance decreased for EHSO bioresins and biocomposites with increased bioresin loading. A significant reduction occurred after 30% bioresin concentration. (Cf. Manthey. 2011) Hence for the scenario of this thesis, a fibre-epoxy ratio of at least 70% is assumed.

Many procedures can also be realized with thermoplasitc biopolymers. An example is the bioplastic PLA (polylactic acid), which has reached the biggest market volume. For the time being it is primarily used for biodegradable packaging. However, together with natural fibres, PLA could also be used in more durable products. PLA has, compared to its petrochemically derived counterpart PP, limited mechanical properties and an unfavourable temperature performance. This PLA biopolymer is of interest for our scenario, as the dust residues from the biorefinery will find their way to a process where they are converted to a biocomposite. The incorporation of a biocomposite made of hemp dust and PLA into the scenario, was the evident consequence. Even more, as the latter one, when without any additives, showed after a temperature of 50 °C problems with stability of shape. For many more durable applications, this is unacceptable, as these temperatures can during summer already occur in parked cars. However, in comibination with hemp fibre, for instance in injection moulding or with compression moudling, the mechanical and thermal properties were considerably improved. Trials on the "Faserinstitut Bremen", have showed for moulded parts that were based on PLA und hemp fibres a stability of shape to 100 °C. Similar results and the feasibility when using hemp dust, which actually is a residue of the fibre and shive constituents, instead of fibre, have also been approved. (Cf. Spierling et al. 2014)

Compared to woodflour and woodfibres, it has been found that natural fibre reinforced polymers are especially superior when used in highvalue applications, for which good performances of stiffness are required for. (Cf. Carus et al. 2008) Dust, a residual product, which results from the processing of the fibres and shives, will accordingly be used for biocomposites in lowvalue applications. It apparently also has great prospects as plastic granules filler. This would moreover account for the endeavour of various hemp processors like for instance the Dutch Hempflax Company, which is increasingly convinced that in future the complete hemp plant may be utilized as biomass. (Cf. Hempflax)

5.2 Animal feed

According to the EFSA, „Hemp seed and hemp seed cake can be used as feed materials for all species. Several species-specific restrictions (fibre for poultry, polyunsaturated fatty acids for pigs) may be considered when incorporating such products into the complete feed. The proportion of rumen undegradable protein in hemp seed is considered advantageous for ruminants.“ Moreover, were there no adverse effects arised in regard to laying performance and egg sensory characteristics when up to 20 % hemp seed or hemp seed cake were applied to laying hens diets,. Linoleic acid and alpha-linolenic-acid however increased in the egg yolk. (Cf. EFSA. 2011) This feature which goes along with a more favourable and to customers well known „Omega 3-Omega 6“ ratio, should be estimated as a key feature of hemp feed, as the seeds contain an ideal ratio of Omega 3 and Omega 6, which are the polyunsaturaed fatty acids of hemp seeds.

Additionally, when compared to soybean meal as a protein feed for intensively fed growing cattle, hempseed cake results in similar production and improved rumen function. (Cf. EFSA. 2011) Other results with calves furthermore have indicated that hempseed cake „gives a higher feed intake, similar growth and lower feed conversion compared to calves given soybean meal. The digestive system works in a more balanced manner when feeding hempseed cake compared to soybean meal which is shown by a higher faecal consistency and DM concentration and a smaller number of long particles in the faecal matter from the experiment with the steers.“ (Eriksson. 2007) □Thus, hempseed cake is a suitable alternative to soybean meal as a protein feed for growing cattle. Consequently, hempseed cake will be used as an adequate animal feed and will be analysed against the background of soybean cake imports to the EU livestock sector.

5.3 Construction material and Insulation Material

As mentionned previously, hemp also provides woody fibres, also called shivs or hurds, which are already used in the construction sector for the production of a concrete-like material. These shivs are reported to be rich in silica (SiO_2), which when mixed with lime, release a mineralization process, which leads to the formation of a lightweight stone-like material. Moreover, is this building material resistant to rodent and termite attacks due to the presence of silica. (Cf. Guerriero et al. 2016) Hemp concrete, also simply called hempcrete, is a non-load bearing material. „It is used in association with a framework that can be steel-, concrete- or wood-framework. Usually, hemp concrete walls are coated on both sides but hemp concrete can occasionally be naked on the indoor side.“ (Prétot et al. 2013) Shives are actually centuries-old resources for housebuilding. The excellent qualities, namely the moisutre-regulation effect in combination with an increase in elasticiy and noise dampening, are still valid aspects until today. Hence, in the ecological building industry and for old-building renovations, hemp shives are used as aggregate for lime clay plaster. Additionally, the proportion of natural substances is related to an increase of the surface temperature of the walls, which causes a comfort effect. The high water absorption of the shives can lead to problems, which is why hydraulic binders as cement or lime are required. Ecological advantages of shives vis-à-vis conventionale building materials are:

- The application of sustainable and renewable resources.

- Fixation of CO2 over the entire lifetime of the building

- Reduction of the greenhouse effect

- Energy saving in regard to the production, transport and insultation of the building

- Avoidance of problematic building material and its deposition at the end of its use (Cf. Carus et al. 2008)

The up to date probably most famous with hempcrete built building is a brewery's new distribution centre in the United Kingdom inSouthwold, Suffolk. Also said to be „Britain's Greenest Warehouse“. It is a 2.382 m^2 warehouse, where the outer and intermediate walls are made of bricks built up of hemp shives, cement and lime. They are reported to have good insultation properties and the construction technique regulates humidity and temperature inside the depot. Even on the hottest summerdays, no additional cooling of the beer was needed. (Cf. Carus et al. 2008)

Generally speaking, as a construction material, hempcrete „combined with a timber frame can be used for walls, roofs and floors, each with a slightly modified compound. It can also be applied to the outer side of an existing home as outer wall insulation. The lime hemp mix is applied by spraying, deposited in a sliding casing or built with prefab pressed bricks. The outer walls can then be nished with a coated wooden cover or with a plaster mix of lime and sand.“ (Grow2build. 2015) The prefabricated hempcrete blocks are used in the same manner as in the traditional way of building with bricks at the construction site. Hempcrete blocks are laid and nished with lime or plaster. Larger bricks can also be laid on shingles as floor filling (Cf. Grow2build. 2015) Also, professor Eierle, lightweight specialist of the "FH Rosenheim", sees in view of an increasing significance of building in existing context, huge future markets for the lightweight building. This includes the use of hempcrete as a permanent supporting element and particularly as lightweight dividing wall, which can be used without strengthening of existing ceilings and structures in old buildings. (Cf. Carus et al. 2008)

In regard to a on hemp fibre based insultation mats, a review on natural insultation material, has pointed out „that the technical performance of several renewable insulation materials, such as cellulose and fibres from hemp, flax, kenaf and cotton, is comparable to that of the mineral benchmarks. According to the findings, renewable insulation materials could therefore easily replace traditional materials without loss of performance. (Cf. Visser et al. 2015) Today, mostly Glass wool, Stone wool and EPS are used for insulation materials. (Cf. IAL Consultants. 2014)

A good example for a successful implementation of hemp fibre insulation material is the german company „Thermonatur“, to which the highly paid German Environmental Prize of 250.000 Euros was awarded in the year 2013. (Cf. DBU. 2013) During the award ceremony, general secretary of the German Environment Foundation, Brickwedde, precised that the company acts as a role model, as it brings ecology and economy successfully in line and facilitates healthy building and resuscitated regional business cycles. The owner of the company, Carmen Hock-Heyl, got the idea to produce ecological insulation, because glass and rock woll rasp and irritate the skin. Furthermore, the fibre dust, which trickles down, at work irritates the eyes. She stated that it actually seemed ridiculous, that energy should be saved with conventional insulation with regard to the high-energy demand for the production of these products. Hemp insulation mats are however produced with considerably less energy input and chemical or harmful substances, she said. (Cf. DBU. 2013) Consequently, this paper will not only include hempcrete but also insulation material as a productline for the construction sector.

6. Scope of the productlines

This chapter is destined to further expose the data, which is necessary for an adequate assessment of the contribution that hemp could offer to the EU demand of the specific productlines. Namely, glass-fibre reinforced composites, soybean meal for animal feed, as well as conventioanl insulation material and concrete.

6.1 Composites production in the EU

Glass fibres are mostly used in composite materials, which are said to be the materials of the future. The most extensive use of glass fibre is as a raw material for composite materials. “Glass fibres are used for reinforcement in over 95% of the total volume of composites.” (Witten. 2014)□Moreover, are glass fibre composite materials used in an increasingly wide variety of applications. Presently, this is primarily the case in the automotive and transport sectors, the construction industry and the electrical or electronics industry. (Cf. GlassFibreEurope. 2013) In order to get an image of the EU glass fibre market, the data will be based on a press release of the „AVK – Industrievereinigung Verstärkte Kunststoffe“, which is the industrial association for reinforced plastics. Accordingly, 1,069 million tons of glass-fibre reinforced composites are produced for the European market per year, which is the highest stand since eight years. (Cf. AVK. 2015) This figure encompasses the composites, which are based on thermoset plastics, which are in most cases expoxides. It will be used as a reference to the purely on hemp based biocomposites product line. This demand would equal 21,024 tons per year for 10 million EU citizens.

