LIFE CYCLE ASSESSMENT OF HEMP BIOMASS FIELDS FOR COMMERCIAL CANNABIDIOL RESIN PRODUCED IN URUGUAY

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Abstract:

A life cycle assessment (LCA) for hemp biomass with data supplied by a Uruguayan company "Innovaterra Ltd." was conducted in this study. The LCA analyses only the agricultural phase and not the industrial production of the resin. Therefore, the system boundary utilized is "cradle-to-gate". The functional unit is kgs fibre/hectare, with the time constrain from the vegetative to the flowering phase until the harvest of the plant (approximately seven months). The aim of the thesis is to discover how much greenhouse gasses (GHG) will be produced in one hectare of hemp biomass field and to reveal the environmental impacts. GaBi LCA software is utilized for the computation of the LCA. This LCA was conducted through following the ISO standards 14040-140440 The inputs and outputs for creating the scenarios, plan, and processes of the LCA are based on literature review and data provided by Innovaterra Ltd. A negative result from the CO_2 total emission was achieved, with a value of – 2.8 tons of CO_2 equivalent. This is due to the higher CO_2 sequestration that one hectare of hemp produces a year with the sowing density and fields design with grass corridors. Additionally, the irrigation system is powered by hydroelectric power. The irrigation utilizes fresh water from a lake located in the vicinity. Also, in the results of the LCA, the hotspots are identified. A total amount of 1.3 tons of CO_2 equivalent were produced by the production of plastic utilized for the mulch. This is since a large amount of plastic is utilized for one hectare. The mulch plastic is made of polyethylene (PE), which requires crude oil for its production. However, currently, there is biodegradable mulch plastic that is already utilized by other agricultural farmers. Even though the hot spots have high GHG emissions, the total global warming potential (GWP) is negative. Also, Innovaterra Ltd. recycles its mulch plastic every year, but this was not included in this study.

Keywords:	LCA: life cycle assessment, CBD: cannabidiol, hemp, CO_2 sequestration, environmental impact
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ABBREVIATIONS

CF: Carbon Footprint

CO_2: Carbon dioxide

GHG: Greenhouse Gases

GWP: Global Warming Potential

LCA: Life Cycle Assessment

LCI: Life-Cycle Inventory

LCIA: Life Cycle Impact Assessment

PPM: Parts Per Million

FOREWORD

This thesis was performed for Arcada University of Applied Sciences under Materials Processing Technology engineering department. The collaborating company was Innovaterra Ltd., who provided valuable information for the study to happen. The content of this thesis was decided with advice from Innovaterra ltd, and Arcada University.

I would like to thank my thesis supervisor Stewart Makonnen-Craig for his patience and support during these years, especially while I was overseas in Uruguay. Hishard work and commitment inspired me to keep going in the most challenging time of my career.

From Innovaterra. Ltd I would primarily like to thank to Carlos Ezequiel Rodriguez Roig who supported my whole progress. Carlos has given interesting ideas and was one of the main advisors for the whole thesis. I would like to thank Dr Fernando Carrau from Innovaterra Ltd. for explaining me nicely all their processes when I visited the company.

I want to communicate my gratefulness to Mirja Anderson, Harri Anukka and Silas Gebrehiwot from Arcada, for accepting me as a laboratory assistance for two years, and allow me contribute for the school and at the same time to prove my competencies. I am very fortunate to have participated in the laboratory work, and on Arcada projects that provided me with good experience and economic rewards, even during covid-19 time.

After all, I want to thank my family who has been the base pillar and encouragement for my education career in Finland, and in the end to all friends who provided me with support through the thesis writing process.

INTRODUCTION

1.1 Background

There is an urgent need to dive into studies of renewable sources of materials that help to mitigate a climate catastrophe. Global warming is a topic that has already resounded all around the world. The 2015 Paris agreement in the United Nations Convention on Climate states efforts to limit the temperature increase to 1.5 degrees Celsius globally (United Nations for Climate Change, 2020). Several countries worldwide signed the 2015 Paris agreement, promising to reduce their CO_2 emissions and take necessary actions towards recyclability and waste management. Nevertheless, some countries like Uruguay are yet to advance in recyclability and waste management. Still, they contribute to slowing down the CO_2 emission of the planet in other ways, like harvesting plantations of hemp biomass.

The usage of these materials allows high carbon storage due to the CO_2 sequestration during the agricultural phase (Asdrubali *et.al.* 2020). Quantitative estimation of the CO_2 flows by using a life cycle assessment approach can show the positive and negative contributions of the different life cycle phases. Hemp plantations are low in water consumption and can store 22 tons of CO_2 per year per hectare. It is possible to grow two crops per year, so the absorption of CO_2 will double. The rapid growth of hemp makes it one of the fastest CO_2-to-biomass conversion tools available, more efficient than agro-forestry. (Vosper, 2011).

The legislation for growing hemp biomass in Uruguay changed from 2013 when Uruguay legalized hemp production (Lopez, 2018). Also, this was the birth of “The Institute for the Regulation and Control of Cannabis” (IRCCA). It was established by Law No. 19.172 to regulate the planting, cultivation, harvesting, production, processing, collection, distribution, and dispensation of Cannabis in Uruguay. (Uruguay XXI, 2020). These events created a gap left behind and this is when many entrepreneurs focused on producing hemp fields for cannabinol (CBD) oil. During this time, Innovaterra Ltd. in Uruguay also started to cultivate medical hemp, to analysed and industrialized so that it could be sold worldwide. In Figure 1, there is a map with the location of Uruguay and the company. Innovaterra Ltd. started to analyse the most suitable plant to be harvested. As a result, the company created their own breed of Cannabis sativa L. specific for CBD oil and Uruguayan weather. This plant was named "Interra1801". It is a unique kind of plant with 15% of CBD and 0,5% THC (Uruguay XXI, 2020). Innovaterra Ltd. make tests in their own laboratory for the quality of CBD oil. This study is called the certificate of analysis that provides a resume from the bottle specifications and quality in a certified lab report. An example of certificate of analysis can be found in appendix 1. They test their product to ensure that it is not contaminated. Also, Innovaterra Ltd. ensures that it does not contain accidentally tetrahydrocannabinol (THC) levels above the allowed limit permitted by the Institute for the Regulation and Control of Cannabis (IRCCA) (Uruguay XXI, 2020).

The utilization of CBD is growing exponentially every year. According to the Bank of Toronto - which already provides credit for cannabis - estimates a global market for medical cannabis at US $194 billion by 2025 (Uruguay XXI, 2020). For all this and the need for climate change, the author encountered the need to answer the following questions: Is this plant environmentally friendly? Can this plant be utilized as a carbon capture tool while being utilized as medicine? Due to this reason, there is a need to conduct a life cycle assessment (LCA) about the hemp biomass for CBD oil production.

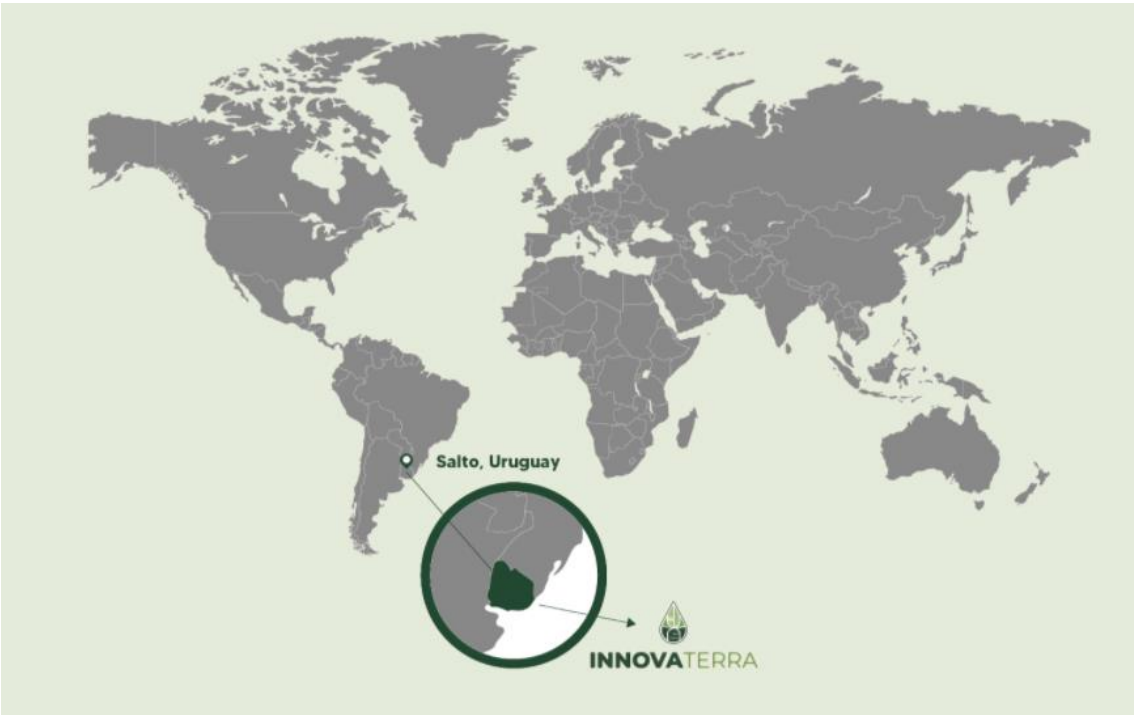

Figure 1.Location of Innovaterra in the world (Innovaterra Ltd., 2021).

1.2 Aims of the Thesis

This thesis aims to produce a life cycle assessment as a tool for relieving global warming. The LCA study will reveal how environmentally friendly it is to grow crops of hemp and how it could be aiding in the absorption of carbon dioxide from the atmosphere. aim of the thesis is to perform a literature review about hemp biomass production for CBD and LCA theory. As a result, this will aid in identifying the relevant data to be included within the chosen system boundaries for all processes produced by the hemp plant from Innovaterra Ltd. Lastly, the third aim of the thesis is to learn about the LCA software GaBi and to analyse the results, identifying the hotspots from carbon emissions, along with suggestion for improvement of the models and scenario analysis to help prevent Climate change with agricultural companies.

1.3 Research Strategy and Scope

The thesis process is described in the following steps:

- Connecting with the company Innovaterra Ltd.
- Create a thesis plan for Arcada UOAS.
- Researching literature for hemp biomass and LCA."Read the Arcada Writing Guide Version 3.0."
- Develop questions for the company to fill in the LCA software.
- Study and learning GaBi software.
- Gathering information from the company and apply it to GaBi software.
- Start the writing process of the thesis.
- Analyses and evaluate the results from GaBi software.
- Present results and generate discussion.
- Final adjustments and conclusion.

Before the first meeting with the company Innovaterra Ltd. in Uruguay, the author generated as many questions as possible through relevant videos and articles. The first visit to Innovaterra Ltd. was on the 17th of December 2020. The author travelled in Uruguay from Salto city to “El Espinillar” with the agricultural engineers, Dr Fernando Carrau and CEO, Carlos Rodriguez Roig. Interviews with the engineers at Innovaterra Ltd. supported in obtaining the essential information from how they operate in their plantations. The first meeting was inspiring and helpful for the author to become more acquainted with the goals and missions of the company. During this meeting, the owner and engineers agreed for the author to proceed with this LCA study. They complemented with knowledge and with their experience about the hemp plant. Finally, a study plan for Arcada UOAS was submitted, to receive the thesis approval.

Extensive literature research and study about hemp biomass production was accomplished to learn and identify each step of the agricultural process and to link it with climate change. Scientific research about the photosynthesis of a similar plant was studied to calculate the carbon dioxide intake. Research about LCA was conducted through following the ISO standards 14040-140440 and through material resources from Arcada's course "Life Cycle Assessment" available in its Learning online platform of studies and assessments from Arcada University of applied sciences (UOAS).

Chapter 2-7 describes the necessary steps for performing an LCA. A literature review of the hemp plant, for the photosynthesis and the carbon absorption of grass and soil is conducted in chapter 2. Chapter 3-5 shows the methods utilized for the LCA, the data gathered and the results. In chapter 6-7 there is a discussion and conclusion of the LCA. For the writing process of the thesis, Arcada provides the students with sufficient tools to be able to accomplish the last goal in their career: writing a thesis. Before starting, the students must pass the course called “Thesis Seminars”, which is taught in the school. This course will provide the foundations and timeline of what to expect by creating a thesis and how to procced step by step. The student is also provided with a word file template to be utilized. Arcada as well provides the students with the Writing guide. It can be accessed from Arcada website and it exhibits step by step the structure of the thesis, as well as layout, page format and advice for how to keep a scientific tone. This way thesis made by Arcada students can be accepted international

2 LITERATURE REVIEW

In this chapter hemp biomass production in relationship with the research questions and the differences between recreational hemp and medicinal hemp are explained. It is also described how they are positively impacting the environment through the photosynthesis of the crops. Moreover, the process of LCA in general is described in this chapter. These steps are also taken into consideration when performing the LCA for this thesis work. Finally, an introduction to GaBi software is presented and how it will be applied in connection with this thesis.

2.1.1 Hemp Plant

To better comprehend what hemp biomass is and its potential uses, the hemp plant must be explained. There is a common misconception between hemp used for illegal activities and industrial hemp. Industrial hemp, mainly biomass, is used for various industries like construction, textile, food industry, and automobile manufacturing (Barth & Carus, 2015). The hemp plant has many benefits, such as its high fibre tensile strength, Young's modulus, storage of CO_2, and environmentally friendly harvest (Griffin, *et. al.* 2020).
Hemp is a type of Cannabis Sativa species and it is similar to traditional marijuana. However, the outward features of the plants differ clearly. The female plant gives flowers with high levels of CBD and low levels of THC, the same as the hemp plant utilized for this thesis study. THC or Tetrahydrocannabinol is the chemical molecule that produces psychedelic activity when used. CBD or cannabidiol is known for the calming and medicinal effects, counting as stress and pain relief without the psychoactive component. The World Health Organization further states that pure CBD can be an effective treatment for epilepsy, according to several clinical trials. (World Health Organization, 2018). The European Monitoring Centre for Drugs and Drug addiction (2018) mentions that in the European Union the international treaties require the whole plant to be controlled. However, the exceptions may be for plants with a THC content less than 0.2% and it grown for fibre. The European Union also provides the terminology for cannabis and should be as follows: "Cannabis products used for medicinal purposes — whether the psychoactive THC or the non-psychoactive cannabidiol (CBD) — are generally referred to as 'medical cannabis.' Cannabis products used in manufacturing are commonly referred to as 'industrial hemp'." (European Monitoring Center for Drugs and Drug

addiction, 2018, p. 6). Cannabis sativa is the natural source of cannabinoids, a unique group of terpenoid-phenolic compounds that accumulate in the glandular trichomes of the plant (Chandra, *et. al.*, 2011). The terpenoid are from the aromatic group and are hankered from the CBD oil producers. According to the interview with Innovaterra Ltd., terpenoids and flavonoids are the ones that will aid in increasing the quality and the amount of cannabidiol in the flower. According to Ofir (2021, p. 137), "the mode of action of synergism may involve interaction of terpenes/flavonoids with CBD receptors or other receptors; as small metabolites, terpenes/flavonoids may help cannabinoids to cross dermal barrier/to be absorbed orally and/or to cross the blood-brain-barrier". Even the molecular structure of THC and CBD differs, as seen in Figure 2.