As glass reinforced composites are by far the largest group of materials in the composites industry, they also are used for reinforcement in thermoplastic matrixes. 1,16 million tons were accordingly produced for the European market for thermoplastic, glass short-fibre reinforced compounds in 2013. The majority of these compounds are primarily based on polyamide and polypropylene. (Cf. Witten. 2014)□In our scenario, this respective figure will be taken as a reference for the on PLA and hemp dust based biocomposites, as the latter is a suitable short-fibre. In accordance to the demand of 10 million EU citizens this would amount to 22,824 tons per year.

6.2 Soybean based animal feed in the EU

The aim of this productline is to verify the extent to which hemp feed production can meet the EU demand for imported animal feed from non-EU countries. As soybean imports constitute by far the main import of animal feed to the EU, it will be subject to this paper.

Firstly, a broad overview of animal feedingstuffs, including feed materials and compound feeds, which are the main input into livestock production will be depicted. Each year, about 478 million of Tons of feedingstuffs are consumed by livestock within the EU-28. Most out of these 233 million Tons are roughages grown and used on the farm of origin. The balance, 245 million Tons of feed, includes cereals used and grown on the farm of origin (51 mio. t) and feed acquired by livestock producers to supplement their own feed resources. (Cf. FEFAC. 2014) Moreover, it seems crucial for the endeavour of this chapter to briefly outline the background on the EU livestock sectors import for animal feed. This short digression seems justified, given the tremdendous environmental burdens, which are exported and dislocated to the countries where the production of soybean animal feed is taking place.

In that context, it must be emphasized that one of the most important characteristics of the EU's agricultural system is the lack of balance between feed cultivation on one hand, and livestock production on the other. The EUs dominant production of meat and dairy products is highly dependent on protein feed imports, in particular soy imports from Latin America. This obviously has created some number of serious problems within the EU as well as in the rest of the world. Not only is the large scale import of feed a precondition and root cause behind the development of the EU as a large scale exporter of meat and dairy products. It is also not sustainable from an ecological point of view. A fundamental aspect of sustainable agricultural systems is the circulation of nutrients. This means concretely that manure from livestock is used to fertilize the fields where feed is grown. With the seperation of animal production and cultivation of feed and grains, nutrients cannot circulate. This will beyond doubt lead to waste problems in feed importing regions and to a depletion of the soils in feed exporting regions. Furthermore, are the large scale imports reinforcing soy production in large monocultures in feed producing countries, creating a number of ecological and social problems. (Cf. APRODEV. 2011.) These findings are considered as an absolute exigency to the significance of the objectives of this thesis. And must also be seen against the backdrop of the EU policies and their aims, which tend to ignore that the current situation is provoking environmental pollution in but also outside of the EU. Some of the already mentionned CAP reform measures actually aim to increase supply of EU produced proteinrich feed materials. (Cf. FEFAC. 2014) This was particularly due to the Commission's November 2010 communication on the future of CAP, where the need to enhance protein crop production within a more integrated crop rotation system was highlighted. (Cf.Euractiv. 2008.) Hence, the role which hemp seed presscake could play in this context will be reflected in our scenario.

The most recent figures of soybean imports to the EU consist of 19.0 Million Tons soybean meal and 13.2 Million Tons soybean oilseeds. (Cf. European Commission. 2016b) This amounts to a total of soybean meal of about 29.6 Million tons, based on the assumption that 80% of soybean oilseeds are processed to soybean meal. (Cf. De Visser et al. 2014) That would correspond to a 0.58 Mt/year demand of soybean cake for 10 million people. As we can see from the next table, soya meal is by far the main protein source for animal feeding in the EU.

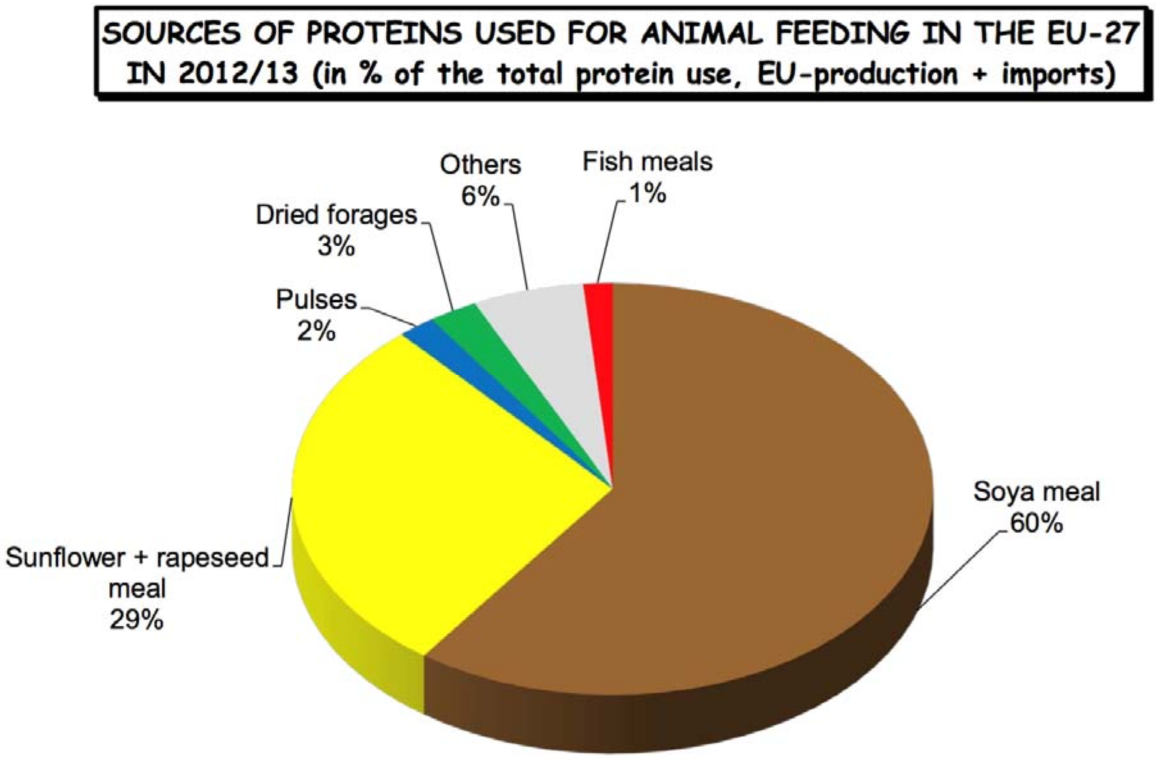

Figure 8: Sources of Proteins used for animal feeding in the EU-27 (FEFAC. 2014)

6.3 Construction material in the EU

In this chapter, an overview of the EU demand for insulation material and concrete, which could be substituted by hemp based materials, will be undertaken.

Concrete is the most widely used construction material in the world. It is made of aggregate concrete, which is normally bond together by a fluid binder in the form of cement. Also according to the European Commission's Communication on resource efficiency in the building sector, concrete is the most used material in buildings and its recycling reduces natural resource depletion and land filling of waste. (Cf. Cembureau. 2014) The non-load bearing concrete could partially be substitued by an on hemp shives and lime based construction material, called „hempcrete". Hence the total amount of EU demand for concrete as such is not comparable, as the hempcrete can currently only substitute the demand for non-load bearing concrete. Moreover, one needs to be cautious with approximation numbers for the possible subsitution of concrete with hempcrete. "Every different application requires a different technical specication of aggregates, some with extremely demanding requirements in respect of shape, durability, abrasion, frost resistance and other factors" (UEPG. 2012)

The most accurate number for concrete production in the EU stems from a EUROSTAT table for the EU-27 from the year 2007. Accordingly, 943,628,000 tons have been produced. (Cf. EUROSTAT. 2007). As previously mentioned, a rough estimation of how much of this concrete is used for non-load bearing applications is required. To find out about it an architect and a civil engineer were considered, who both assumed that 20-30 %, hence about 235,907,000 of concrete would be non-load bearing concrete. Thus, this would lead to a demand for ten million EU citizens of roughly 4,639,721 tons per year.

A total of 7,400,000 tons was according to a market research the EU demand for thermal insulation material in the year 2014. (Cf. IAL Consultants. 2014) Hence, the demand for 10 million EU citizens would amount to 0.146 Mt/a.

As we can see from the figure, 85% of the EU insulation materials consist of Glass wool, Stone wool and EPS (expanded polystyrol), which is a plastic material.