As shown in Figure 2, CBD and THC have almost similar chemical structure, 21 carbon atoms, 30 hydrogen atoms, and two oxygen atoms. The chemical arrangement of the molecules is variation. So forth, the human body accepts in a differently. In conclusion, Cannabidiol (CBD) and tetrahydrocannabinol (THC) are both naturally occurring compounds from the hemp plant. Therefore, CBD is non-psychotropic and is not illicit, whereas THC is psychotropic and the illicit compound. (Li, *et. al*., 2020).

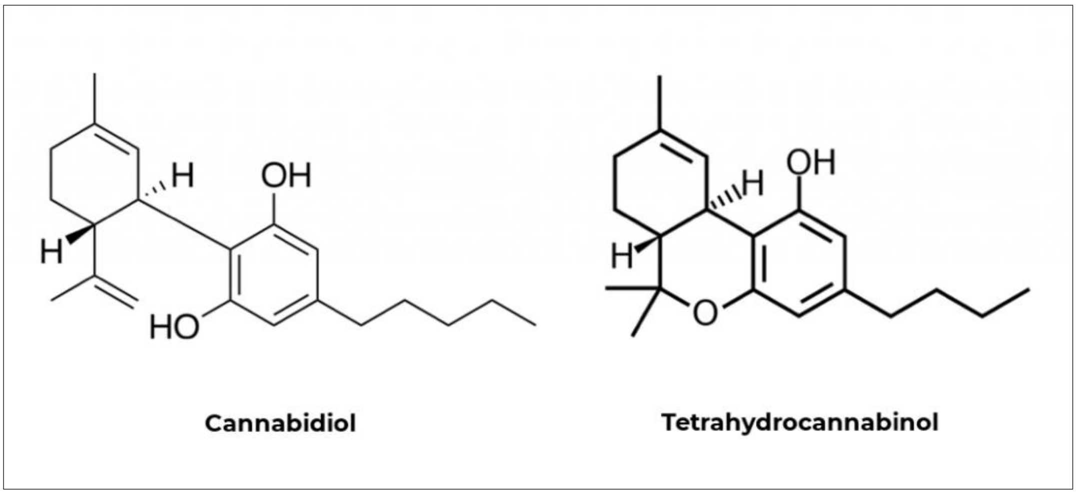

Figure 2. Molecular differences between THC and CBD (Russo & Guy, 2006).

2.1.2 Photosynthesis and the Role in Global Warming

Harvesting hemp, thanks to the large vegetative sections of the plants, has a high biomass and captures CO_2 during photosynthesis. Photosynthesis or biosynthesis is how plants synthesize light, carbon dioxide, and water for growth. This happens at the stomata, the pores in the leaves. Photosynthesis occurs in the “respiration phase” when it absorbs CO_2 and creates and converts sugar into energy, exhaling oxygen into the atmosphere. (Lambers & Bassham, 2021). In plants, the chloroplasts occur in the green plasma, and they are connected to the parenchyma cells. Chloroplasts are structures inside a plant cell, where photosynthesis happens. (Britannica, The Editors of Encyclopaedia Britannica, 2018). Thanks to the photosynthesis of the plants, it is possible to utilize most plant species as a carbon capture tool. Having accurate values on how much carbon the plant can sequestrate, and how much oxygen it can release, is crucial for convincing the public for developing this technology, as a tool to clean the atmosphere. The method which measures the amount the green leaves absorb carbon dioxide is called “Spectroscopy”. This system works with infrared light and can determine how much parts per million (PPM) of CO_2 concentration are absorbed by the leaf by the reflection of the light. This method has been advanced and is called an infrared gas analyser, in which it measures CO_2 uptake with two chambers. The first is a reference chamber, and the second is a sample chamber. These are employed to find the “Flux”. Flux is the difference between both. This value equals the amount of CO_2 absorbed by the plant. (Di Donato & Groot, 2015). According to Chandra, *et. al.* (2011), “one of the main advantages of infrared-based spectroscopies is the extreme sensitivity to the conformation and the environment in which a molecule is fixed”. Moreover, photosynthesis happens at a molecular level, it is possible to measure it, and it is crucial for life on earth. In the atmosphere there are around 390 to 400 PPM of CO_2 now, but due to global warming there are estimation that suggest that levels of CO_2 will increase in the planet between 415 and 421 ppm by 2025. (Anastasi, Hudson and Simpson, 2003). Therefore, due to above mentioned predictions, it is important to consider hemp and similar renewable fibres as a sustainability tool. Thanks to large scientific research around the world, it is becoming easier to access information about the CO_2 uptake of this fibres. As it is shown in Figure 3, the negative columns are interpreted as the CO_2 absorption of the plant, throughout its life span. In the first two columns there are two different scenarios of hemp fibre production. Scenario one is with mineral fertilization and scenario two with organic fertilization. Despite of the fact that scenario one produced 40 tons more of CO_2 than scenario two with organic fertilizer, both hemp plants absorbed 1,393 of CO_2 equivalent per tons of fibre.

In the thesis photosynthesis of grass and soil will be taken into consideration for the LCA

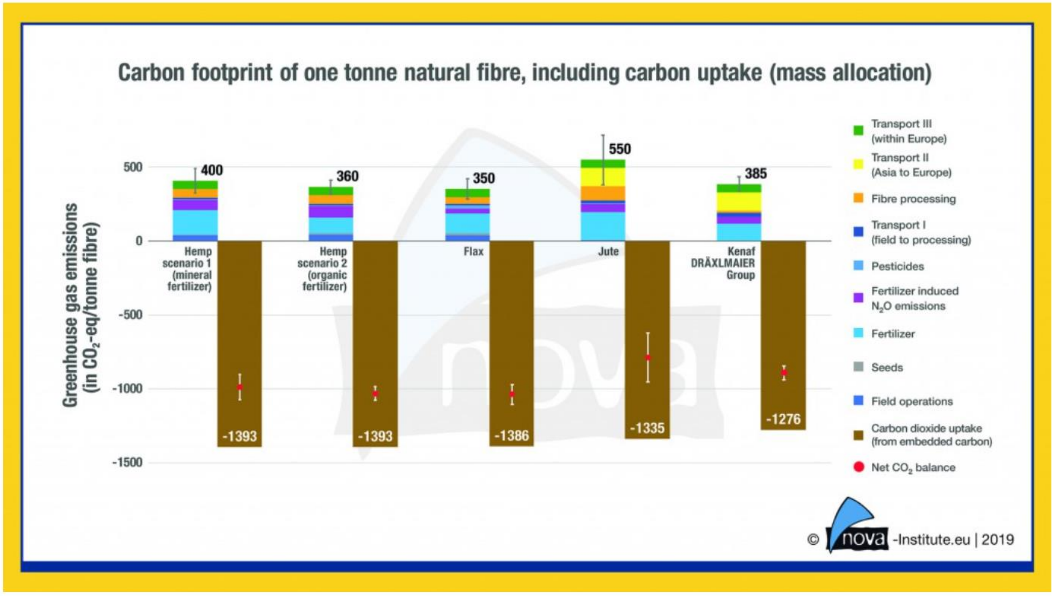

Figure 3. Carbon footprint, carbon uptake of natura fibre Nova institute (Nova-Institute GmbH, 2019).

2.1.3 Sequestration of Carbon in Soil

Even though the research of carbon uptake in nature is generally only focused on plants, Feger (2010) suggests that research in soil organic matter is just as important. Soil can sequestrate carbon and other greenhouse gases and help to balance or stabilize a large amount of CO_2 emissions. Soil can work as a pool to secure carbon storage. (Lorenz & Lal, 2010). Up to 60-70 Mt of CO_2 is possible to sequestrate in agricultural soils, based on a study of European soils during the first commitment period. This is a significant value, as it is approximately 1.5% of the anthropogenic CO_2 emissions in EU. (European Climate Change Programme, 2015). When calculating how much carbon the soil potentially can uptake/or has taken up, the soil respiration must be held into account. The living soil organisms respire, meaning they release CO_2. The rate of soil respiration depends on temperature, moisture, nutrients, and even oxygen levels. Also, human activities like land-use change or harvesting can be a factor for carbon uptake loss. (Lorenz & Lal, 2010). The land field from Innovaterra Ltd. are cleared after harvest, and the soil can breathe, and a winter grass is grown. During this process, the land can capture more CO_2, adding to the total amount of CO_2 sequestration per year in one hectare at Innovaterra Ltd.

2.2 LIFE CYCLE ASSESSMENT (LCA)

Many factors, such as demands from the government, good citizenship, and especially customer requirements, encourage industrial companies to take steps towards more environmentally friendly processes. Several companies are therefore required to perform an LCA on their product. LCA is a powerful tool to assess the environmental impact and resource consumption for a certain product or process. The LCA report reveals where the largest environmental impacts are created, thereby helping the companies to target specific stages in the manufacturing process. Currently, the following ISO standards are set for companies (or any other user) to be able to perform an LCA with global standards: ISO 14040 (*Principal and framework*), ISO 14041 (*Goal and scope definition and inventory analysis*), ISO 14042 (*Life cycle impact assessment*) and ISO 14043 (*Life cycle interpretation*). ISO 14044 (*Requirements and guidelines*) is for practitioners of LCA, describing the steps required to perform an LCA. ISO 14040 clearly states the four phases required to conduct an LCA: "1) The goal and scope definition phase, 2) the inventory analysis phase, 3) the impact assessment phase, and 4) the interpretation phase" (ISO, International Standard Organization, 2006a). The four phases are presented in Figure 4, as well as the direct applications on an LCA.

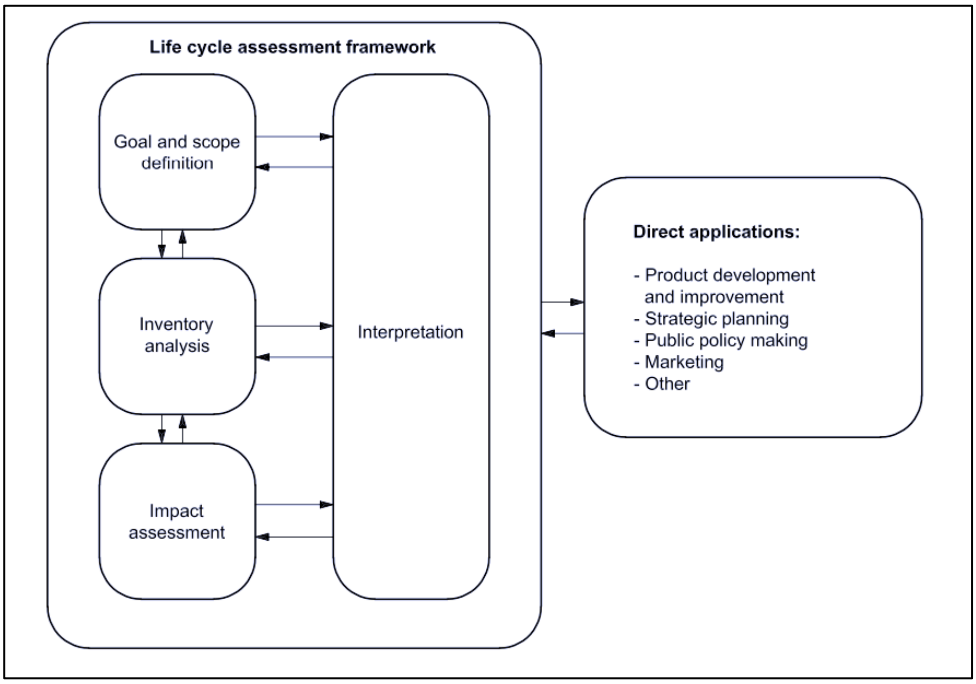

Figure 4. Stages of an LCA, ISO 40040 (ISO, International Standard Organization, 2006a).

2.2.1 The Goal and Scope

The goal and scope are the first components of any standard LCA (Grahl & Klöpffer, 2014). The international standard 14044 describes that the goal and scope must be clearly defined and in line with the intended application. ISO 14044 further explains that especially the scope can change during the study, as LCA studies tend to have iterative nature. (ISO, International Standard Organization, 2006b). The goal is set together with the different stakeholders (e.g., the companies, environmental offices, industry, and trade associations, etc.). In the goal, the depth, and the accuracy of the LCA are clearly defined. (Grahl & Klöpffer, 2014). In ISO 14040, it is mentioned that the LCAs might differ from each other considerably, depending on the depth of the study. Furthermore, it is explained that during the critical review process, the goals, or the intended use of the LCA cannot be verified nor validated. (ISO, International Standard Organization, 2006a). The scope is set by the product system, system boundaries and the functional unit. In the product system, the function of the system is briefly explained to set a basis for the functional unit. Preferably, the product system should be presented in a system flow chart. (Grahl & Klöpffer, 2014). For system boundaries also shown in Figure 5, the processes which will be included in the LCA, are decided. Mainly there are three system boundaries:

1) *Cradle-to-grave*, which describes the full life cycle assessment.
2) *Cradle-to-gate*, which limits the LCA from raw material extraction only up to production. Here the transportation to the customer is excluded.
3) *Gate-to-gate*, which describes only one process in the whole production chain. (Horn, *et.al.*, 2019).

The functional unit is highly recommended to choose at this stage of the LCA already. If one does not have a clear definition of the functional unit at this stage, some serious data leaks or unsatisfactory results may be the outcome from the LCA. Also, it could reveal if an LCA is the suitable method for solving the problem or not. (Grahl & Klöpffer, 2014).

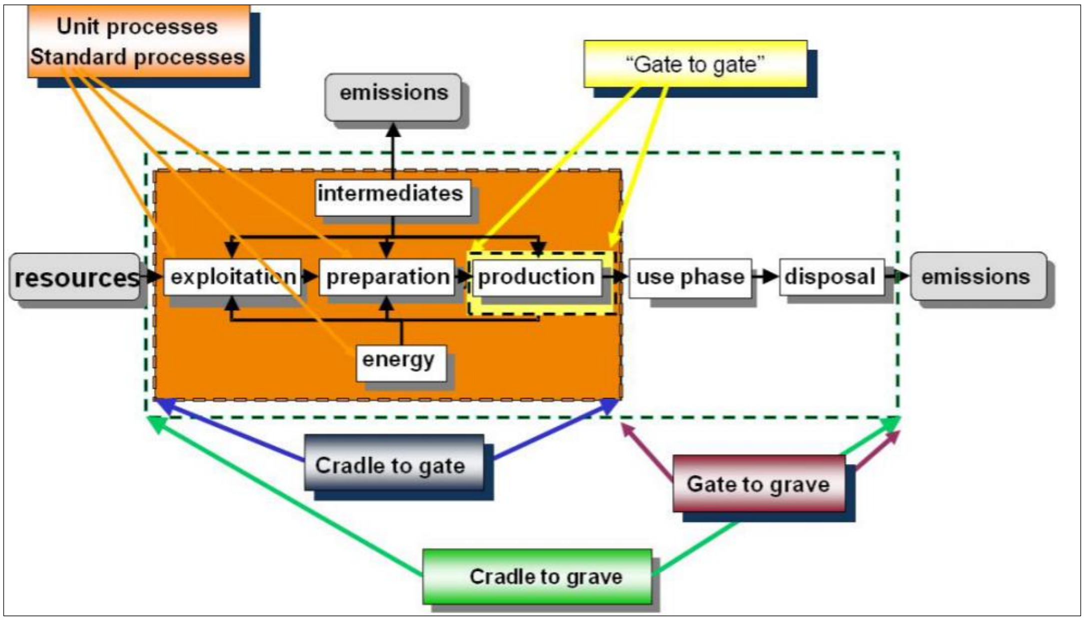

Figure 5. System boundaries for LCA. (Bos, et. al., 2019).