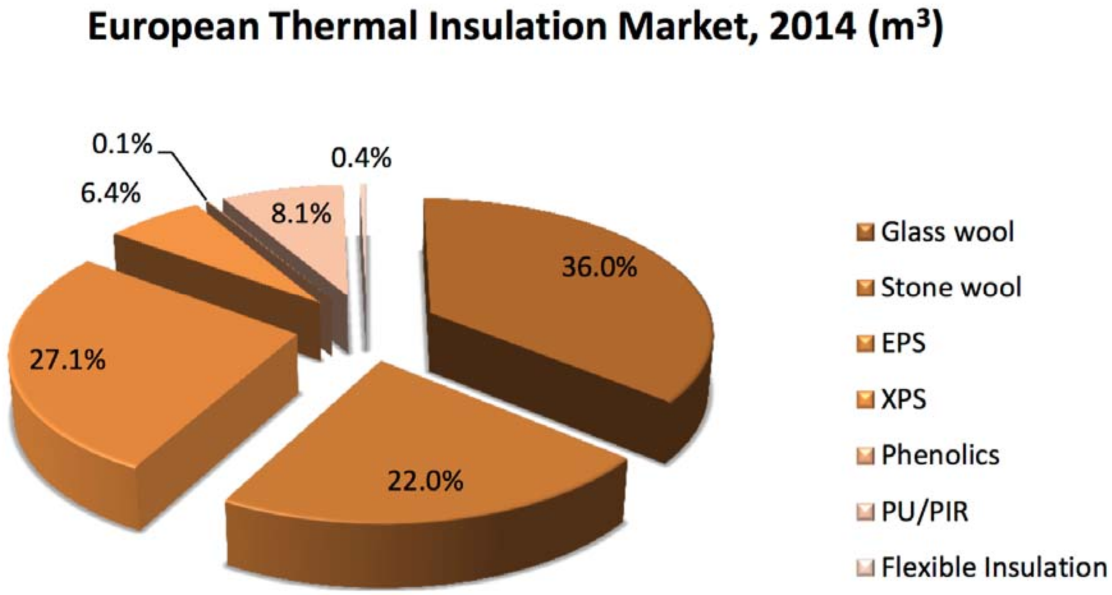

Figure 9: European thermal insulation market (IAL Consultants. 2014)

6.4 MFA

The MFA will be applied according to Brunner and Rechberger. (2004) This thesis will in accordance with the objectives incorporate the findings and illustrations provided by a MFA. A well established tool that is widely used in the scientific community for its applications in calculation of resource efficiencies, for optimizing waste management, regional planning and for environmental and resource management. "The MFA is a tool promoted by renowned scientific organizations such as the International Society for Industrial Ecology (ISIE) for instance, for environmental protection and resource conservation." (Baccini and Brunner 2012) This approach is in the "Hempland" context, genuinely new, as a representative and hollistic input-output estimation of the so-called "Hempland" is undertaken and fed with various already existing data sets. Hence, this consitutes a new contribution to the illustration of hemp cultivation, processing and the disposal of waste. The scenario helps to understand the impacts and consequences of how hemp provides viable biomass and with which major inputs.

6.4.1 System and Data considered

The MFA is founded on important system boundaries and frameworks necessary to realistically illustrate the "Hempland". Hence, it is based on some assumptions:

1. Due to land scarcity and in order to mitigate competition between lands used for food or non-food activities, both activities will be incorporated. Thus a coupling of straw and seed production is envisaged.
2. A biorefinery will refine the constituents, which result from the hemp cultivation and allocate the adequate proportions to the four subsequent processes. In our case these are decoupled from the former process in order to better illustrate the flows and processes. However, in reality a biorefinery, which incorporates the three production processes for biocomposites, insulation material and hempcrete could be envisaged.
3. The total annual input and output mass flows of "Hempland" as well as the long-term variations over a time period of 100 years will be taken into consideration. Hence, in regard to the objectives of this thesis, the extent of utilizable biomaterial will be reflected, which could arise in the long run by incorporating a reuse of the respective biomaterials. Thus, also what has been accumulated in the stocks over 100 years will be considered in the realm of possibility.
4. As "Hempland" should constitute a prototype region for a possible future scenario of hemp biomass supply for the EU Bioeconomy, data provided by diverse EU research studies from different countries across the EU will be considered.
5. It is assumed, that the waste-to-energy facility only processes clean biomass. Hence, the ashes can be reused for fertilisation.
6. Nearly one quarter, 24.7% of the EU-27 Land surface is cropland. Thus, hempland will use a chosen number of hectares of the available land.
7. Hemp cultivation is moreover considered as a favourable crop rotation plant, and hence it is assumed that cultivation on 10% of the EU cropland would be adequate. Consequently, the cultivated area corresponds to the average cropland available for a region with ten million inhabitants in the EU. Accurately, 212,843 hectares.

Fundamental for the establishment of the “Hempland” MFA and the data consideration, is the precise land surface on which the hemp crop will be grown. According to Eurostat, nearly one quarter (24,7 %) of the EU-27 Land surface is farmed cropland. (Cf. Eurostat. 2015a) The total EU-28 land surface is of 4,381,376 km2. In hectares: 438,137,600. This number is then divided by the 24,7 % in order to obtain the figure of available EU cropland. Which amounts to: 108,219,987 Ha. According to the latest statistics the total population of the EU-28 is of 508,450,856. (Eurostat. 2015b) This amounts to 0,21 hectares of cropland available per person in the EU and 2,128,426 hectares for ten million people. Of this available cropland, only 10% will be used for hemp cultivation. Consequently, 212,843 hectares will be cultivated with hemp.

The considered data will next be given a summary, which reflects the procedure of the “Hempland” system.

First of all, the imported terms and data will be elaborated. Thus, the main requirements, which the crop needs for an optimal growth, will be considered. This includes the mean values of recommended values of fertilisation, as well as the average water demand of the crop. The following terms will be subject to the initial „import“ part of the MFA: Nitrogen, Phosphor, Potassium, Water and Carbon Dioxide. In general, as already specified in chapter 4.1, hemp can be grown without any pesiticides, herbicides or fungicides. It therefore easily fulfills the requirements of organic farming.

In diverse studies found by the Nova Institute, hemp has following fertilisation requirements per hectare: 80-100 kg nitrogen, 100 kg phosphor and 150 kg potassium per hectare. (Cf. Carus, Piotrowski. 2011) Also suggested were, 75-125 kg nitrogen, 70-80 kg phosphor, 80-120 kg potassium. (Cf. Barth, Carus. 2015) According to Italian researcher, “the optimal dose resulted in 60–80 kg N/ha, which can be considered a low rate if compared to most arable crops.” (Zatta et al. 2012) Other sources from Austria consider a requirement of nitrogen, which lies between 100-150 and 100-140. For phosphor 50-75 and 80-120 kg/ha and for potassium 200-300 and 160-200 kg/ha have been considered. (Cf. Ofner. 2014.) Concerning the potassium fertilitzation, the results of a study lead by Burke should be reminded which suggests that the potassium requirements of hemp may be lower than previously assumed. (Cf. Burke. 2013)

Thus, the mean values for the respective nutrients per hectare are:

Nitrogen: 101 kg.

According to the “Hempland” scenario: 21284 Tons per year

Phosphor: 84 kg

According to the “Hempland” scenario: 17879 Tons per year

Potassium: 170 kg

According to the “Hempland” scenario: 36183 Tons per year

Carbon dioxide uptake of Hemp plants is based on data, which was estimated in a research study. “Usually, 1 g of dry biomass contains 0.5 g of Carbon, so it was estimated that 1 Ton of dry hemp contained 1.83 ton of biogenic CO2.” (Zampori et al. 2013) Thus in our case, the overall impact, when assuming a Biomass yield of 10.5 (data considered from this chapter) tons, for the cultivation of 1 ha, it is equal to about 19.2 Tons CO_2 eq/ha. According to the “Hempland” scenario: 4,086,586 tons of carbon dioxide per year.

In regard to the water import, data will be based on what has already been specified in chapter 4.1. In the United Kingdom, it has been shown that the water requirement to produce 1kg of dry matter is of 300-500 L per growing season. (Cf. Cherrett et al. 2005) As a result of an average of about 10.5 Tons of dry matter per hectare, the water requirement will be 4200 m3 per hectare. The study also elaborated that the hemp crop requires precipitation in the form of rainfall of about 500-700 mm per growing season. (Cf. Cherrett et al. 2005.) Hence, the mean value of 600mm corresponds to 600 Liter per m2 or 6000 m3/Ha. Totaling a mean value of 5100 m3/ha. In accordance to the “” scenario, this amounts to a water import of 1,085,499,300 m3 per year.

Regarding the export of the water losses, the mean value will include the green, blue and grey water footprint as mentionned by Mekonnen and Hoekstra. The numbers are in m3 per ton and are based on the faostat crop codes for hemp seed and fibre cultivation. The blue water footprint refers to the volume of surface and groundwater consumed and evaporated as a result of the production of a good. It is assumed that the water consumed is related to the import of water by rainfall. The green water footprint refers to the rainwater consumed. “The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards." (Mekonnen and Hoekstra. 2010)

Accordingly, the first prove for hemp seed has been asserted as follows:

Green: 3257, Blue: 12 and 417 for the grey water footprint. A Total of 3685.

For the second crop code of hemp fibre and tow:

Green: 1824, Grey: 624 and no Blue. Total of 2447 (Cf. p. 19-20, Mekonnen and Hoekstra. 2010)

As for the "Hempland" scenario, both seed and fibre production are envisaged. The average seed and fibre yield per hectare will be incorporated in the calculation. In accordance to the mean values obtained in this chapter, 1.1 Tons/Ha of seeds and 2.6 Tons/Ha of fibre will be considered. Hence, water losses will be represented by the green water footprint, which as according to Hoekstra is when considering both crop codes 4053 m3/Ha and 6382 m3/Ha, amounting to an average of 5217 m3/ha. This will be the water consumption in general. Meaning, also the total rainwater evapotranspiration and the water incorporated into the harvest crop,. For the "Hempland" scenario, this amounts to 1,110,401,931 m3 per year.

Nitrate leaching resulting from the hemp cultivation is of about 20kg/ha. (Cf. Van der Werf. 2004) Hence, for the "Hempland" scenario we consider nitrate losses of 4257 Tons per year.