2.2.2 Inventory Analysis

When the goal and scope has been defined and explained, the life cycle inventory analysis must be performed. The inventory analysis is the phase of the LCA where one collects and measures the inputs and outputs for a certain product for its whole life cycle. (ISO, International Standard Organization, 2006a). This may be one of the most time-consuming phases of the entire LCA. The inputs for the LCA usually considers energy inputs, material inputs, or any other physical input. Furthermore, for inputs and outputs for the LCA, all the products and waste must be considered, as well as emissions to the environment. There might also be other environmental aspects that must be considered for the specific case. (Horn, *et. al.*, 2019). Preferably, one should also create a flow chart at this stage, to examine the real production distribution. This is executed with small boxes that contain the processes involved, and the boxes (processes) may be dependent on each other or not. (Grahl & Klöpffer, 2014).

2.2.3 Impact Assessment

The purpose of performing a life cycle impact assessment (LCIA) is to show the possible environmental impacts and its significance. Generally, this is executed by linking inventory data with environmental impact categories. The first element involved in an

LCIA is to select the impact categories or category indicators. Afterward, one must do a classification (assignment of the life cycle inventory result). Additionally, one must characterize the category indicator results. Optionally, one can finally perform grouping and weighting for the impact assessment, where the characterization results are sorted and given different values. However, this is not mandatory. (ISO, International Standard Organization, 2006a). The impact assessment is necessary for performing a complete LCA, as it, e.g. shows the potential impacts on the environment, aids in presenting the large data on emissions or resource consumptions and reveals the true performance of a system. (Grahl & Klöpffer, 2014). The limitations involved with LCIA are directly connected with the goal and scope phase, as only the environmental issues set in that phase are considered. Additionally, the life cycle impact assessment is usually incapable to demonstrate the differences from impact categories and related indictor results. This again is highly linked to the life cycle inventory phase, depending on which accuracy and depth it is performed. (ISO, International Standard Organization, 2006a).

2.2.4 Interpretation

The life cycle interpretation phase is where conclusion is made from the inventory assessment and impact assessment. The results from the interpretation phase should be in line with the goal and scope set in the beginning of the LCA. Also, the inventory phase should reveal if the LCIA results are performed on a suitable approach. (ISO, International Standard Organization, 2006a). Likewise, in this phase any necessary recommendations should be made. One should, however, critically review here if the boundary conditions were chosen correctly and if the results are easily comprehensible. If the results are only presented in a formal manner following the process presented in ISO 14044, the desired benefit may not be achieved for the reader. (Grahl & Klöpffer, 2014). Reporting and critical review is not officially part of the interpretation phase, as they consider all stages or phases of the LCA (Grahl & Klöpffer, 2014). The report, however, is a natural part of the LCA, as it collects all the data from different the phases and report the conclusions. Also, the critical review aids in verifying the LCA, disclosing whether it was performed with the required methods and principles. The critical review creates a higher credibility for the conducted LCA, which may be useful for any interested party. (ISO, International Standard Organization, 2006a)

2.3 LCA with GaBi Software

GaBi software is an extensive tool for creating life cycle assessments. It supports all the phases of an LCA, from data collection all the way to presenting the results. GaBi software can automatically track the flows of the material, emissions and energies. Additionally, GaBi can track the defined monetary values and social issue. This gives a result that considers several environmental impact categories. In GaBi software it is also possible to create rapid models from complex processes. It allows the user to modify the data, or add data (e.g. economic cost or social impact). This makes GaBi software, according to GaBi Education Handbook, “a holistic life cycle analysis tool”. (PE International, 2009). The LCI database in GaBi software is one of the most extensive ones on the market. On a time of over 25 years, the database has collected over 10,000 LCI profiles, with more than 20,000 generic plan systems (each containing several sub-systems). In addition, it is possible for the user to obtain a custom database with the help of “data-on-demand” service. (Baitz, *et. al.*, 2018).

2.3.1 GaBi Agricultural Data Base

To perform a LCA for agricultural systems is difficult, as they belong to one of the most complex production systems. This is since the environmental conditions vary greatly from location to location. Also, factors like land use, water usage, variety of agricultural practices, varying pest populations and vast number of farms affects the accuracy of the resulting LCA. Nonetheless, GaBi software has taken these varying factors into account, creating a flexible, highly parametrized, and suitable tool for any plantation or agrarian product in the world. (Bos, *et. al.*, 2019).

3 METHODS

This chapter describes how the data was gathered for the LCA and what models or equipment were utilized by the company. The goal and scope from this thesis are definition in this chapter as well.

For the cultivating it requiresa small amount of water. Also, it is very efficient in the consumption of resources. Almost no phytosanitary product is utilized. It is a rustic crop that adapts to different conditions and, due to its production capacity, is a sustainable crop. It has a high rate of growth and fixation of CO_2 in the atmosphere. (Asdrubali, *et. al.*, 2020). The most crucial issue is the planning and development of cultivar fields is to obtain as many flowers as possible. This is called plant density. In this study, the crop evaluated has a plant density that has been planned meticulously by the engineers of Innovaterra Ltd. The plant is environmentally friendly and aids in recovering the soil from old crops and soil fields damaged through years of usage. It can grow quickly in those environments and need little water irrigation in comparison with traditional crops. Innovaterra Ltd. also uses organic fertilizers made by them rich in amino acids but a secret formula that allows the plant for healthy rapid growth. It is a crop that has a culture with bioremediation. It adapts to marginal plantation conditions, and in addition, in places where there are soils that are worn down by other types of crops, hemp has the property of rebuilding and reusing those soils. These plants are female, so there is no risk of heterogeneity in the cultivation because the plants are produced from cuttings from the mother plant. These mother plants are the original plants since the year 2018 (Interra1801) that are kept alive in a greenhouse, as shown in Figure 6. In this regard, Innovaterra Ltd. is saving time, money, resources and producing less GHG by avoiding the cultivation process of "seeding". (Uruguay XXI, 2020). The cuttings are placed into plastic re-usable planter boxes, inside a greenhouse until they grow in a good size to be ready for transplantation into the ground on the corridors of the field. They start to plant them in the fields somewhere around September and November depending on the humidity and the rain, harvesting from March to April.

Figure 6. Mother Plants inside a greenhouse (Innovaterra Ltd., 2021).

According to the agricultural engineer from Innovaterra Ltd., Dr. Fernando Carrau states that this system also helps to reduce the post-transplant stress from the plants. In other words, if the seeds have grown into a planter box and then transplanted to the land, they could have significant stress after transplantation. Interra1801 has been genetically designed for that weather conditions, and they only let the plant grow from 1 m to 1.5 m soon after there are harvested. This is due to summer thunders storms that are strong in that region of the country. Winds can reach over 100 km per hour, and it can rain 100 ml in one hour. Other kinds of hemp plants that can grow up to six meters Therefore, during thunderstorms the plant will break easily, in Figure 7 it is shown the height of the plants. The irrigation system works with an electrical water pump. The water is sucked from the Uruguayan river at a rate of 700 litres per second. The river is also shown in Figure 7 in the back of the image.

Figure 7. El Espinillar hemp plantations, grass corridors and Uruguay river (Innovaterra Ltd., 2021).

Innovaterra Ltd. has strategically designed the way they locate the plants on their crop. The crops are created by sectors, considering the angle of unevenness or the inclination from the land fields. When it rains plenty, the water runs into a set of streets in the desirable direction, running towards the outside of the plantation and not eroding the ground where the plants are. There is a creek at the bottom of the pendant of the land where the water is recovered and flows to neighboring plantations. This system helps to avoid erosion of the ground, and it protects the field. In this way, Innovaterra Ltd. considers it essential for future generations to utilize that land in 100 years. In Figure 8, how the pendant of the land is decreasing towards the water creek on the left of the image. Innovaterra Ltd. has a specific “sowing density” to maximize the efficiency of the land and the plants to provide ecosystem service. In this way, the tillage layout has grass field corridors or grass streets between tree plantations, as shown in Figure 7.

Figure 8. Land field and creek (Innovaterra Ltd., 2021).

Furthermore, this grassland also helps to absorb carbon dioxide and provides nitrogen naturally to the plants. For the analysis of carbon sequestration in grass, the most suitable type of grass is chosen to be as similar as the grass in the fields of Innovaterra Ltd. in Salto, Uruguay. In other words, the data that did reflect the current condition of the local environment was found through literature research. The selection of grass is important as there are over 12 thousand different types of species of grass (Byng & Christenhusz, 2016). The name of the grass chosen is “Tall Fescue” or Festuca Arundinaceous. According to Saikkonen (2000) “this species is a bunchgrass native to Europe. It is an important forage grass throughout Europe, and many cultivars have been utilized in agriculture. It is also an ornamental grass in gardens and a phytoremediation plant “. “Tall Fescue” is a suitable grass type for this study, as the colour and shape match the grass on site. Other studies have also proven that grass does absorb carbon dioxide, but there are many variables to consider before conclusions. These variables are for when and where, and how the experiment has been done to measure CO_2. Berglund, *et. al.* (2018) claims tall Fescue, as well as reed canary grass to have high carbon capture efficiency. This type of grass does not only absorb CO_2 but also aids in providing natural nitrogen. This is supported by Fribourg, Hannaway & West (2009) as well as from the interview with Innovaterra Ltd.

Based on the interview with Innovaterra Ltd., they can produce one tone of biomass of flowers per hectare. Only 10% from one tone of flower can be converted into CBD resin after treatment in the laboratory. Thus, they get 100 kilos of resin per hectare, and from this, approximate 80% is CBD with 0.5% THC. The company also conducts a post-treatment called remediation with a chromatography machine. This aids in reducing the levels of THC to 0 - 0,2 % and then being able to export it worldwide with low THC levels. Ultimately, the company also burns the leftover of the plant to produce energy for their laboratory of resin production. In this regard, this establishment is in the category of Circular Economy by utilizing renewable resources. According to Aytaç (2018, p. 5), the "CO_2 emitted from burning hemp is the same amount of CO_2 that the plant has received from the environment when it lives. Thus, it will not negatively contribute to the environment and produce a so-called carbon cycle system of energy production and slow down the effects of global warming." In other words, the burning of hemp biomass for energy creates neutral carbon emission due to the high uptake of CO_2 of the plant. Nevertheless, this study only focuses on the LCA of the agricultural phase, from when the plant is first planted until its harvested.

3.1 Goal and Scope

The goal of this thesis is to produce an LCA to determine the environmental impacts that generates cultivating hemp biomass for the CBD resin production. As well to identify the hotspots produced by the company during the agricultural process. The data was gathered by interviews with the company and by performing research about the topic. The equipment utilized is GaBi software, and taking into consideration the data researched for the absorption of CO_2 of grass fields and the absorption of CO_2 of Hemp plants from Innovaterra Ltd. A literature review for the calculations for the CO_2 uptake has been produced. This is due that GaBi database does not have information about this type of plant. Nonetheless, after six months of literature research and with the guidance from Arcada UOAS supervisor, one study was chosen for the manual calculation. This study is based on kilograms of fibre that will absorb CO_2. Further explanations and calculations will be described in this chapter.

For the LCA performed in this thesis, the most suitable system boundary is cradle-to-gate, as it evaluates the environmental impact of the production of a product. All the relevant information for the cultivation process was introduced into GaBi software, i.e., the fertilizers and their transportation and production. The model will include the cradle-to-gate emissions from the fuel consumed, as well as the direct emissions into the air. The fertilizer and emissions that are produced during and after the application will be considered. (Bos, *et. al.*, 2019).

The result of the LCA is converted into the reference unit of the input flow category. Example GWP all categories are converted into Kg CO_2 equivalent. CO_2 is the reference substance for this input category. To convert this to standard units, every quantity is multiplied by a characterization factor. Characterization factor, as shown in Table 1, are determined by a scientific group based on different methodologies and philosophical utilization of the environmental issues. (Thinkstep, n.d.).

Table 1. Global warming potential of the considered free house emission (Barth & Carus, 2015).

Greenhouse gas emissions	Formula	Characterization factor
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265

Table 1 specifies the characterization factor utilized for the LCA models. Under the characterization factor, it is stated that methane (CH_4) has a characterization factor of 28. This means that methane causes 28 times more global warming potential compared to carbon dioxide. For instance, if there is 6 kg of CH_4-emissions, multiplied with 28 (the characterization factor), it equals 168 kg CO_2 -equivalents to the total GWP. The same system for N_2O is applied. (PE International, n.d.).

3.1.1 System Boundaries

The system boundary is ***cradle-to-gate*** for crop production and the emissions associated with crop production. But when modelling the plan in GaBi software end of life had been added because was not possible otherwise for the author to manage the software.

3.1.2 Functional Unit

The functional unit was calculated for the amount of hemp fibre produced with a time constraint of 7 months in one hectare. The time constraint is based on information from the company, from sowing the plant until the plant is harvested. The total amount of net weight of the plant is considered, not only the flowers for CBD oil production. The functional unit used for this LCA is kg of fibre/hectare.

3.2 Carbon Footprint Methodology

This method for recognizing and estimating the individual ozone-depleting substance discharges from every action inside the supply chain measures the steps and the systems for attributing these to each output product. This is referring to the carbon footprint of a product. (Barth & Carus, 2015). As Barth & Carus (2015) states: “The introduction to the carbon footprint methodology is an abbreviation, aside from carbon being created, a greenhouse gas as well, and this adds to the carbon dioxide. This methodology also includes Methane (CH_4), nitrous oxide (NO_2) and chlorofluorocarbons”. The major difference between an LCA and carbon footprint is that CF excludes almost all the impact categories from the study. CF only considers the impact category global warming potential, excluding, e.g., global warming potential, ozone depletion, eutrophication, and acidification potential. (Barth & Carus, 2015). Despite the differences between an LCA and CF, the carbon footprint is an assessment from cradle-to-gate. For this reason, the author confronts the need to utilize the carbon footprint methodology in this study for a tool to the final LCA.

3.2.1 Biogenic Carbon Capture

The calculations of CO_2 uptake are based on critical assumptions based on relevant literature reviews. It was impossible to obtain the exact CO_2 uptake from Innovaterra Ltd.’s hemp plants. Hence, results from similar studies are presented. Biogenic carbon storage refers to carbon stored in plants or soil. Currently, there are no international standards or agreements on how to incorporate biogenic carbon in LCA. Nevertheless, the study performed by Barth and Carus (2015) shows that the stored CO_2 in hemp is 1.39 kg CO_2/kg fibre (see Table 2). It is also mentioned that the different fibres presented in

Table 2 are similar regarding stored carbon dioxide and the material data sheet they used can be found at the appendix 2.

Table 2. Biogenic carbon storage (Barth & Carus, 2015).

	Unit	Flax	Hemp	Jute	Kenaf
Cellulose	kg/kg fibre	0.72	0.65	0.57	0.55
Hemicellulose	kg/kg fibre	0.18	0.15	0.13	0.14
Lignin	kg/kg fibre	0.03	0.10	0.14	0.12
Stored carbon dioxide	**kg CO_2/kg fibre**	**1.39**	**1.39**	**1.33**	**1.27**

To calculate C_{O2} capture of soil and grass, the values have been taken from the measurements for increasing soil carbon stock in agricultural soils and potential yearly soil carbon sequestration. In Figure 10 the table from this study is situated.

According to with European Climate Change Programme (2015),

- "Crop residues have ***2.5 tons of CO_2 equivalent*** of uptake per year."
- "Convert arable land to grassland has ***5 tons of CO_2 equivalent*** of uptake per year."

In Table 3, there are the selections for this study in the carbon capture, based on the literature review. Indeed, the means and systems for those studies how they have been concluded must be taken into consideration. To produce this study without an infrared gas analyser machine, the author must compromise the accuracy of the results. The selection of hemp literature has been made for a similar breed, but for carbon capture, the plant density, location, and agricultural system must be taken into consideration. For this reason, this study states the kg of CO_2/kg of fibre. Fortunately, Innovaterra Ltd. has provided the mass per plant on average, as shown in Table 3.

Table 3. Carbon Dioxide capture and from different process. (Juan Silva 2021)

TYPE	AMOUNT CO_2 equivalent	SOURCES
SOIL AND ROOTS	2.54 Tones	(ECCP, 2015)
HEMP	1.39 kg of CO_2/ kg of fibre	(Barth & Carus, 2015)
GRASS	5 tones	(ECCP, 2015)

Figure 10 represent a table from European Climate Change Programme (ECCP), 2015.

Measure	Potential soil carbon sequestration rate ($t\ CO_2\ ha^{-1}\ y^{-1}$)	Estimated uncertainty (%)	Reference / notes
Crop-land			
Zero-tillage	1.42 but see reference	> 50%	1, 2
Reduced-tillage	< 1.42	>> 50%	3
Set-aside	< 1.42	>>50%	4
Perennial grasses and permanent crops	2.27	>50%	5
Deep-rooting crops	2.27	>50%	5
Animal manure	1.38	> 50%	1
Crop residues	2.54	> 50%	1
Sewage sludge	0.95	>50%	1, 15
Composting	1.38 or higher	>>50%	6, 15
Improved rotations	>0	Very high	7
Fertilisation	0	Very high	8
Irrigation	0	Very high	8
Bioenergy crops	2.27	>>50%	1
Extensification	1.98	>>50%	1
Organic farming	0-1.98	>>50%	9
Convert arable to woodland	2.27	>>50%	1
Convert arable to grassland	7.03 ± 2.08	110% (2.3 to 11.2)	10
Convert grassland to arable	-3.66	>>50%	11
Convert permanent crops to arable	-3.66	>>50%	11
Convert woodland to arable	-?	?	?
Grassland			
Increase in the duration of grass leys	0.4-1.8	?	14
Change from short duration to permanent grasslands	1.1-1.5	?	14
Increase of fertiliser on nutrient poor permanent grassland	0.7	?	14
Intensification of organic soils with permanent grassland	-3.3-4.0	?	14
Livestock management	??	??	?
Cutting method and frequency	?	?	?
Fire protection	??	-	?
Revegetation			
Abandoned arable land	2.27	>>50%	12
Farmed organic soils			
Protection and restoration	Up to 17	Range 0–17. Spatial	13
Avoid row crops and tubers	0	>50%	13
Avoid deep ploughing	5	>50%	13
More shallow water table	5-15	>50%	13
Convert arable to grassland	5	>50%	13
Convert arable to woodland	2-5	>>50%	13
New crops on restored wetlands from arable	8-17	>50%	13
New crops on restored wetlands from grassland	3-12	>50%	13
Sheep grazing on undrained peatland	>8	>50%	13
Abandon for conservation	>8	>50%	13

Figure 2. Potential soil and grass carbon capture rate. (ECCP, 2015)

4 INVENTORY FOR THE LCA

In this chapter is described the inventory for the input flows for the LCA are based on questions presented to the company, following by the inventory analysis of the data collected and scenario modelling for the making the plan of this LCA.

4.1 Inventory from Innovaterra Ltd.

This inventory is aimed to target one hectare of land during the agricultural phases.
The agricultural phases are:

1. Soil preparation, tillage
2. Plant transplantation, sowing
3. Crop fertilization and irrigation
4. Maintenance of the field
5. Harvesting when the hemp plant has given their flowers.

These five steps mention above can happen between seven-month time, varying between one month, depending on the weather.

Innovaterra Ltd. rent their licenses to other agricultural companies. This way other growers can plant under license of Innovaterra Ltd. without going through the process from the Institute for the Regulation and Control of Cannabis (IRCCA). In total, around 80 hectares of biomass are produced under Innovaterra Ltd. license in Uruguay.

- Number hectares in Innovaterra Ltd.: 28 hectares at ¨El Espinillar¨
- Numbers of plants: approximately **5000 plants/hectare**
- Size of the plants before harvest: 1.5 meters height, 1.5-meter diameter
- One plant weighed approximately 1.5 kilograms.
- One plant gives approximately 500 to 650 grams of flowers and leaves that are suitable for the extraction of CBD as seen in Figure 11.
- Innovaterra Ltd. grows the hemp plants 1.7 m apart horizontal and 80 centimetres separation lineal as shown in Figure 12.

Figure 3.Flower and leaves from one hemp plant. (Innovaterra Ltd. 2021)

Figure 4. Separation between the plants. (Innovaterra Ltd. 2021)

The numbers of the plant were calculated manually is an approximation that depends on the land layout as well. From that total amount, there is a certain percentage of the plants that die or do not survive the transplanting. They usually replant the plants that die, but precisely there is a 95% percent of rooting from all the plants and around 5% from the replanted plants. The reason for the death of the plant is from the effect of climate like strong wind or for illnesses. In Figure 13, it is seen the plant density in the flowering phase.

Figure 5. Plants before harvesting. (Innovaterra Ltd. 2021)

Numbers of workers per hectare: For sowing and harvesting, **ten persons/hectare.** For fertilization and maintenance, approximately 3 per hectare. Temperature average during seven months of cultivar starting from September fluctuates between 20.8°C and 9.1°C. It was increasing all the way to summer in December, fluctuating from 30.2°C to 17.1°C. It can reach up to 40°C or more, and stay relatively high though February, for then start to decrease in the month of March. (Weather Atlas, 2021).

4.1.1 Fertilization

Fertilizer ratio and names:

Usually, in a container or bag of fertilizer, as shown in Figure 14, it is written three numbers, for example, “15-15-15”. This means that inside of the bag of 25 kilograms net weight, there are 15 % of potassium (K), 15 % of phosphorus (P), and 15% of nitrogen (N). In other words, the numbers represent the percentage of the total amount of that bag. The numbers are allocated to units NPK compound fertilizer with magnesium, sulphur, and micronutrients in agricultural terms.

The fertilizer brand name is Compo Expert, they have their headquarters are in Münster Westphalia. It is an international company with 21 sales offices in Europe, North and

South America as well as in Asia and Africa. (Compo Expert, 2021a) The fertilizer from Compo Expert utilized by Innovaterra Ltd. is called "Hakaphos". It is purchased in the same state, 71 km distance between Salto city and El Espinillar, the farm of Innovaterra Ltd. location (Google LLC, 2021).

First, they utilize Hakaphos Verde (green) 15 N-10 P-15 K. It is soluble in 100 liters of water. These bags are 25 kilograms each. This formula is used for the vegetative phase. It is high in N and K content. Compo Expert (2020) states that this is the "recommended formula for the beginning and maintenance of the crop in fruit trees, horticulture, banana trees, citrus, etc. This fertilizer contains all stated plant nutrients for customized fertilization of agricultural and horticultural crops". (Compo Expert, 2021b)

The second fertilizer is Hakaphos Rojo (red) 18N-18P-18K, recommended formula for flowering and balanced crop growth. This fertilizer contains all stated plant nutrients for customized fertilization of agricultural and horticultural crops. The total amount per hectare: approximately 400 kilograms.

Figure 6. Hakaphos Verde and Rojo. (Compo Expert, 2020 & 2021b)

Finalizing with the fertilization in the soil, before the sowing of the plants, they make an analysis of the ground, and they make a correction of fertilizer according to that evaluation. They also use another ingredient, but it is a homemade secret recipe. They do soil management for the incorporation of the new biomass. First, the soil can rest, then a winter greening grass is a sow before tillage manures for the following crop.

4.1.2 Diesel Consumption and Field Operations

For operating the hemp plantations with machinery at Innovaterra Ltd., the total approximate amount of the consumed diesel is **155 liters** per hectare.

The agricultural machinery is hired from another company and is the following:

- John Deere 3530
- Ford 250 HP
- Valmet 90 HP
- Chisel Plough.
- Disc Plow or plough
- Land Plane
- Marking
- Rotovator

For the preparation of the soil the tractor passes one time with the chisel plough, one time disc plow, one time land plane and then makes the markers. After all these, the flower beds are made with a rotavator machine connected in the back of the tractor. This machine applies the mulching layer of black nylon plastic, and at the same time, the drip tape is installed underneath, as shown in Figure 15.

Figure 7. Land field after installing mulch and drip tap on the flower beds (Innovaterra Ltd. 2021).

The drip tape is the one that provides the water irrigation inside the bed plants, and the mulch helps to keep the soil warm, as many other advantages.

- Drip tape tube 4,000 meters/hectare

A drip tape tube is a kind of miniature water system framework that can save water and supplements by permitting water to trickle gradually to the foundations of plants, either from over the dirt surface or covered underneath the surface. The objective is to put water straightforwardly into the root zone and limit dissipation. In China, commercial disposable drip tapes are commonly made from a mixture of low-density polyethylene (LDPE). (Guo, Wu & Zhu, 2018).

- Mulch 4,000 meters/hectare

According to Jabran (2019), the "advantages of black plastic mulch surpass the straw mulch, but straw has a lower cost, easy availability, and no residue. Black plastic mulch is likely to provide higher weed control, water conservation, and other benefits but has a higher cost and leaves residues in the soil. Biodegradable mulches (made from starch or some other degradable polymers) are an excellent alternative to the plastic mulch."

4.1.3 Water Source and Irrigation system

The drip irrigation system for the plantation is done with two pumps. One pump is for the pressurization of the water in the drip hose inside the flower beds. The primary pump is a Hammelmann high-pressure pump **150 kW**. The approximate model is "HP 140," as shown in Figure 16. (Hammelmann Corporations, 2020). These pumps are manufactured in Germany, but they have a retailer in Uruguay that provides maintenance.

Figure 8. Electric water pump 150 kW (Hammelmann Corporations, 2020).

The water consumption is approximately **1500** $\boldsymbol{m^3 / h}$**a**. This freshwater comes from the river called "Uruguay". Innovaterra Ltd. is geographically located in the banks of the river at the coast, as shown in Figures 17 and 18. This lake was formed after constructing the hydroelectric dam 40 years ago (Salto Grande.org, 2021). The water consumption depends on the rain season.

Figure 9. Innovaterra Ltd. costal line (Google LLC, 2021).

Figure 10. El Espinillar from Google Map view (Google LLC, 2021).

The Uruguay river, in the zone where Innovaterra Ltd. is located, it is actually a lake as seen in Figure 18. This point is taking into consideration to produce the LCA in such a manner that there is none freshwater scarcity in the zone.

4.1.4 Hydroelectric Energy

The energy that powers Innovaterra Ltd. water pump is from the hydroelectric plant called "Salto Grande Dam". This dam has an installed capacity of 1,890 megawatts (MW), with 14 turbines of 135 MW. This dam is in the Uruguay river, as is shown in Figure 19. Uruguay has a total of 4 hydroelectric dams, and the other three hydroelectric press are in the river called "Rio Negro". Also, there are 43 wind farms with an installed capacity of 1505 MW. With all that say, the country is 98 to 100 percent powered by electricity from renewable sources. (International trade administration, 2020).

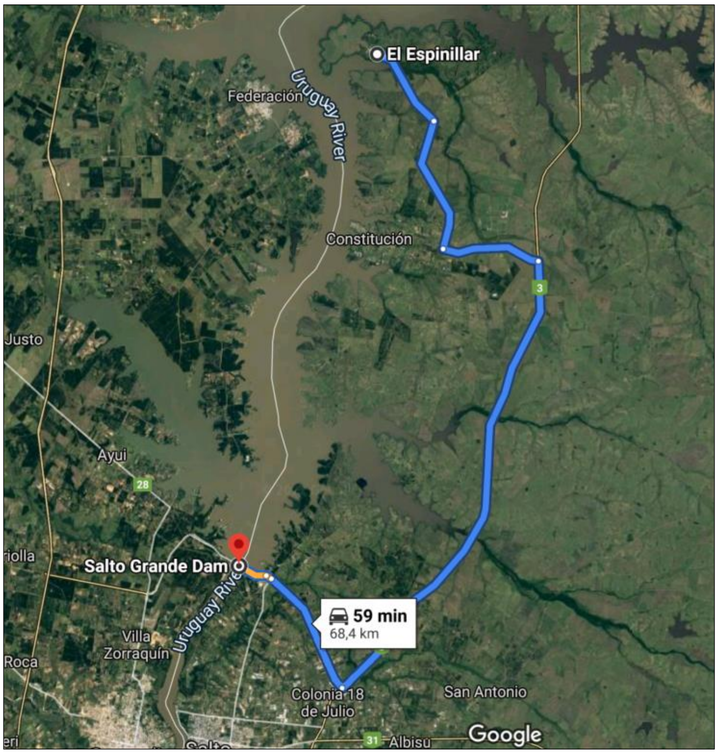

Figure 11. Location of Salto Grande Dam and Innovaterra Ltd. (Google LLC, 2021).

4.1.5 The Calculation for Amount of Grass

To aid in the visualization of one hectare (100 m x 100 m) hemp plantation, the author created a sketch in AutoCAD LT 2018. The green area in Figures 20 and 21 represents the grass, and the black area with cross symbols represents the hemp.