For the export of oxygen, we need to assume rather uncertain figures, as these are not easy to assess in regard to many variables and factors, which influence the exact amount of oxygen, which is released on one hectare of hemp. Thus the data from the german "Maiskomitee" on 1 hectare of corn, which is assumed to produce the yearly human demand for oxygen of 55 people, will be taken as reference. (Cf. Maiskomitee. 2016) Consequently, when the yearly demand of oxygen for 11 people is of 4500 kg oxygen (Cf. RESET. 2016), the totaling oxygen produced on one hectare of corn will be of 22.5 tons. For the "Hempland" scenario, this would result in 4,788,968 tons of oxygen.

The next step will be to elaborate on the data, which resulted from the hemp cultivation process. The flows resulting from the hemp cultivation include the yields of fibre, shive, seed and dust. In a second step, the thereto quantitatively linked processed products will be outlined and elaborated

Some of the numbers for fibre and shive yields are based on the figures for hemp straw yield. 6-8 T/Ha of Hemp straw are according to an interview with Piotrowski from the Nova Institute a normal staw yield of hemp cultivation in Germany. 7.3 T/Ha per hectare is the average straw yield of EIHA members. (Carus et al. 2013) In Italy, researchers reported 15 tons of hemp straw yields for one hectare (Zampori et al. 2013) And in northern Italy, total straw yield for a variety called „Futura 77", ranged from 18.7 to 8.3 t ha over years and locations. (Cf. Salentijn et al. 2015) In a study which has been conducted in Ireland a hemp straw yield of roughly 12 tons has been found. (Cf. Burke. 2013)

Ofner has conducted one very detailed and more broadly based study compared to some other. In his doctor research study valuable data from field tests, which range from 2011-2013, has been investigated on two different locations in Austria. Also, a coupling scenario like for the "Hempland" approach has been adopted. According to his findings, the mean value for the years 2011-213 of all investigations resulted in a hempstraw yield of 4.1 T/Ha. The year, the location, the variety, the sowing density and various interdependencies have decisively influenced the yields parameters. (Cf. Ofner. 2014)

Hence, the mean value for hemp straw per hectare is of 9.8 Tons. It is assumed that of the total hemp straw from one hectare results in roughly 55% shives, 28% of fibre and about 13% of dust. The remaining percents, in the form of i.e stones are not of interest to this thesis, as they are assumed to remain on the fields. (Cf. Carus et al. 2008) Thus the 9.8 Tons/Ha of average straw yield per hectare can in average be processed into 5.4 tons of shives, 2.7 tons of fibres and 1.3 tons of dust. According to information of the EIHA, roughly one seventh of the total processed hemp straw results in dust. Thus, 9.8 tons/Ha straw yields would result in 1.4 tons of dust per hectare.

For solely fibre, 1.2 to 3.0 Tons (Salentijn et al.2015) and 3 Tons (Zampori et al. 2013) have been reported per hectare.

Regarding seed yields, a mean value which reflects the mean values identified by Ofer over a period of three years will be calculated.

2011 Seed yield: 969 kg/ha

2012 Seed yield 995 kg/ha

2013 Seed yield 822 kg/ha and 759 kg/ha (Cf. Ofner. 2014)
This results in a mean value for the three years of: 929 kg/ha.
According to Salentijn, a seed yield between 0.7 to 1.8 Tons/Ha is appropriate. (Cf. Salentijn et al.2015)
Referring to Eilenbecker, seed yield in Luxembourg and Belgium is reported to be between 1-1.2 Tons of seeds per hectare.
Thus, our final mean value for the diverse outputs of the „Hemp cultivation" output will incorporate following figures and result in the consequent mean values:

Fibre: 3 and 2.1 and 2.7 = 2.6 Tons/Ha

Shive: = 5.4 Tons/Ha

Seed: 1.3 and 1.1 and 0,9 = 1.1 tons/ha

Dust: 1.3 and 1.4 tons= 1.4 tons/ha

Concludingly, this would result in a total yield of Biomass of 10.5 Tons/ha.

For the "Hempland" scenario, the Hemp cultivation would result in 553,392 Tons of fibre, 1,149,352 Tons of Shive, 234,127 Tons of Seed and 297,980 Tons of Dust. Hemp fibre, shive and dust can and will already flow to the Biorefinery in a dissociated form. In in the Biorefinery will take place the further processing.

The occurring 297,980 tons of dust will completely flow to the biocomposites production and be used to produce lowvalue Biocomposites applications. 45% of the total fibre will flow to the biocomposite production and 55% to the insultation material production. The acuumulated shive yield will entirely flow to the production of hempcrete.

The seeds will in the Biorefinery be processed into expoxy resins and presscake. In this context, the mean value of oil content of the seeds is important to know. By this we will know the amount of presscake resulting from the oil pressing and the amount of oil. Hence, data on the oil/presscake ratio after pressing is necessary and has for this purpose been evaluated. Wuzzella has suggested in a conversation lead in the context of this thesis that all of the oil can be used for epoxy resins. In his case 36% of the total amount of seeds were converted to oil, of which again 100% was converted to EHSO. (Cf. Wuzella. 2016) Rene Allmer from the Austrian „Ölmühle Fandler" stated that they extracted 40% of oil from their seeds. (Allmer. 2016) A farmer from Luxembourg stated to extract 19-20% of oil from the seeds. (Cf. Eilenbecker. 2016)

Thus the mean value of oil content per Ton of Seed is of 32%.

According to this, out of 234,127 tons of seed, 74,921 tons will be oil and 159,206 tons will be presscake.

After processing the constituents in the Biorefinery, the accumulated raw materials, namely fibre, shive, epoxy bioresins (EHSO) and presscake will flow to the next respective processes. The presscake of 159,206 tons, which remains after the oil extraction, will flow to the „livestock breeding" process.

The fibre and EHSO will flow to the „Composites Production". Here 249,734 tons of fibre will be used as reinforcement of the biocomposites, as well as 297,980 tons of dust and 74,921 tons EHSO as a matrix biopolymer. Assuming an average fibre/matrix ratio of 70/30 as suggested in chapter 5.1, the production will result in 324,655 tons of highvalue biocomposites per year, which flow to the customers.

The hemp dust is suitable for reinforcement in PLA biocomposites up to content of 40% with the currently used processing equipment. (Cf. Spierling. 2014) Hence, 297,980 tons of dust tons will be mixed with 446,970 tons of imported PLA. PLA is a polylactic acid made of dextrose (sugar) and is sourced from bio-based products. It currently is the most popular Biopolymer. (Cf. Resinex. 2016) This will result in the production of 744,950 tons of so called lowvalue biocomposites per year.

Then, 55% of the amount of 303,658 tons of fibre, and the total amount of 1,149,352 tons of shives will flow to the „building construction sector". After processing, 341,615 tons of insultation mats will flow to the "insulation costumers". The amount of fibre needed per ton of insultation mats was calculated by using the data sheet of the „Thermohanf premium plus" product from the german „Thermohanf" company. According to their data sheet the hemp insulation mat is made of 85–90% hemp fibre, 8–10% biopolymer on PLA-Basis and 2–5% Soda salt as fire protector. Hence, it is a completely bio-based product, where for the purpose of our pruductline, insulation mats are made up of 85% of fibre and of a 15% mix of PLA and soda salt. (Cf. Thermohanf. 2014)

Regarding the production of hempcrete, 1,379,222 tons of hempcrete will flow to the „hempcrete customers“. This finding is based on the 1,149,352 tons of shives, which are used in combination with a binder to produce hempcrete. According to “isohemp”, hempcrete is based on 80 % shive and 20% lime. (Cf. Isohemp. 2016)

According to Article 11 (2) of the in 2008 of the EU parliament adopted directive 2008/98/CE, affecting the recycling objectives for 2020, 50% for domestic wastes and 70% for construction and demolition waste must be re-use, recycling and other material recovery. (Cf. European Parliament and European Council. 2008)

For the reuse of biocomposites, it has been retained that „composites of PP and vegetal fibres are recyclable following the European directive 2000/53/EC, which imposes the reusing/ recycling of at least 95% of a worn vehicle weight before 2015.“ (Soroudi et al. 2013) The mechanical and thermophysical behaviour of PP/hemp or sisal composite after seven injection cycles showed furthermore a small decrease in tensile strength and modulus of the seventh-time recycled composite, which could be compensated by adding extra fibres/polymers in proporion to the recycled materials. This could retain the mechanical properties of the material. (Cf. Soroudi et al. 2013) However, these are still vague assumptions, which heavily depend on the various compositions and applications of the biocomposites. Hence, also here one has to be cautious with sharp assumptions on how much of the materials can actually be reused. The stocks have been estimated on the basis of a 25 years life expectancy. The amount of reused material flowing back to the production process should best possible reflect the EU reuse endeavours. Thus, for the reuse I, 50% of the till the year 25 inflowing biocomposites will be incorporated. Of these 50%, conform to their former part in the yearly input to the biocomposites customers, 31% of the reused material will again flow into the hemp based biomaterials flow and 69% into the hemp/PLA based biocomposites flow.

The reuse of hempcrete is definitely feasible as has been stated by Daly and others. „A hemp lime mix can be reused at the end of its life by crushing it, mixing it with water and some additional lime binder and casting it anew. This applies to any form of hemp lime application, be it monolithic walls, bricks or blocks.“ (Daly,et al. 2009) Moreover has Spina from Chaux de Contern in Luxemburg confirmed, that at least 50% could be reused without efforts. (Cf. Spina. 2016) As mentionned before, the stocks for the hempcrete incorporating process will be based on the life-time expectancy of traditional buildings materials of 100 years. Hence, 70% of the in the reuse flow incorporated hempcrete will flow back into the hempcrete output of the production process.