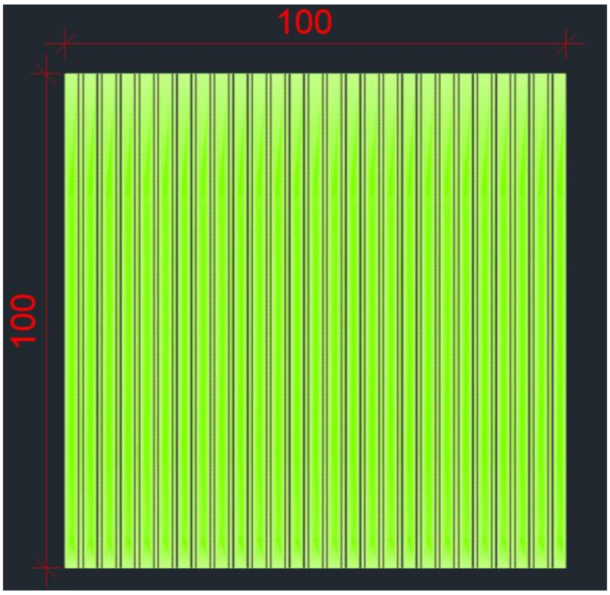

Figure 12. One hectare plantation drawn in AutoCAD LT 2018. (Juan Silva 2021)

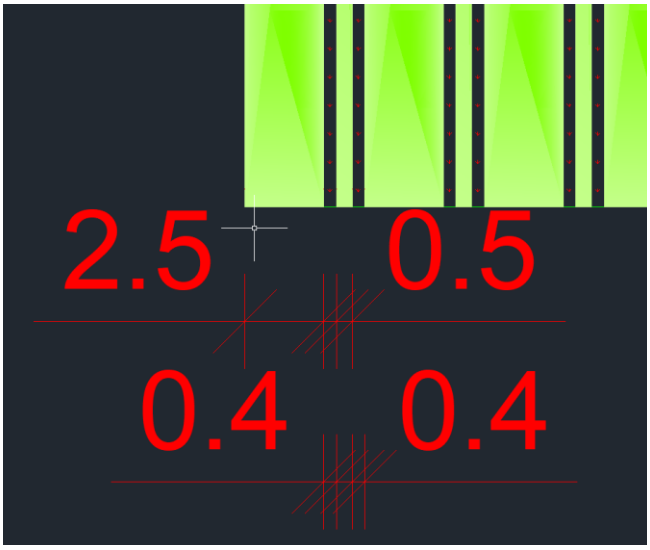

Figure 13. Detail of hemp plantation with dimensions in meters (Juan Silva 2021).

The plantation at Innovaterra Ltd. is built up in the following way:

- The first corridor is 2.50 m of grass, followed by two approximately 0.40 m expansive hemp plantations.
- The hemp plantations are separated with a 0.50 m wide grass corridor, as shown in Figure 14.
- In 100 m, 26 of these" sets" fit in, adding 1.20 m of grass in the end. ‘
- It can be calculated that the amount of grass per "set" is 2.50 m plus 0.50 m, equalling 3 m.
- Now, multiplying 3 m with 26 (and adding 1.2 m from the end) gives 79.20 m.
- To receive the area of grass, 79,20 m is multiplied by 100 m.
- They are resulting in ***7920 m²,*** the total amount of grass in one hectare.

This, however, is describing a perfect scenario of one hectare of hemp plantations. The objective and accurate description of the hemp plantations can be seen in Figure 22. This aid visualization helps to calculate the most approximate value of the grass field. This value will be utilized for the carbon uptake in Chapter 4.

Figure 14. Hemp plantations layout from Innovaterra Ltd. (Google LLC, 2021).

In Figure 22, at the end of the main road is located the storage warehouse where the biomass of flowers is dry. It takes around two weeks for the flowers to dry before they can start the manufacturing process of creating the resin from the flowers. The flowers are hanged from a high line in the ceiling for the drying stage. When the flowers are dry, they are stored inside of big white plastic bags. These bags are made for approximately 50 kg of dry biomass per bag. In Figure 23 it is shown small bags with dry biomass of hemp flower. Additionally, Innovaterra Ltd. re utilizes these bags for the small planter box made of plastic when the cuttings are taking from the mother plants.

Re-usable plastic:

- Irrigation hoses
- Small plant pots
- Big white storage bags for biomass

Recycled plastic, sent to a plastics recycling company located in Salto, Uruguay.

- Mulch, black plastic from the flower's beds
- Drip tapes, irrigation system inside the flower beds
- Empty fertilizer bags

Figure 15. Dried hemp flowers after harvested, ready for extraction of the CBD. (Innovaterra Ltd. 20201)

4.2 Inventory Analysis

This is the phase where all the inputs and outputs flow for the LCA are collected.

- Tillage
- Harrowing
- Sowing
- Fertilization
- Irrigation
- Labour
- Harvesting
- Drying
- Agricultural Machinery
- Renewable energy
- Fresh water recourse
- Plastic utilization
- Transportation

This list is considered for the development of the LCA scenarios, where the plan is made of processes, and the processes have input flows and output flows.

4.3 Scenario Modelling

For this study, three scenarios have been developed to model the plan with all the processes required for a product system. This plan alone is required for the calculation of the final LCA. A plan is formed with many processes, and each process has an input and an output flow. In other words, for a biomass LCA to be performed accurately, three or more of these plans must be combined in one big scenario. For this reason, the author has chosen to only model ***scenario number three*** in GaBi software.

1. Scenario one models the plan for the “Mother Plant”.
2. Scenario two models the plan for the “Soil Management”
3. Scenario three models the plan for “Crop 7-month period”

The mother plants need to have their own plan for a complete LCA. The mother plant is modelled as a process because it is from where the cuttings are produced. Also, if they are studied by themselves as one process only, they must be considered as ***cradle-to-gate*** for the boundaries. For this thesis, the mother plant is added to the LCA as a "***multifunctional process factory*** ".

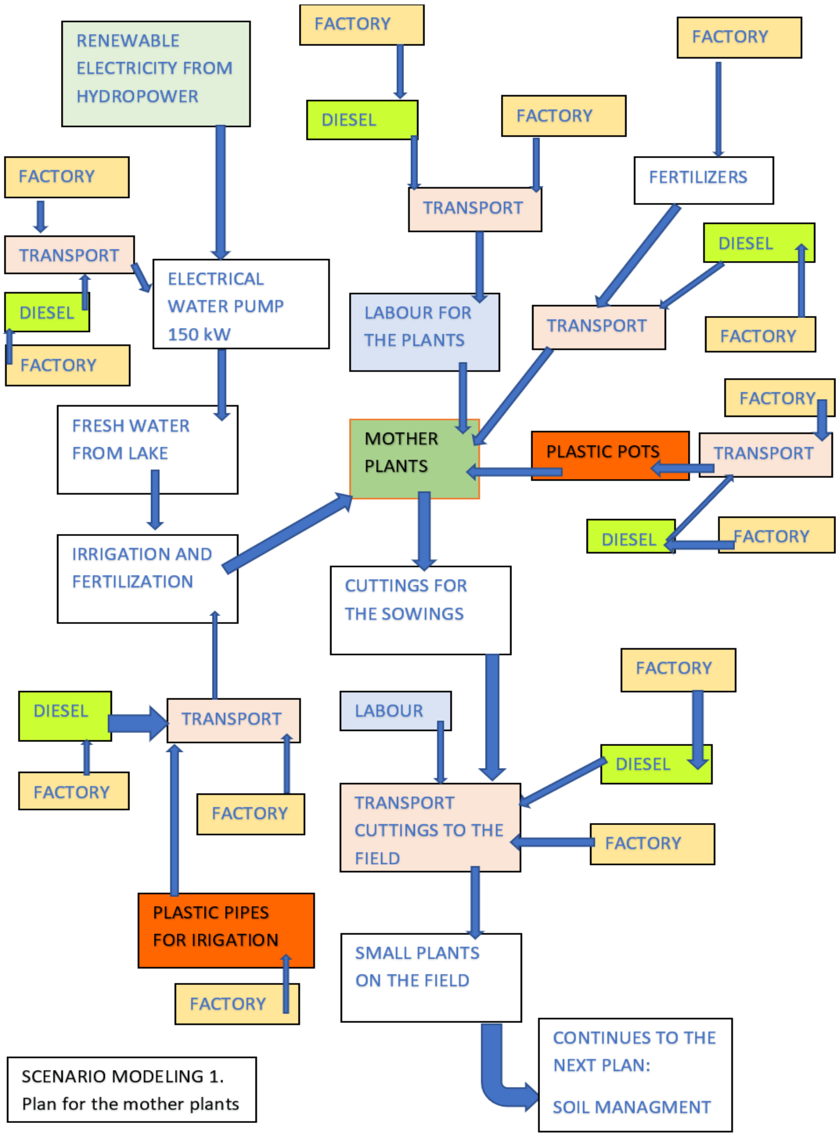

Figure 16. LCA mother plants. (Juan Silva 2021)

Figure 24 it is aimed to illustrate all the process needed to create a product called mother plants. For example, the plant requires fertilizer. Therefore, a factory has been created. The factory requires an input flow: energy, water, and chemicals. Then the output flow from the factory will be the fertilizer. This fertilizer will be allocated as input flow into the "mother plants" process. For that to occur, transportation is needed. Transportation is created in a factory. Factories, as mentioned before, require raw material and energy to create a product. The raw material and energy are input to the factory, and the truck created in the factory is the output. This truck is utilized as transport for the fertilizer. For this reason, it required diesel. The diesel is created in a factory, so the output of a factory is used for transportation products like fertilizer to consumers.

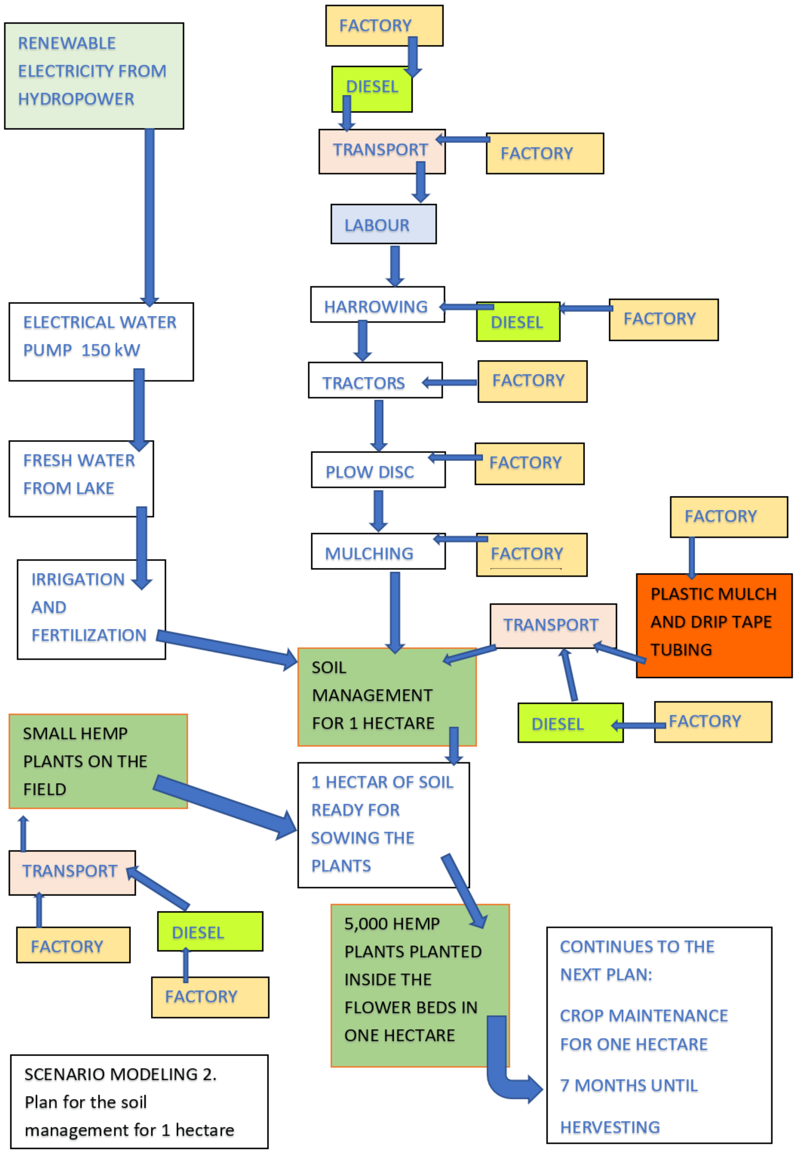

Figure 17. LCA model of soil management. (Juan Silva 2021)

Figure 25 illustrates all the processes needed for the soil management for 1 hectare. In other words, all the inputs needed for the soil to be ready for the small hemp plants to be sowed in the landfill. The distinction between Figure 24 and Figure 25 is that there are two different plans. The reason for this is that, until the soil has not been prepared for the plants to be ready, the "mother plants" will not be and input into the land. In Figure 25, the functional unit is one hectare. Also, it is shown that after all the chain of inputs to the field for tillage are done, the output will be one hectare ready. The small plants are illustrated as a different process and then added to the ready land as an input.

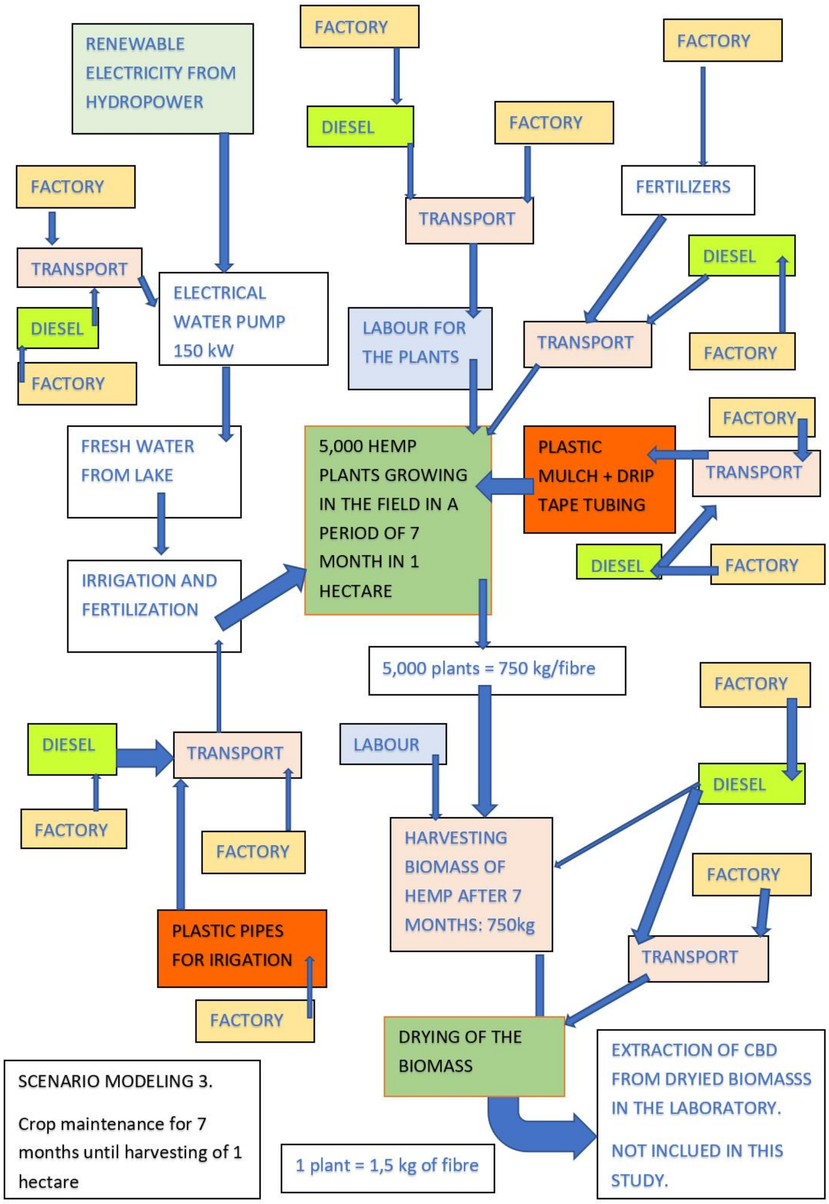

Figure 18. Plants growing in a period of 7 month. (Juan Silva 2021)

Figure 26 illustrates the plan for 5,000 plants in seven months because this is from when the plants are sowed to when the plants are harvested. All the inputs required for the plants to be alive and grow exponentially with the time constraint for the vegetative phase and the flowering phase. This scenario modelling is the one modelled in GaBi software will be presented in chapter 5.