For mainly hemp-based insulation material as provided by the german „Thermohanf" company, it is openly known that they are unproblematic for reuse. For the stocks of insulations mats, the average life expectancy of insulation material of about 50 years has been assumed. (Cf. Visser et al. 2015) As for hempcrete, 70% of the material will be reused.

Concerning the amount of ashes, which result from the waste-to-energy process, the average ash content of matured timber is taken as a reference for the incineration of the waste streams which occur in "Hempland". This seems to be the most adequate and comparable data in order to estimate the ash, which will result from the incineration of the speficied productlines. The upper bound is 12% and the lower bound is 6% for matured timber. Hence, a meanvalue of ashcontent of 9% is assumed for the waste, which flows from the Biocomposites customers and the Insulation customers to the WTE facility. (Cf. Obernberger. 1997) The remaining ashes from the waste-to-energy facility will be returned to the agricultural land in the form of fertilizer. The flue gas leaving the chimney is assumed to amount to the remaining mass, which is not incorporated in the ashes content.

6.4.2 The processes and stocks (in Tg = Mt)

Biocomposites production (P3)

The *biocomposites* process represents the completely bio-based composites, which are made from hemp *fibre* II (F11) and *EHSO* (F10) for highvalue applications named *hemp* (F15) and from hemp *dust* II (F9) and *PLA* (F37) for lowvalue applications named *hemp/PLA* (F33). These biocomposites then flow to the *biocomposites customers* (P4), from where the *reuse I* (F23) input also originates. This flow reflects the amount of biocomposites, which can be reused from the *biocomposite customers* (P4). In *reuse I*, 50% of the till the year 25 inflowing biocomposites will be incorporated. Of these 50%, conform to their former part in the yearly input to the biocomposites customers, 31% will of the reused material will again flow into the hemp based biomaterials flow and 69% into the hemp/PLA based biocomposites flow.

Biocomposite customers (P4)

Here, inputs are *Hemp* (F15) and *Hemp/PLA* (F33). After, that the biocomposites have been used, they will flow to the outputs of *reuse* (F23) and *waste I* (F28). As there is a wide range of applications for biocomposites, an average lifetime of 25 years is assumed. Thus, 20.25 Tg biocomposites will accumulate in the stock.

Biorefinery (P2)

The next process will be the *Biorefinery* where the main constitutents of the crop are adequately seperated and prepared for a further utilization in the following processes. These include the *biocomposites production (P3)*, *livestock breeding* (P5) and *construction material production* (P7). The input of fibre will be split into the outputs of *Fibre II* (F11) and *Fibre III* (F13). The entire amount of *dust I* (F9) will flow by *dust II* (F16*)* to the *biocomposites production* (P3) and all of the *shive I* (F7*)* to *the construction material production* (P7) by the flow of *shive II* (F14). 32% of the seed (F8) will in the form of *EHSO* (F10) flow to the *biocomposites production* (P3) *and 68% in the form of presscake* (F12) to the livestock breeding (P).

Construction material production (P7)

The inputs of *fibre III* (F13) and *PLA/Salt* (F38) contribute 85%, respectively 15% to the *insulation mats* F20). The inputs of *shive II* (F14) and lime (F36) are used for the *hempcrete* (F21). Moreover, are the *reuse II* (F24) and *reuse III* (F22) inputs, which result from the to an extent of 70% reused material that flowed year per year into the stock of *hempcrete customers* (P10).

Hemp cultivation (P1)

The first process, *hemp cultivation* encompasses the imports for the agricultural land where hemp is cultivated. This includes *water* (F1)*, carbon dioxide* (F5)*, nitrogen* (F2), *phospor* (F3) and *potassium* (F4) and consequently also reflect the amounts of *fibre* (F6)*, shive I* (F7), *dust* (F9) *seed* (F8), which result out of a successful *hemp cultivation* on this land. Inputs are manure from the *livestock breeding* (P5) and debris from the *hempcrete customers* (P10*)*. Moreover, a flow of *nitrate leaching* (F25), oxygen (F3) and water losses (F34) are exported out of this process. The stock is expected to decrease by 26.20 Tg/a with an uncertainty of 0.63 Tg.

Hempcrete customers (P10)

This process has as an input *hempcrete (*F21), which comes from the *Construction material production* (P7). Hemp–lime walls are expected to last over 100 years or at least equal to traditional construction. (cf. Ip and Miller. 2012). Consequently, after 100 years, 138 Tg of hempcrete will be in the stock. The outputs will be incorporated in the *reuse I (*F23) and *debris* (F29) flow.

Insulation Material customers (P8)

The *insulation material customers* have the *insultation mats* (F20) as input. *Waste II* (F30) and *reuse* II (F23) are outflows. After 50 years, a total stock of 17 Tg will have accumulated. The yearly outflow from the process is by 70 % of the intial yearly input, incorporated in the *reuse II* (F24) flow and the flow into the *waste II* (F30) will be of 0.34 Tg/a. Hence 0,24 Tg/a flow to the *Construction Material production* (P7) and 0.34 Tg/a to the *WTE (*P9) facility.

Livestock breeding (P5)

In this process, the hemp seed meal is adequately used for animal feeding in the *livestock breeding*. The input is constituted of 0.16 Tg/a *presscake* (F12). The output is naturally measured by the amount of *manure* (F27), which makes up 0.16 Tg/a. It is assumed that the adequate amount of manure which can be brought back to the *hemp cultivation* (P1) process, makes up more or less the amount of presscake which has been added to the diet of the in the livestock living animals.

Waste-To-Energy (P9)

In this process, the waste materials from the *insulation customers* (P8) and *biocomposite customers* (P4) will be processed into energy. It is assumed that only clean Biomass is incinerated, as this allows a subsequent disposal of *ash* (F31) to the *hemp cultivation* (P1) land. The remaing output will be *fluegas* (F32) A meanvalue of ashcontent of 9% is assumed for *waste I* (F28) and *waste II* (F30).

6.4.3 The flows (in Tg/a = Mt/year)

Ash (F31)

The 0.13 Tg/a ash results from the *WTE* (P9) and flows back to the *hemp cultivation* (P1), where it will be used as a fertiliser.

Carbon Dioxide (F5)

This flow encompasses the whole *carbon dioxide*, which is taken up by the hemp plants, grown in the *hemp cultivation* (P1) process. A total of 4.09 Tg/a

Debris (F29)

This flow amounts to 1.38 Tg/a and comes from the *hempcrete customers* (P10), where not all can be reused and hence will immediately be disposed on the *hemp cultivation* (P1) area.

Dust I (F16)

The dust resulting from the *hemp cultivation* (P1) is incorporated in this flow. Amounting to 0.30 Tg/a.

Dust II (F9)

Dust II refers to the amount of dust, which is flowing from the *Biorefinery* (P2) to the *biocomposites production* (P3) process. It still amounts to 0.30 Tg/a

EHSO (F10)

EHSO represents the yearly production ofthe Biorefinery that flows to the *biocomposites production.* (P3) In total 0.08 Tg/a.

Flue gas (F32)

The *flues gas* is a stream of an estimated 1.29 Tg/a, which is occurring due to the incineration of Waste I (F28) and II (F30). 91% of the total waste will result in *flue gas*.

Fibre I (F6)

The *fibre* flow stands for the amount of fibre, which results from the *hemp cultivation*

(P1). It amounted to 0.55 Mt per year.

Fibre II (F11)

Here, 0.25 Mt/year flow from the *Biorefinery* (P2) to the *Biocomposites production* (P3).

Fibre III (F13)

This flow represents the other 0.30 Mt/year that are going from the *Biorefinery* (P2) to the *Construction material production* (P7).

Hemp (F15)

Hemp is the abbreviation for on *EHSO* (F10) and *Fibre II* (F11) based biocomposites, which flow from the *biocomposites production* (P3) to the *biocomposite Customers* (P4) process. Amounting to 0.45 Tg/a.

Hemp/PLA (F33)

Here as well, the flow is inflowing from the *biocomposites production* (P3) and will continue to the *biocomposite Customers* (P4) process. In this case, only 40% of the biocomposite are made from hemp *dust II* (F9) and the rest from *PLA* (F37), in total 1.03 Tg/a.

Hempcrete (F21)

This flow encompasses the total amount of 2.35 Tg/a of *hempcrete* that flows from *construction material production* (P7) to the *hempcrete customers* (P10).

Insulation mats (F20)

Here, the total amount of 0.58 tg/a is reflected, which flows out of the *construction material production* (P7) and subsequently goes to the *insulation material customers process* (P8).

Lime (F36)

The *lime* is estimated to contribute 20 % to the *hempcrete* (F21*)*, which is being processed in the *construction material production* (P7). Amounting to 0.23 Mt per year.

Manure (F27)

The *manure* flow of 0.16 Tg/a incorporates the manure that results from the *livestock breeding* (P5) and consequently flows to the *hemp cultivation* (P1).

Nitrate losses (F25)

This flow encompasses the nitrates, which are, dependingly on various factors, in average leached out of the *hemp cultivation* (P1) area and consequently transmitted into the surface water and groundwater. The flow resulted in an export of 0.004 Tg per year.

Nitrogen (F2)

It represents the import of 0.02 tg/a of the total *nitrogen* fertiliser requirement to the system and the *hemp cultivation* (P1) process.

Oxygen (F35)

The export of oxygen is the estimated amount of about 4.79 tg/a, which is released by the plants on the *hemp cultivation* (P1) area.