Summarizing:

- Mother plants are a process or service that as an output provide 5,000 cuttings to be input in one hectare of ready land and for this reason need its own scenario modelling.
- Soil management needs many processes as input, and as output, it is one hectare of land ready for receiving 5,000 cuttings of hemp plant.
- Crop maintenance is the scenario for sustaining 5,000 plants for one month in one hectare of land, providing fertilization, irrigation, and labour as input. The output is 5,000 plants that now have a mass of 750 kg or 1.5 kg per plant in which 650 grams per plant are flowers.

4.4 Calculations for LCA Modelling

4.4.1 Carbon Capture

In table 4, the calculations for the uptake of CO_2 equivalent of hemp fibre for 5,000 plants in time assumed of 7 months are shown.

Table 4. The calculation for CO_2 uptake in hemp fibre. (Juan Silva 2021)

		Kg CO_2 eq. uptake/kg fibre
Number of plants per hectare	5,000 plants	1.39 kg of CO_2/ kg of fibre
Kg of fibre/plant from Innovaterra Ltd.	1.5kg/ plant	2.04 kg of CO_2 eq. per plant
Kg/fibre/hectare	7500 kg	10,200 kg of CO_2 eq. per hectare. (Equation 2.)

- One plant has 1.5 kg of total fibre.

$$1.5\,kg \times 5{,}000\,plants = 7{,}500\,kg \qquad \textit{Equation 1.}$$

$$(7{,}500\,kg) \times (1.39\,kg\,CO2\,eq.\,kg/\,fibre) = 10{,}425\,kg\,of\,CO_2\,eq. \qquad \textit{Equation 2}$$

Table 5. Amount of CO_2 equivalent uptake for Grass and Soil. (Juan Silva 2021)

UPTAKE FROM:	SOIL AND ROOTS	GRASS FIELDS
One hectare / year	2.54 tons of CO_2	5 tons of CO_2
7,920 m^2 of grass in 1 hectare	2.54 tons of CO_2	3.960 tons of CO_2

$$10{,}000\ m^2 = \frac{(5{,}000\ of\ CO2 \times 7{,}920\ m^2)}{10{,}000\ m^2} = 3{,}960\ kg\ CO_2\ equivalent$$ *Equation 3*

$$2{,}54\ tones\ of\ CO2\ \times 10{,}000\ m^2 = 2{,}540\ kg\ \ CO_2\ \ equivalent$$ *Equation 4*

Summation of biogenic carbon capture:

Taking into consideration that Innovaterra Ltd. has the mother plants all year around as well as winter pastures after the biomass is harvested, it is estimated that an additional 1,7 tons of CO_2 is captured and is added to the GaBi calculation.

Table 6. Summation of biogenic CO_2. (Juan Silva 2021)

Type	Grass (eq. 3)	Soil and roots (eq. 4)	Hemp fibre (eq. 2)	Estimated additional value	Total sum
Amount of CO_2	3,960 kg	2,540 kg	10,200 kg	1,700 kg	18,400 kg

In table 6 is represented the summation for the total biogenic carbon capture use in the GaBi computation: **- 18,400 kg of** CO_2 **equivalent.**

4.4.2 Mass of the Plastic

Mulch back plastic film-like, made of Polypropylene (PE).

Length: 4,000 m

Width: 1.40 m

Thickness: 1.5 mm

Density: 0.92 g/cm^3 (PE MDS, 2021)

Total mass: 7,728 kilograms

$$4{,}000\ m \times 1.40\ m\ \times\ \ 0.0015\ m \times\ 0.92\ \text{g}/cm^3\ = 7{,}728\ \text{kilograms}$$

Drip tape tubbing. Made of **LDPE** (low-**density** polyethylene)

Length: 4,000 m

Width: 0,04 m

Thickness: 2 mm

Density: 0.940 g/cm^3 (LDPE MDS, 2017)

Total mass: 2,256 kilograms

$$4{,}000\ m \times 0.04\ m\ \times\ \ 0.015\ m \times\ 0.940\ \ \text{g}/cm^3\ = 2{,}256\ \text{kilograms}$$

4.4.3 Energy Consumption of the Water Pump

Pump flow rate $= 1500\ m^3\ in\ 7\ months$

$$\frac{1500\ m^3}{20.6\ m^3/\text{h}} = 72824 \times (54 \times 10^8) = 40\ GJ$$

40 Giga Jules are the approximated amount of energy consumed by the pump during seven months for water irrigation.

4.4.4 Amount of Fertilizer

The amount of fertilizer per hectare is approximately 400 kilograms. This is based on estimation, so 400 kilograms of fertilizer are 16 bags of 25 kg. Each bag has an NPK percentage, as shown in table 6.

Table 7. Fertilizer calculation for 1 hectare. (Juan Silva 2021)

FERTILIZER	PERCENTAGE	TOTAL
NITTROGE	15% N	60 kg
PHOSPHORUS	10% P	40 kg
POTASIOUM	15% K	60 kg
MAGNESIUM	2 % Mg	8 kg
SULFUR	31% S	124 kg
OTHERS	27 %	108 kg
TOTAL AMOUNT	100 %	400 kg

Innovaterra Ltd. also utilizes another type of fertilizers like Hakaphos violet and orange. However, this depends on what it is available in the market at the moment of purchasing the bags. For this study only 400 kg of NPK 15 10 15, is utilized.

5 RESULTS & ANALYSIS

The results obtained from the computation of GaBi software are presented in this chapter in a combination of the analysis for each graphic.

5.1 GaBi Plan & Process

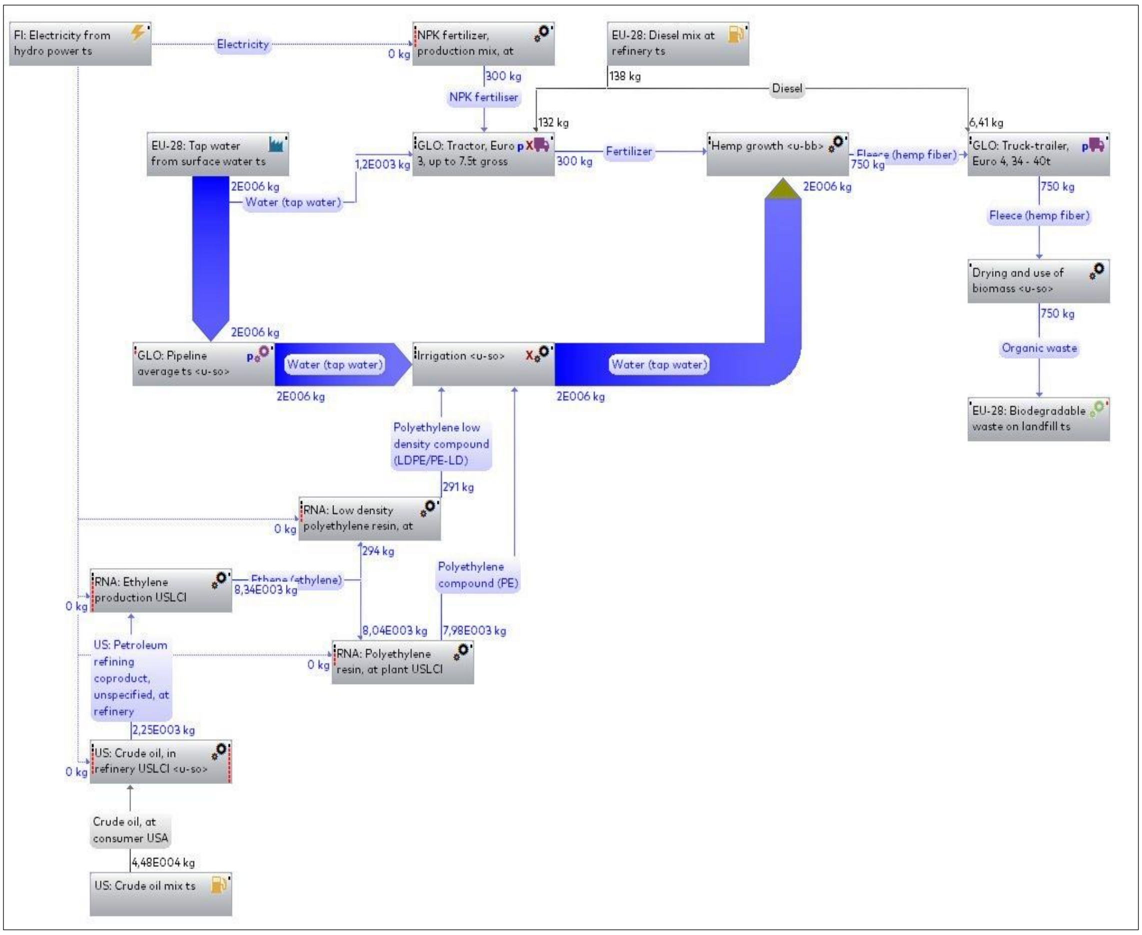

Figure 19. Results from GaBi software. (Juan Silva 2021)

The result of GaBi software is only possible if the planning model is complete in the "model windows". When the plan is completed, the arrows turn into blue colour, indicating that the LCA is completed. For the completion of this plan, it is necessary to create several processes manually due to the educational licenses of GaBi software has a limited database. In this case, as shown in Figure 27, it is added ***"end of life biodegradable waste on landfills***" for the study to be complete. Even so that for Innovaterra Ltd.'s is not the case because they burnt some biomass, and they keep other parts for future industrialization. This means that to compute this study in a GaBi software with educational licenses, the LCA performed was ***cradle-to-grave*** instead of ***cradle-to -gate*** as mentioned before in chapter 4.1.1. In other words, the data gathered for this LCA is only for ***cradle-to -gate*** scenarios. However, it was required to manually input end of lice scenario to complete the LCA. The irrigation process was added as input flow of the water from the lake, but to join this process, the only option available was tap water. Tap water is representing the water traveling through the pipes to the landfill. This model plan was able to use electricity as hydroelectric power, shown in the top left corner of Figure 27. The fertilization, transportation, and diesel utilization were represented without issues with the corresponding inputs and outflows. The direction of the flow is observable to progress in the direction of a process called "hemp growth". This process was chosen to be one hectare of land in a period of seven months with the output of "carbon dioxide (biotic)" of a total amount (–18400 kg CO_2) equivalent and 750 kg mass of fibre of hemp as it is shown in Figure 28 in the bottom half of the image, under "outputs, flow".

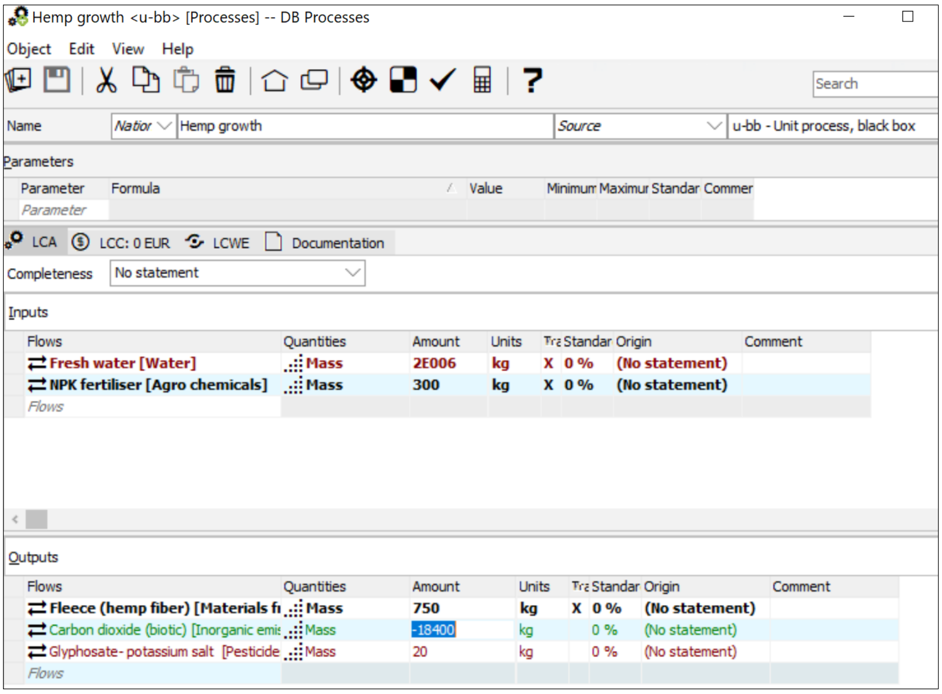

Figure 20. Hemp Growth processes, GaBi. (Juan Silva 2021)

This amount of biogenic carbon capture was introduced in this process as a summation of all the biogenic carbon capture. The hemp calculation is represented in chapter 4.5.2. The production of (PE) process was made with a factory in the U.S. because the database has not information about Uruguay. The mulch plastic required considerable amount of crude oil to be produced and had to be added for the software to be able to connect the process, and this is represented in Figure 27 on the left-hand side of the image.

5.2 Impact Results

The first graphic is for the GWP, global warming potential, and it is measure as kg of CO_2 equivalent as shown in Figure 29.

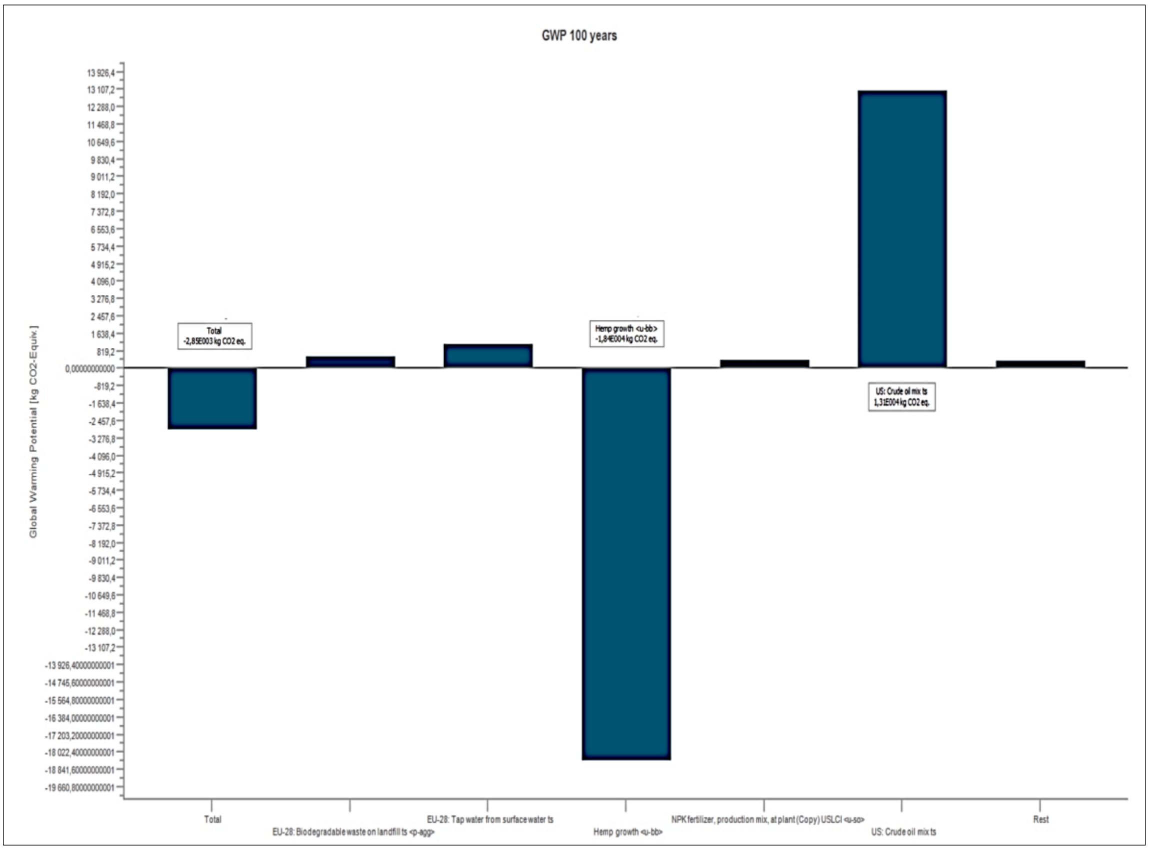

Figure 21. GWP graph from GaBi. (Juan Silva 2021)

Global warming potential (GWP) is the high-temperature gasses absorbed by the atmosphere (Azapagic, Emsley & Hamerton, 2003). In Figure 29, in the first column, it is the Total amount of CO_2 equivalent. The reason the graphic shows negative is that the plants, soil, and grass has been taking into consideration. This value is – 2,800 kg CO_2 equivalent for the total amount. This is the calculation for the total CO_2 is the summation of all the processes introduced into the GaBi plan, as shown before in Figure 27.

Hemp growth indicates the amount of biogenic carbon introduced manually in the output flow, as mentioned before in Figure 28. Figure 29 shows for hemp growth -18,400 CO_2

equivalent exactly like Figure 28. This is due that the software simulation is working. For the process of “US crude oil mix,” their result is 13,059 kg of CO_2. For the creation of almost 8 tonnes of mulch plastic for the flower beds, crude oil is required to create ethylene. This is the reason for so much release of GHG to the atmosphere.

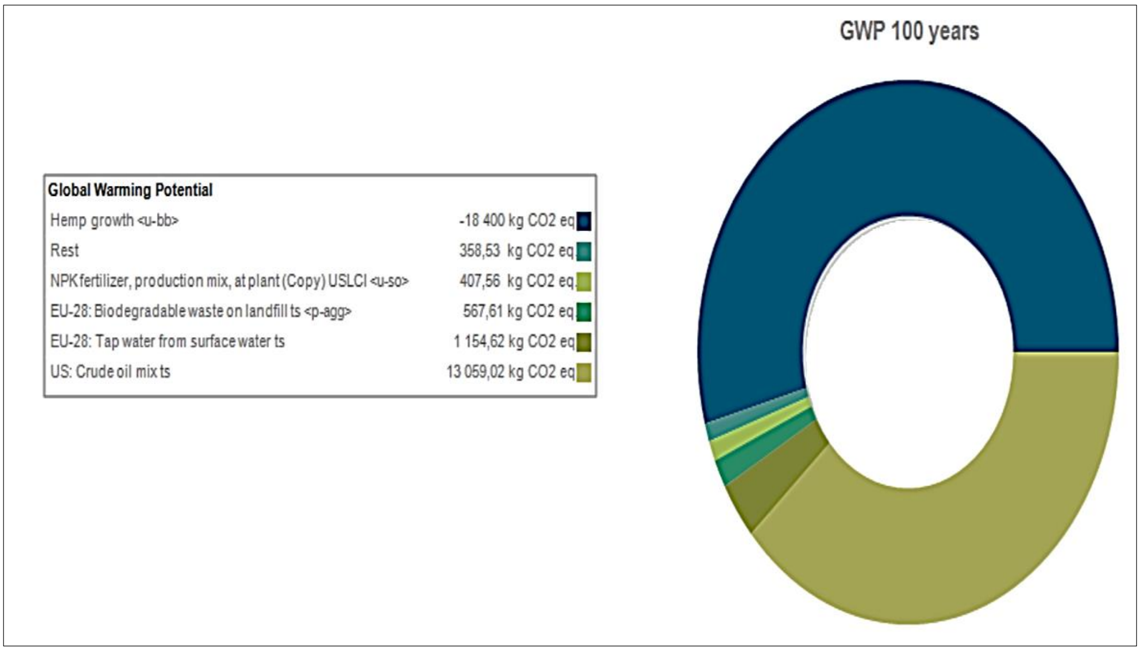

Figure 30.GWO 100 years donut graph. (Juan Silva 2021)

Figure 30 is a graphical representation for the GWP in 100 years in donut shape aids for the visualization of the other process. NPK fertilizer production has a result of 40756 kg of CO_2 eq. Biodegradable waste has a total of 567.61 kg CO_2 eq., biodegradable waste had to be added just for the computation, but this result is not 100% true. Similarly, for the case of tap water, that indicates 1,154.62 kg of CO_2 eq.

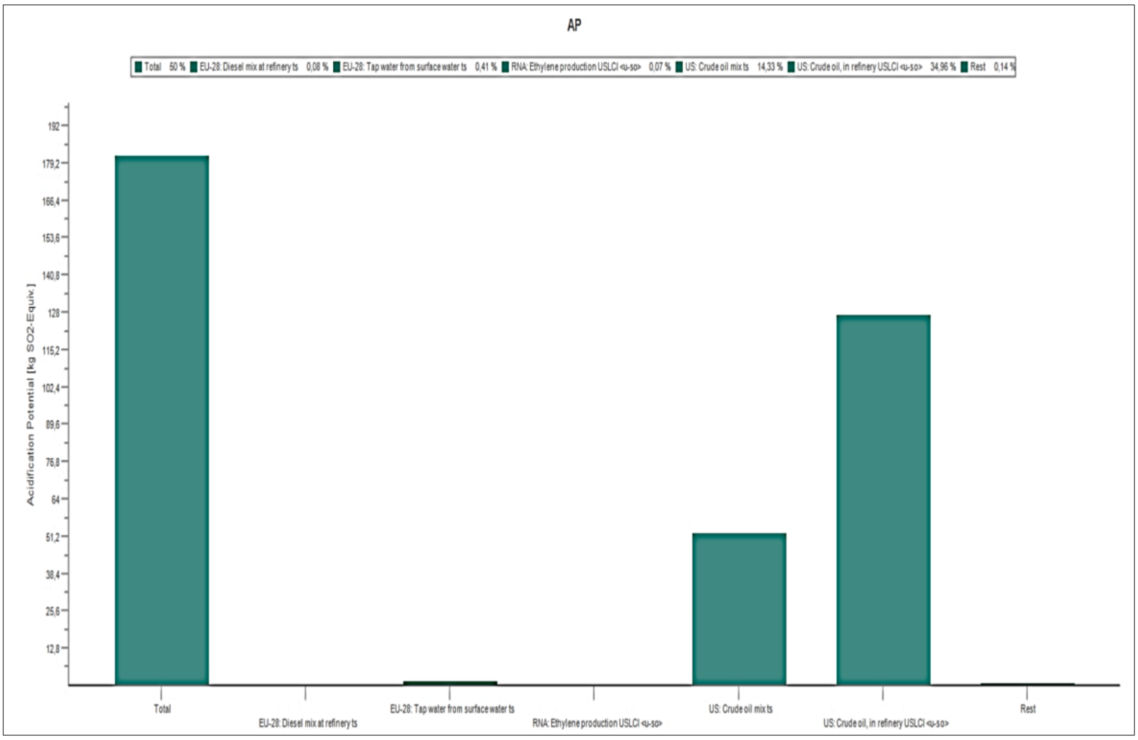

Figure 31. Acidification Potential graph, GaBi. (Juan Silva 2021)

The acidification potential alludes to the mixtures that are antecedents to corrosive downpour. This incorporates sulphur dioxide (SO2), nitrogen oxides in kg equivalent (Azapagic, Emsley & Hamerton, 2003). In Figure 31 it is shown the result for the processes that accounted for the acidification potential. The major hot spots for this environmental impact are US crude oil mix with 14.44% of the total and US crude oil in a refinery with 34.96 % acidification. Tap water, ethylene production, and Diesel mix refinery are less the 1% each.

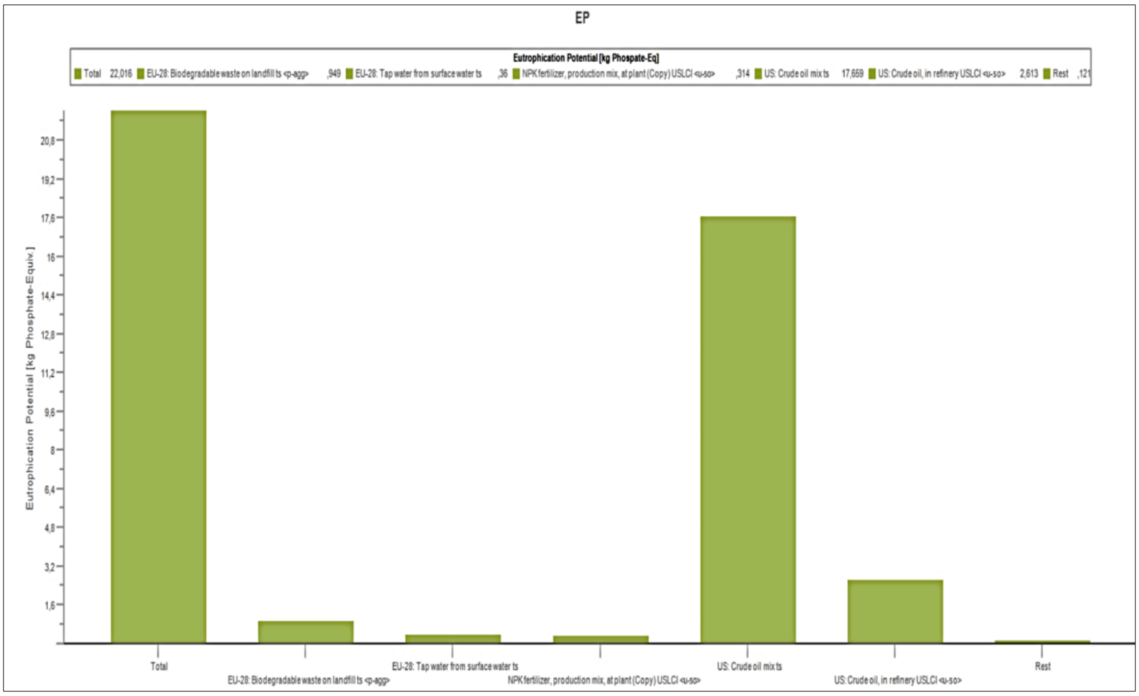

Figure 32. Eutrophication Potential graph, GaBi. (Juan Silva 2021)

The eutrophication potential is caused by using too much fertilization on the water. The unit utilized is kg Phosphate equivalent (Azapagic, Emsley & Hamerton, 2003). Figure 32 shows the result for the eutrophication potential and indicates that the "US crude oil mix" is the biggest with 17,659 kg of Phosphate eq. The second most significant impact is "US crude oil in the refinery" with 2,613 kg of Phosphate eq. NPK fertilization production mix is the lowest impact for eutrophication potential with 314 kg of Phosphate equivalent.

Figure 33. Ozone Layer depletion Potential, GaBi. (Juan Silva 2021)

The ozone depletion potential is the emissions realized from chlorofluorohydrocarbons (CFCs) and chlorinated hydrocarbons (HCs) (Azapagic, Emsley & Hamerton, 2003). In Figure 33. The 50 % of this emission is accounted for the US crude oil in a refinery with approximately 6,000 kg of R11-equivalent. The rest of the processes are accounted for 0% for the ozone depletion impact.

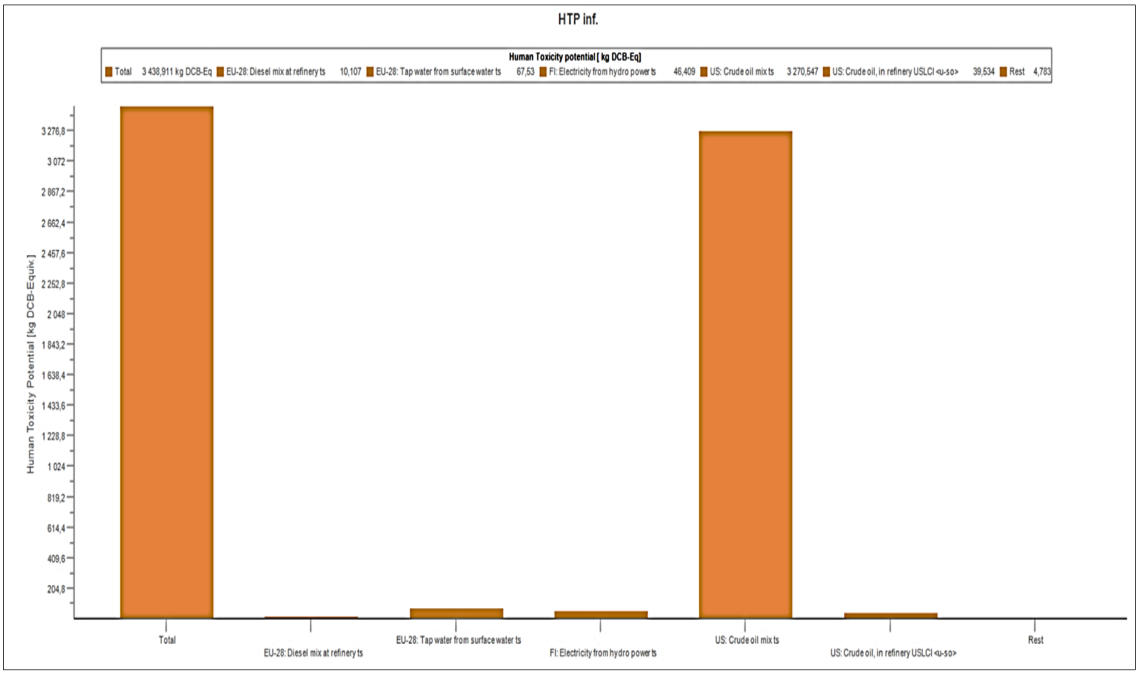

Figure 34. Human Toxicity Potential. (Juan Silva 2021)

Human toxicological classification factors for the effects of the toxic emission to air, water, and soil, respectively (Azapagic, Emsley & Hamerton, 2003). Figure 34 shows the highest impact for human toxicological accounting for US crude oil production with 3270,547 kg DCB equivalent. All the other processes are shown a small amount in contrast with US crude oil.