Phosphor (F3)

This flow stands for the import of the total *phosphor* fertiliser requirement to the system and the *hemp cultivation* (P1) process. Amounting to 0.02 Tg/a.

PLA (F37)

The PLA import which is needed for the production of Hemp/PLA bicomposites in the *biocomposites production* (P3) amounts to 0.45 Mt per year.

PLA/ Salt (F38)

Here, 10% of PLA and 5% of Salt are imported to the *construction material production* in order to contribute 15%, in total 0.04 Tg/a, to the production of *insulation mats* (F20).

Potassium (F4)

It represents the import of the total potassium fertiliser requirement to the system and and the *hemp cultivation* (P1) process. In “Hempland” this amounts to 0.04 tg/a.

Presscake (F12)

This flow incorporates the total amount of hemp seed *presscake,* which resulted from the oil extraction in the *Biorefinery* (P2). In total 0.16 Tg/a.

Reuse I (F23)

This flow reflects the amount of biocomposites, which can be reused from the *biocomposite customers* (P4) and can hence be reincorporated into the *biocomposites production* (P3). It amounts to 0.40 Tg/a.

Reuse II (F24)

The second reuse flow of 0.24 Tg/a, incorporates the used material flowing from the *insulation customers* (P8) back to the *construction material production* (P7)

Reuse III (F22)

Here, the used hempcrete material is flowing from the *hempcrete customers* (P10) back to the *construction material production* (P7). In total 0.97 Tg/a.

Seed (F8)

This flow represents one of the four outputs of the *hemp cultivation* (P1) in which the amount of 0.23 Mt of *seed* per year is incorporated.

Shive I (F7)

The s*hiv*e *I* flow results from the *hemp cultivation (*P1) and amounts to 1.15 Mt/year.

Shive II (F14)

From the *biorefinery (*P2), the entire input of *shive I* (F7), accurately1.15 Mt are per year transferred to the *construction material production (*P7).

Waste I (F28)

The waste, which flows out of the *biocomposites customers* (P4) process and consequently is incinerated in the *WTE (*P9) process, amounts to 1.08 Tg/a.

Waste II (F30)

Within this flow, the total waste of 0.34 Tg/a out of the *insulation customers* (P8) to the *WTE* (P9) process is incorporated.

Water (F1)

Here the approximate amount of water of 1,085 Tg/a, which is imported to the hemp cultivation. (P1) is represented.

Water losses (F34)

The water losses reflect the occurring losses of water during the *hemp cultivation* (P1) and are consequently exported. To a total of about 1,110 Tg is estimated the yearly seepage of water on the area where hemp is cultivated.

6.4.4 MFA Hempland

On the next page, the MFA of the "Hempland" scenario will be illustrated.

It will be followed by an illustration of the "Hempland" scenario, where the flows related to water, namely "Water" and "Water losses" are excluded. This should help to even better recognize the crucial points at first sight.

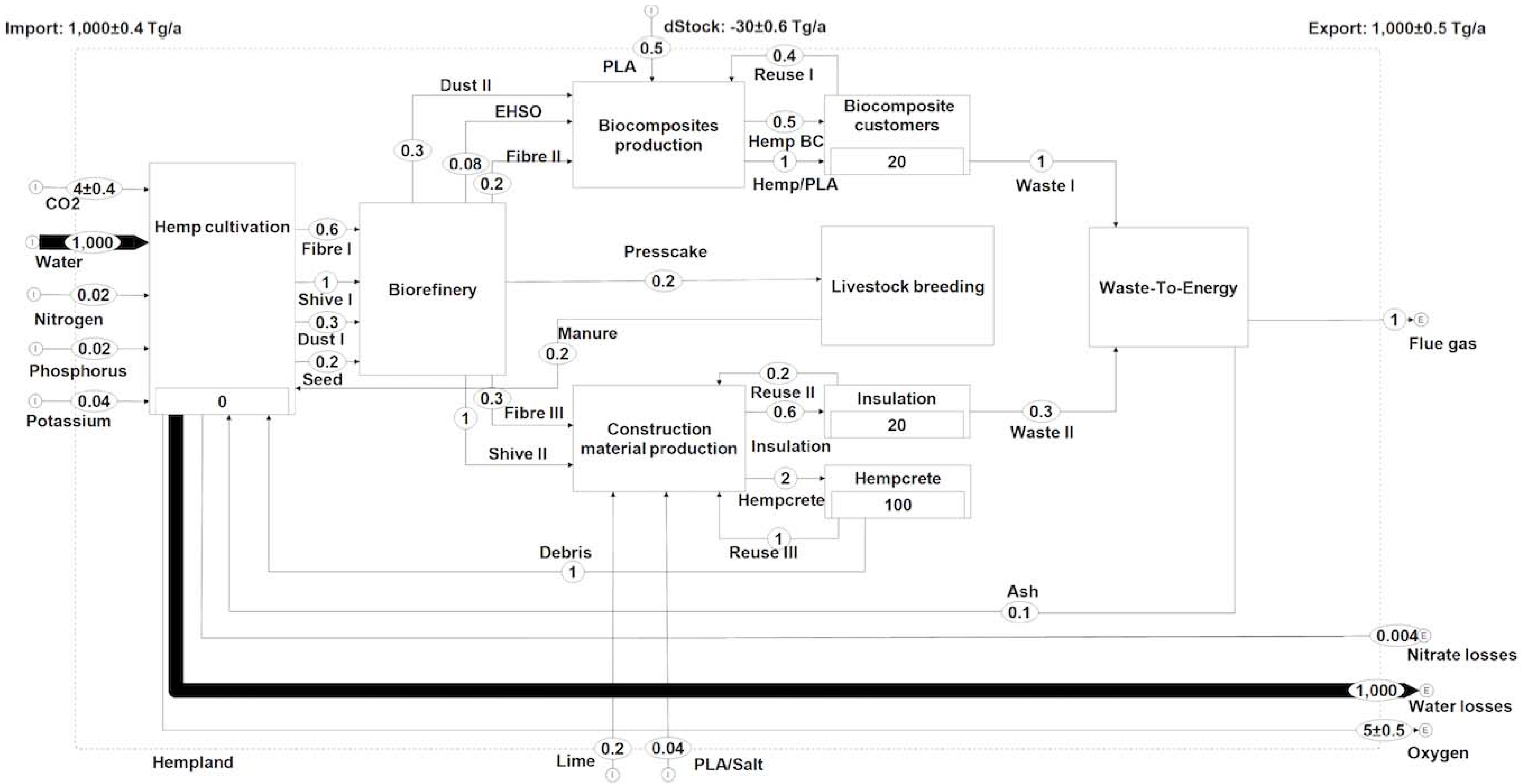

Figure 10: MFA of the “Hempland” scenario

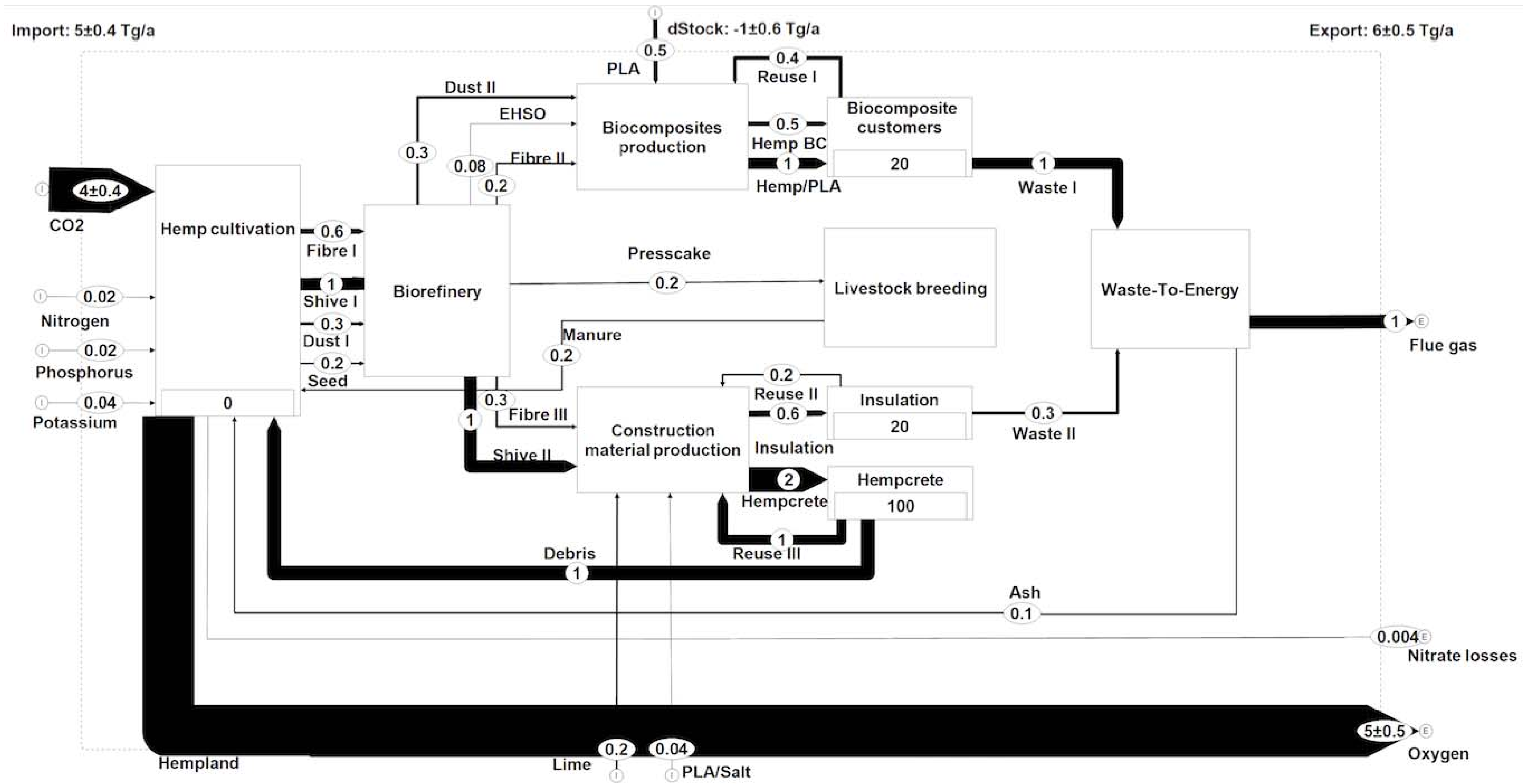

Figure 11: MFA of the “Hempland” scenario without water flows.

6.5 Overall assessment and discussion of the results: Assumptions, Approximations and Missing Data

The MFA has disclosed the processes, flows and stocks of major importance in the "Hempland" system. The hemp cultivation process is by far, with the import of water and the export of losses of water, as well as the import of carbon dioxide and the subsequent export of oxygen, the most mass loaded process. It was also the most challenging one. Due to missing data and the complex biophysical dynamics and challenges of such a process, some assumptions and approximations had to be made. Moreover has an uncertaintity of 10% in this context been assumed for carbon dioxide and oxygen. Evidently, the amounts of water losses by evapotranspiration and incorporation into the crop or the import of carbon dioxide, respectively the export of oxygen are more complex and difficult to estimate then expected. Thus, assumptions, estimations and approximations were incorporated in order to estimate adequate quantities had to be based on findings presented in literature. The same is true for the strong decrease of the hemp cultivation stock of about 26.20 Tg/a, which can mainly be attributed to the difference between water import and export of water losses.

Although the mass is more significant then expected, the water is only to a neglible extent contamined with harmful substances as for instance nitrate leachate. A yearly nitrate load of 0.004 Mt/year opposes an estimated total water import of 1085 Mt/year and water loss of 1110 Mt/year. Actually, the outstanding quantities of water seem to be the only commodity, with a major environmental relevance.

Furthermore, the MFA has shown in the long run, that of the 1.44 Mt of the all in all waste per year, an amount of 0.13 Mt ashes is generated per year. Hence the ashes, will together with the long-term accumulation of 1.38 Mt/year debris, contribute to a significant reflow of potential fertiliser to the hemp cultivation process. This fact must be seriously taken into account when looking on the overall effect on ressources. These findings are also deemed crucial when conducting a project, which reflects the traits of the "Hempland" system. Moreover the 1.29 Mt of fluegas per year are of further environmental relevance, as well as the already mentionned decrease of the hemp cultivation stock. In reality, however there is a stock of water on every hectare of land. Due to a lack of data, no consideration was possible in that sense. Hence, the depletion of the stock must be analysed with care as adequate data is missing and therefore puts a decisive obstacle to the endeavours.

Beside, the MFA has additionaly reveiled another limiting factor, which plays a major role in a “Hempland” scenario, namely the rate of reuse. As a matter of course, the various reuse flows constituting the inputs to the respective production flows, have shown that they are contributing to an increase in material production after the assumed end of the stocks accumulation. The state of the art, however did not allow a further investigation of how the reuse and subsequent production of new materials will furthermore influence the system after the 50 years of the insulation material stock accumulation and 25 years for the biocomposites stock accumulation. In regard to biocomposites for instance it seems not clear how much extra fibres/dust/polymers in proportion to the reused materials should be added for an optimal outcome. This is due to the fact, that these materials and their end of life phase are still relatively unreflected in research. Moreover can the rate of reuse of biocomposites, insulation mats and hempcrete, strongly vary depending on their sepecific application and composition. Assumptions had to be made in regard to the percentage of new material, which needs to additionally be added in order to reuse biocomposites, insulation Material and hempcrete. Hence, no additional supply of material for the reuse of previously in the stocks stored material was envisaged.

However, it can be said that from a first reuse of products, which were before stored in the respective stocks, originate a crucial amount of new potentially reusable material for the production processes. In regard to hempcrete this would, after the stock has accumulated hempcrete for 100 years, amount to 2.35 Mt per year and for insultation material to 0.58 Mt per year. The biocomposites reuse could increase the flow of entirely hemp-based biocomposites to 0.45 Tg/a and 1.03 Tg/a for hemp and PLA based biocomposites. The change in reuse rates for the respective customers processes, moreover reveil how important it is to optimally control the inflows and outflows of the hereto-linked flows and processes. Adequate reactions and adaptations in the supply of new materials and reused ones are indispensable in order to guarantee a sustainable handling of the dynamics, which may originate. This also regards the amount of waste, flowing to the WTE.

In general, it was obvious that for the objectives of “Hempland”, data would be very limited and inconsistent as the research activites are only about to have started and due to the dynamics and variations of the data used for the system. There is still plenty of scientific work required, in order to precisely determinate viable inputs and outputs of all processes, stocks and flows which were incorporated into this scenario. Nevertheless, „Hempland“ can give a good basis for future research, when additional data may be more accessible and widespread.

7. Summary and conclusions

After a brief description of the bioeconomy and more specifically the challenges and endeavours of the EU bioeconomy, some of the possible applications for hemp in that context were further elaborated. A short excursion to the main environmental and ecological implications of hemp cultivation has allowed a deeper understanding of the impacts and their interlinkages with the bioeconomy as such and the EWFD and the CAP. Their main objectives and key endeavours to improve the situation of the involved stakeholders situation were illustrated and described. In this context, the data assembled and resulting out of the MFA, suggested that only the nitrate leaching might to a certain extent foil the nitrate directive of the EWFD. Possibly, the considerable water consumption of the hemp crop may, for instance in a period of drought, lead to additional pressure on water resources. However, the water consumption is still considered to be very moderate and not as severe as for other widely cultivated crops. Although, this comparison is not part of this thesis, it would be of major importance in regard to an overall environmental assessment and should be investigated in further research. The same is true for nitrate leaching.

In regard to the EWFD, the absence of pesticides and herbicides during hemp cultivation would significantly contribute to the achievment of objectives, like those related to the groundwater directive, which is broadly characterized by the fact that it should not be polluted at all. The European Commissions has stated its aim of a general protection of groundwater with a minimum of anthropogenic impacts. Also could hemp cultivation act supportive regarding the integrated pest management, where the general intention is to apply agrochemicals as little as possible when necessary and to best possible renounce on the use. Hence, it is also more specifically complying in regard to the endeavours of the EWFD, which complements Directive 2009/128/EC and the integrated pest management. As it promotes low pesticide-input management including non-chemical methods, "Hempland" would significantly lead to a better achievement of these objectives. In annex 3 of the latter directive is moreover suggested to achieve the aims of integrated pest management by the means of crop rotation. This again would lead to an evident need to politically foster or at least be in favour of hemp cultivation in the context of a growing bio-based economy and the environmental objectives of EU directives. This must be further accentuated.

While not foiling the EWFD, an intensified hemp cultivation is also considered to comply with the three long-term CAP objectives of viable food production, sustainable management of natural resources and climate action and balanced territorial development. Here, the possible interlinkages and the challenges of the CAP obviously seem to be perfectly fitting with the advantages of hemp cultivation. “The reform focused on the operational objectives of delivering more effective policy instruments, designed to improve the competitiveness of the agricultural sector and its sustainability over the long term.” (European Commission. 2013) Briefly said, the EU agriculture needs to attain higher levels of production, while preserving the natural resources that agricultural productivity depends upon. Farmers are for example rewarded for applying crop diversification. Thus, as a crop with no pesticide requirements, good weed competition, soil improvement and suitability for crop rotations, hemp seems to be a legitime crop, in regarde to the esteem of CAP and EWFD policies and their objectives.

This positive outcome comes furthermore along with a considerable output of valuable goods, which can sustainably substitute current commodities, like traditionally with glass fibre reinforced composites, soybean meal, insultation material and concrete. The crucial inputs to a biorefinery where hemp is processed for the specified purposes of its constituents are made of 0.55Mt/a of fibre, 1.15Mt/a of shive, 0.30 Mt/a of dust and 0.23Mt/a of seed. These ressources can be processed into 0.33 Mt/a of, on hemp fibre and EHSO, based biocomposites. And with a share of 60% of PLA, 0.30Mt/a of dust can be processed to 0.75 Mt of lowervalue biocomposites. The rest of the seed, which is left after the oil extraction, can be processed into 0.16Mt/a of animal feed. In terms of construction material, 1.38Mt/a of hempcrete with a 20% content of lime and 0.34 Mt/a of insulation mats with a 15% content of PLA and salt can be produced. However, except for the animal feed purpose, the outputs look different when incorporating the effect of material reuse in the long run. Then the available biomaterial for the production of goods increases to even more important amounts.