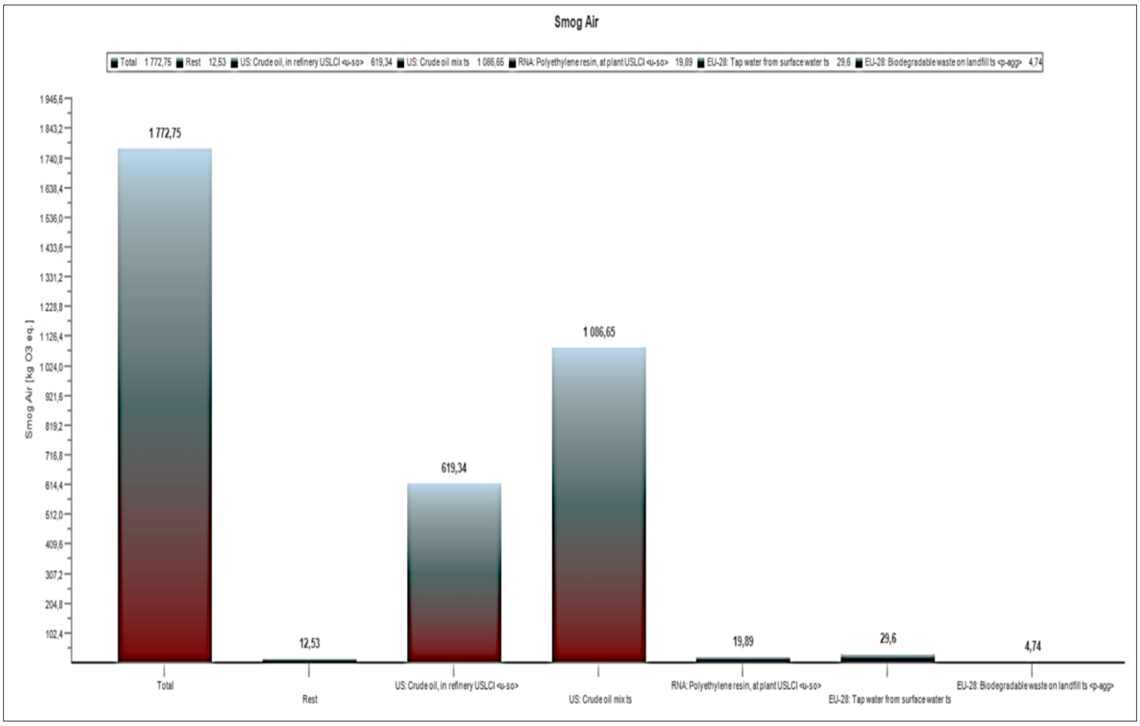

Figure 35. Smog Air graphic, GaBi. (Juan Silva 2021)

Smog is air pollution accumulated in the atmosphere (Azapagic, Emsley & Hamerton, 2003). Smog name describes it, the combination with smoke and fog. In Figure 35, the smog for US crude oil is 1086.65 kg O3 equivalent, ranking as the higher impact for all the LCA processes. Second, on the list is the US crude oil in a refinery with an amount of 619.34 kg O3 eq. The total amount of smog with all the processes combined is 1778.75 kg O3 eq.

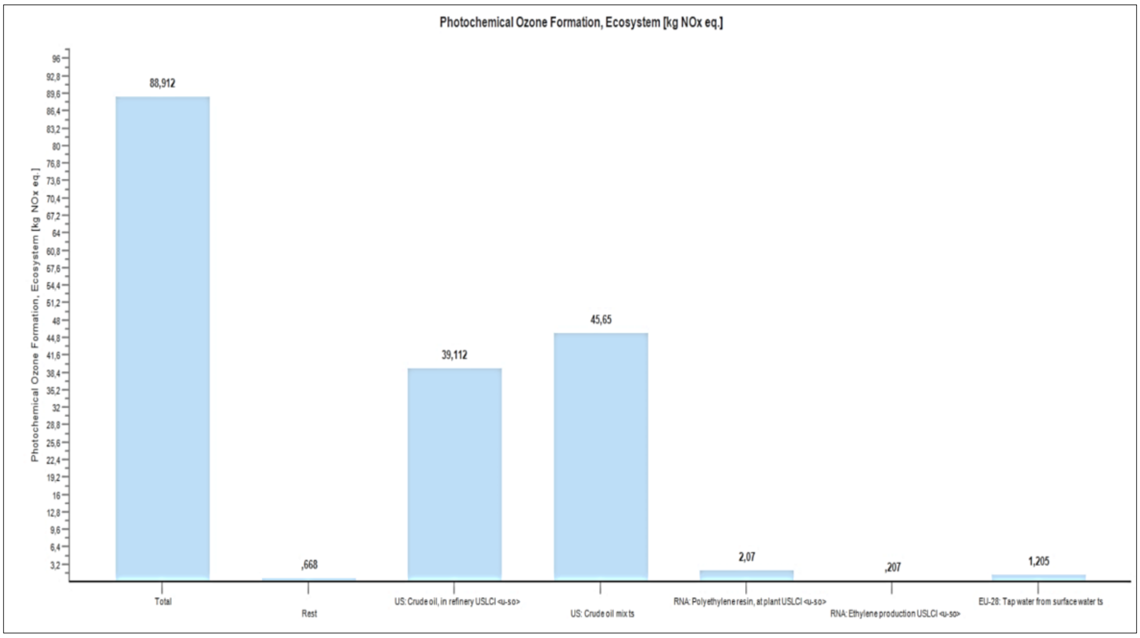

Figure36. Photochemical Ozone formation graph, GaBi. (Juan Silva 2021)

Photochemical oxidants arise as the product of reactions between OH-radicals, photochemical oxidants, and the air pollutants nitrogen oxides (NO_X) (Azapagic, Emsley & Hamerton, 2003). Figure 36 is represented for US crude oil 42.65 kg NOx equivalent. In chapter four, Table 1, it is stated a characterization factor of nitrous oxide as 265. Therefore $46.65 \times 265 = 12,362.25$ kg of SO2 equivalent. For US Crude oil in the refiner, the amount of 39,112 kg of NOx eq. A total amount of 88,912 kg of NOx equivalent, for all the processes combined shown in the first column on the right-hand side of the image. This amount is large, but it is expected in agricultural LCA's due of the use of fertilizers and plastic products.

5.3 Limitations

The study of this thesis has been limited to only one scenario analysis from all the LCA possible to be made for a biomass plantation. The calculations presented in this work aim to be as accurate as possible. The results are not 100% accurate, as this LCA requires extensive amount of data gathering to produce accurate results. Therefore, it was not possible to produce better high-quality data, as per GaBi software educational license database does not contain all the information required. More recommendations on further studies are discussed in chapter seven.

6 DISCUSSION

After the definition of functional unit, system boundaries, and the inventory, the impact of the seven combinations was evaluated by the GaBi software education version. The environmental impact obtained in this LCA does not access all the necessary processes for a complete LCA for Hemp biomass production. This is since GaBi software educational licenses have a limited database. From the theory to the simulation of the program, there is a difference in real life. The software does not have data from Uruguay, and data from the US was utilized. Nevertheless, the data gathered is enough to be expressed into meaningful information. The hotspots have been identified, giving room for a scenario simulation with a variant of the product of that hotspot. This hotspot is allocated for the fabrication of the mulch plastic. Even if the fabrication of mulch plastic would be in Uruguay, it would make no difference in the final CO_2 contaminations of the ethylene production, as the production require large amount of crude oil. Therefore, in real life, the values affect differently, and for this reason, the author has chosen to add more carbon biogenic to the calculation of the software. For this LCA, it must be taken into consideration the pipeline production and installation into the land. It was not possible to add all those values, neither the tractors, agricultural machinery, nor the electrical pump. Some day in the future, all these products could be easier added to any LCA, utilizing an environmental product declaration (EPD). For now, there are many plant cultivators that would like to obtain a replacement for plastic pipes, mulch, and drip tape tubes. Some re-usable material or biodegradable plastic could be utilized. Despite of a large amount of plastic used for agricultural processes, the mulching system might help the soil to capture more CO_2. According to Held (2019), the “flat plastic blocks sunlight from hitting the ground and stimulating weed growth. It's spread over the ground as a form of mulch to suppress weeds, conserve water, and aid plant growth.” All the processes that were not possible to be added to this LCA, would also have contributed to the final GWP. Nevertheless, these contributions would be for the first year only. In other words, the same pipes would be used every year, so the production of such pipe is not calculated for more greenhouse gasses, and the hemp plant keeps capturing CO_2 every year with each new crop planted.

7 CONCLUSIONS

The aims of this thesis were achieved through a combination of data collection, modelling and analysis which was made possible by literature review, company collaboration, LCA software and analysis. The biogenic carbon dioxide of the hemp production was modelled and simulated. The result helped to identify, which hotspots for all the processes contaminate the planet the most. Even though that the LCA utilized data and processes that were not completely accurate, meaningful information was obtained and simulated by the software. It is understood that the total CF results, therefore, lower than the CO_2 uptake due to the biogenic carbon captured and stored during hemp growth (Asdrubali, 2020). The carbon footprint is an actual calculation of greenhouse gasses created by a product, a process, or a service. In this case, the GHGs were assessed, expressed in kg of CO_2 equivalent of the hemp plant cultivation. From the results of LCA conducted, it is possible to highlight the output of the process attributable to the emissions in the air, in soil, and in water. The results of CF for the scenario evaluated have been reported in Figure 22. Hemp has superior properties in terms of oxygen production, carbon dioxide decomposition, and permanent bending to the material produced. Hemp must be used more as it is helpful for the economy and the environment. (Aytaç, 2018). The degree of boost in photosynthesis and the rate of growth of the plants are linked to species, genotype, and diversity. Finding the precise exactly grass type one and its CO_2 absorption in literature could be challenging. For this reason, this experiment is suggested to be redone with a portable infrared gas analyser in the fields, several times a year and at different times. In the upcoming time, the carbon uptake will be more crucial than it is today, but it is critical to act already. In conclusion, we can state that the measurement of the carbon flow cycle and sequestration is relatively complex. The net flux of carbon in hemp fields is the key to knowing how much CO_2 emissions the final product will eventually have. Decision and policymakers must take into consideration many factors and make more Life Cycle Assessments on how much CO_2 emissions the process cultivation would help climate change. For example, in Finland, there are many farmers utilizing hemp already. The author has got in touch with two of them. One of them is “Hamppufarmi” which grows hemp biomass for hemp seeds. They produce many products like protein powders and snacks. The author requested the owner for the possibility to measure the CO_2 uptake of one of their plant in their field, and they agreed. This measurement could be utilized for future studies in Arcada UOAS in Finland.

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APPENDIX 1

Example of Certificate of Analysis for CBD with 0 % THC content (Vitox Vital, 2019).

deepnature project

Deep Nature Project GmbH
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A-7122 Gols
ATU61164411
AT-BIO-301

Analysis Report

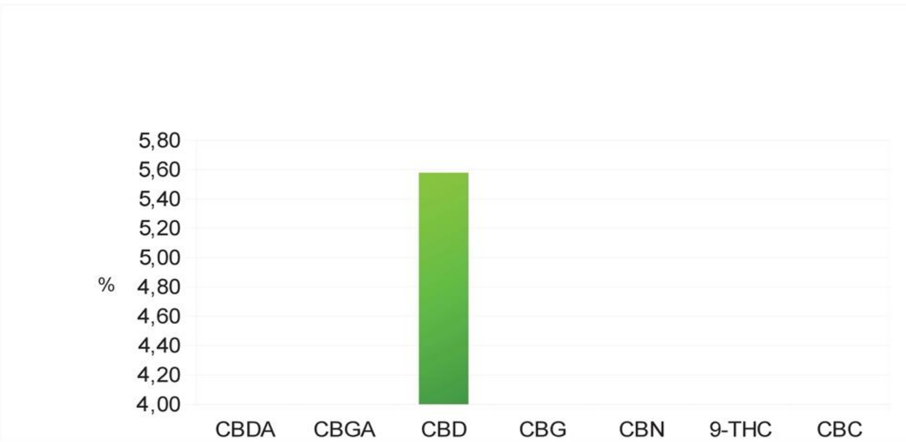
Client name:	CBD Oil		
Sample name:	5% Pure		
Batch number:	1025-1954		
Date of delivery	08.03.2019	Sample type:	Final Product
Date of analysis:	08.03.2019	Analysis Method:	HPLC-UV

Analysis Results

CBDA	n.d.	%	CBD äquiv.	n.d.	%
CBGA	n.d.	%	CBD äquiv. total	5,58	%
CBD	5,58	%	CBD+CBDA	5,58	%
CBG	n.d.	%	CBG+CBGA	n.d.	%
CBN	n.d.	%			
9-THC	n.d.	%			
CBC	n.d.	%			

n.d. = not detectable = < 0,01%

Cannabinoid profile



Performed and Released by: Date: Clemens Capellmann	Approved by: Date:

In Process Control – Deep Nature Project GmbH
Confidential Document – for internal use only
Permission required for distribution to any other person or third parties. Results are limited to the analyzed sample, not being applicable to the whole batch. Possible standard deviation of the Results: ± 10%.

APPENDIX 2

The following material data sheet for hemp plant cannabis sativa L. was used for the calculations from chapter 3.2.1, page 29, Table 8. "Biogenic carbon storage" (Barth & Carus, 2015) .

hemp (Cannabis sativa L.) whole plant (#1702)

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ID-number	#1702
Material	hemp (Cannabis sativa L.) whole plant
Classification	ECN Phyllis classification ▸ grass/plant ▸ hemp NTA 8003 classification ▸ [200] biomassa uit land- en tuinbouw ▸ [220] stro ▸ [225] hennep
Submitter organisation	ECN (Netherlands)
Submission date	1999-10-15
Literature	P.Liebhard: Hanf als nachwachsender Rohstoff fur eine thermische Nutzung. In: Hanf workshop, Bundesanstalt fur Landtechnik, Wieselburg, 7 Dec. 1994, pp. 147-150 (1994).

Values

Property	Unit	Value ar	dry	daf	Std dev	Det.lim	Lab	Date	Method	Remarks
▾ **Main biomass properties**										
▾ **Proximate analysis**										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		6.00							
▾ **Ultimate analysis (macroelements)**										
Carbon	wt%		44.30	47.13					Average	
Hydrogen	wt%		5.34	5.68					Average	
Oxygen	wt%		42.86	45.60					Calculated	
Nitrogen	wt%		0.85	0.90					Average	
Sulphur	wt%		0.20	0.21					Average	
Total (with halides)	wt%		100.00	100.00					Calculated	
▾ **Halides**										
Chlorine (Cl)	mg/kg		4 500.0	4 787.2					Average	
▾ **Heating value**										
Net calorific value (LHV)	MJ/kg		16.90	17.98						
Gross calorific value (HHV)	MJ/kg		18.06	19.22						
HHV_{Milne}	MJ/kg		16.85	17.92					Calculated	
▾ **Ash Properties**										
▾ **Ash composition**										
SO_3	wt% (ash)			1.77						
Cl	wt% (ash)			1.22						
P_2O_5	wt% (ash)			4.04						
SiO_2	wt% (ash)			10.70						
CaO	wt% (ash)			31.50						
MgO	wt% (ash)			3.00						
K_2O	wt% (ash)			21.00						