If a reuse is incorporated, then for hemp-based biocomposites, 0.45 Mt, and for hemp/PLA-based biocomposites 1.03 Mt can per year be provided to the customers. In regard to the construction material, 0.58 of insulations mats and 2.35 Tg/a of hempcrete can be produced. These figures must also be seen against the background of the respective figures for the total EU demand. For glass-fibre reinforced composites with an epoxy matrix, a EU wide demand of 1,069 Mt/year is considered. Hence, 0.33 Tg of on hemp fibre and EHSO based biocomposites could after the first production year replace by far the adequately calculated demand of 0.02 Tg/a of glass-fibre-reinforced composites. The EU demand for the equivalent to hemp dust and PLA based biocomposites with a 40/60 hemp/PLA share, would, with 22,824 tons per year be slighty higher. A total production of 0.75 Tg/a would be available for the substitution of glass-fibre reinforced thermoplastic. After a long-term production of about 25 years, even more important amounts of biocomposites could be produced. Hence, crucial amounts of fibre and hemp seed oil would, in a more sophisticated “Hempland” scenario, be available for other productlines where fibre or oil is needed, like i.e cloth production, cosmetics etc. Hence, a recommendation for the future would be to analyse the junction of various productlines, like for instance hemp fibre reinforced concrete. Dust could beyond the here investigated productline be used for other bioplastic usages, paper and pulp, as an extender for animal feed or for the fabrication of hemp briquettes.

7.4 Mt/a tons of consumed insulation material in the EU, correspond to 0.146 Mt/a for 10 million EU citizens. These could be substitutued by on 85% hemp fibre based insulations mats. The supply in the “Hempland” scenario would by a twice as high amount of 0.35Mt/a and even by 0.58 Mt/a substitute the traditional insulation material, when considering the long-term effect of reused material.

Regarding the average demand of 0.58 Mt/year of soybean cake for 10 million people in the EU, hemp seed presscake could substitute 0.16 Mt/year. Thus, on “Hempland” beside the previously mentioned quantities, enough presscake could be produced to substitute a little less then one third of the demand for soybean meal imports for the livestock breeding.

With an incorporation of 80% of hemp shives, hempcrete could substitute about 1.38 Mt per year and with regard to the reuse of hempcrete, 2.35 Mt per year. This is to be seen against the background of an estimated demand of 4.6 Mt per year for non-load bearing concrete when considering ten million EU citizens. Hence, hempcrete produced in the realm of the “Hempland” scenario could, when starting from the scratch, contribute to a bit less than one third of the demand and more then half when considering the reuse of hempcrete after a period of 100 years. The different rates of substitution of conventional productlines by bio-based products makes a concise assessment of how much of hemp cultivation would be maximal reasonable, very challenging and difficult. This is also due to the fact that this still basic scenario of hemp utilization is not adequately enough to realistically assess the full potential of an even more towards i.e fibre and dust processing oriented biorefinery scenario. Concludingly, this thesis provided further evidence and findings, which are linked to following major points:

1. The hemp crop is able to provide the bioeconomy with crucial amounts of sustainably produced biomass in order to fulfil the demand of various established and uprising sectors within the bioeconomy, without foiling the mainly on human health and environmental protection based essences of the EWFD and the CAP.

2. The MFA can help to better understand, quantify and illustrate the "Hempland" scenario. Hence, this thesis incorporates a new approach with an adequate illustration of the flows and processes, which are part of a scenario where multifunctional hemp is grown for its specific purpose in an average EU region.

3. Water is the most important mass flow in the system. Followed, by the sequestration and release of CO2 and O2. Besides, flue gas, waste and debris are the flows with the most crucial impact in a hempland scenario.

4. In a EU average region with 10 million people, where 10% of the cropland is cultivated with hemp, the first harvest can contribute to the production of 1.48 Mt/year of biocomposites. Additionally 0.16 Mt/year of animal feed, 0.35Mt/year of insulation material and 1.38 Mt/year of hempcrete would result from this region.

All in all, the elaborated outcomes can hence help to contribute to an integrative political and economical action and strategy concept. This should help to foster the bioeconomy rising demand for sustainably produced biomass by acknowledging the effects on environment and resources as well as the valuable, yet high outputs of an adequately cultivated hemp crop. Future research needs are hence cleary existent in regard to a further deepening of the here esablished interlinkages and the optimal cultivation of hemp for, adequately the reality reflecting, productline scenarios. In this respect, the hemp crop should progressively be investigated and developed as a dedicated bio refinery crop from which every part is used to generate value. In this context, a incorporation of further EU polices dealing with i.e waste or climate change could, against the background of the CO2 sequestration capacities of "Hempland", lead in terms of mitigation efforts lead to interesting future research outcomes.

7.1 Critical points for Hempland

As already metionned previously, there are some critical points when analysing the outcomes of the "Hempland" scenario. These should be further indicated in this subchapter.

The data assembled and resulting out of the MFA of "Hempland", suggested that only the nitrate leaching and also the considerable water consumption of the hemp crop may, for instance in a period of drought, lead to additional pressure on water resources. However, the water consumption is still considered to be very moderate and not as severe as for other widely cultivated crops. Besides, the impact on water ressources is considered to be neglible due to the absence of pesticides and herbicides during hemp cultivation. Moreover, the amounts of debris, waste and flue gas must not be neglected in the realm of "Hempland". These are of crucial importance as they presuppose and must be accompanied by adequate infrastructure in order to handle these commodities by appropriate means. Critical for hemp cultivated and processed in the realm of "Hempland" are also the inherent complex biophysical dynamics and challenges of hemp cultivation. This constitutes a further obstacle to properly analyse the circumstance of "Hempland". This also makes an investigation of the stock of a hemp cultivation process very difficult. Furthermore, a correct restitution of the reuse of on hemp-based productlines is a critical endeavour in "Hempland". This goes along with an adequate knowledge of the exact composition of the productlines, which would allow further more precise estimation on how much of the materials should or could be reused, turned back to the fields or incinerated. Furthermore, the inherent and essential traits of hemp cultivation will decisively influence the constitution of the cropland used in "Hempland". Namely, an increased quality of the soil linked to the crop rotation and the positive effects on biodiversity and water resources are crucial.

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Annex I: Information on lignin application from hemp

One interesting example, which should be named in the context of this thesis because it has gained much attention, is the high lignocellulosic contents in hemp whose processing could, in the context of future Biorefineries lead to a broader scope of applications of hemp biomass. Lignin is one of the auspicious future matrix materials for completely biodegradable materials, notably in the plastic industry. Lignin is one of the auspicious future matrix materials for completely biodegradable materials, notably in the plastic industry. Hemp fibres contain 80–83 % cellulose and 17–20 % lignin. (P.6 EFSA. 2011) Amd hemp plants „have stem tissues with contrasting lignification patterns and, consequently, different physicochemical properties." (Guerriero. 2016) Hence, *"Biorefinery of lignocellulose is currently receiving much attention from industrial R&D. The search is for alternative biomass sources and efficient processes to economically produce carbohydrate (C6, C5) feedstock for the industry, that do not compete with food production (sugar and starch) Lignocellulosic raw materials are hydrolysed to produce glucose by chemical and enzymatic methods (…). The monosaccharide sugars derived from cellulose (C6) and hemicellulose (C5) can be used for the production of many products (e.g. ethanol, ethylene, lactic acid, etc.) by chemical or biotechnological (enzymatic) conversion* processes." (Van dam. 2014)

Annex II: Processes of manufacturing for fibre reinforced thermoplastic composites

„The manufacturing of fibre reinforced thermoplastic composites can be attained by different processes. Short fibre filled composite parts can be produced by injection moulding of granules that are composed of compounded fibre and thermoplastic polymer. Other processes for long fibre reinforcement include the manufacture of natural fibre mat (NMT) 'prepregs', e.g. mixed sheets or mats of reinforcing fibres and the thermoplastic matrix polymer (fibres). Commonly, the fibre non-woven is laminated with sheets of thermoplastic polymer and subsequently hot pressed in a mould. This compression moulding / sheet moulding is the most common used technology for manufacturing of composite parts from long fibre reinforced thermoplastic polymers. Most frequently applied polymers are polypropene (PP) based materials.
Thermosets are processed by SMC (sheet moulding compounding) of impregnated non-woven mats or RTM (resin transfer moulding) and vacuum injection technologies, followed by a curing step. In this application polyester- or epoxy-resins are applied for

manufacturing of the parts.“ (Van dam. 2014)

Annex III: EHSO (Epoxidized Hemp Seed Oil)

In general, petro-chemical based resins such as epoxy, polyester and vinyleste are used for fibre composites because of their advantageous material properties such as high stiffness and strength. „However these resins also have serious drawbacks in terms of biodegradability, initial processing cost, energy consumption, and health hazards. Consequently there is a requirement to develop novel bioresins from renewable feedstocks for use in fibre composites and biocomposites.“ (Manthey. 2011) One further specified and used bioresin in the context of this thesis is epoxidized hemp seed oil. „Epoxidation of a plant-oil or triglyceride, entails breaking the C=C and adding an oxygen atom. This creates an epoxide, also known as an oxirane (C-O-C). Epoxidation is an important reaction because the formed epoxides are intermediates that are able to be converted into numerous products. Epoxidation is achieved through the reaction of acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2) on the surface of an Acidic Ion Exchange Resin (AIER) to produce peroxyacetic acid (CH_3CO_3H) and water (H_2O). The peroxyacetic acid reacts with the C=C in the oil to produce epoxides. The unique fatty acid structure of hempseed oil makes it a suitable candidate as a bioresin feedstock. Vegetable oils that are high in unsaturated fatty acids are favoured due to a higher number of reaction sites therefore resulting in a superior polymer.“ (Manthey. 2011)