Université Libre de Bruxelles

Institut de Gestion de l'Environnement et d'Aménagement du Territoire

Faculté des Sciences

Master en Sciences et Gestion de l'Environnement

A physical, environmental and economic analysis of the bioenergy production sector of the Walloon region of Belgium.

Mémoire de fin d'Études présenté par

Jonas Scheire

En vue de l'obtention du grade académique de

Master en Sciences et Gestion de l'Environnement

Finalité Gestion de l'Environnement M-ENVIG 60

Année Académique : 2019 - 2020

Directeur : Prof. Achten Wouter

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Abstract

Biomass, a resource that is omnipresent on our globe and indispensable for humanity for its survival, is used by us in many ways. Besides food, it provides us with feed, fiber and on a more technological level also fuel and fine chemicals. The use of biomass for fuel production has become a big interest in the development of low-carbon societies, which is a goal for every society to develop towards with climate change threatening our current way of life. Biofuels are renewable and do not contribute to the depletion of carbon sinks like fossil fuels do. In order to increase biofuel production, a sustainable development of the bioeconomy has to be assured to obtain efficient results. The planning of this development has become an interest for many nations including for Europe as a whole. A first step in planning the bioeconomy is getting a view of the current situation of how the produced biomass is used. This thesis focuses on giving an overview of the current situation for the bioenergy production sector in the Walloon region of Belgium. It is found that there are two forms of bioenergy being produced in Wallonia currently, being bioethanol and biogas. The crops that are produced for these products are wheat, sugar beet and corn, while there is also a significant portion of biowaste that is converted. This production is done by one major biorefinery, Biowanze, which produces the Ethanol, and 51 methanogenesis plants scattered across the region that produce the biogas. This production comes down to around 300.000 tons of ethanol and 1,13 million m^3 of biogas. To extend on this, a small environmental and economic analysis are also executed. The environmental analysis, using the Ecoinvent 3 inventory to calculate a carbon footprint as a factor for global warming contribution, tells us that the total greenhouse gas emissions of the market are 821 million metric tons of CO_2eq. A comparison with a similar approach to assess the impact for gasoline production tells us that without the consumption stage, bioethanol production is more than six times more polluting than gasoline. The economic analysis shows that corn is currently the most interesting crop to produce for farmers, and also that the conversion of these crops to a form of bioenergy is currently not profitable on itself. It relies on the production of co-products and government support. A comparison with the current GDP of the region makes it also clear that the current bioenergy market is very limited.

Introduction

Biomass and its production, arguably the greatest ecosystem service provided by our planet, has always played a key role in our human development. In order to be able to fulfill the most important of our basic needs as a heterotrophic organism, biomass is needed for our nourishment. Besides nourishment, biomass has also provided us other services, such as the production of feed for animals, fiber for our clothing, construction materials for our homes, oxygen production, and many more. It is clear that the importance of biomass cannot be underestimated. This whole idea of managing biomass as renewable source, of which primary sectors like agriculture and forest management are a big part, is called the bioeconomy (McCormick & Kautto, 2013; O'Brien, Wechsler, Bringezu, & Schaldach, 2017). The production of biomass is one part of the bioeconomy, but the conversion to useful products is another. Since our industrial revolutions, humanity has been developing and perfecting even more ways to use the biomass available to us, extending the bioeconomy in a big way (Liu, Abrahamson, & Scott, 2012). Industries like the chemical and energy industry have found more ways to use biomass as one of their resources and this tendency is still going on (Lipinsky, 1981). In general, there are five applications to be distinguished, which are food, feed, fiber, fuel and fine chemicals, also known as the five F's (Chum & Overend, 2001). One of the most important usages for biomass that has been coming up the last few decades, is its use for fuel and energy production. Taking the whole global warming problem into account, biomass as energy source is a great alternative to fossil fuels (Liu et al., 2012).

Bioenergy and a developing bioeconomy

Climate change and its causes have become a worldwide concern. The main driver of the trend is the growing carbon dioxide (CO_2) concentration in our atmosphere, which is a product of heavy anthropological activity based on fossil fuels as an energy source (Rockström et al., 2009). These fossil fuels have always acted as an important sink for carbon sequestration, but since the industrial revolutions in the beginning of the 19th century we have been depleting these carbon sinks (Andres et al., 1999). The rising concentration of carbon in our atmosphere is causing a greenhouse effect which is bringing our natural carbon cycle and our earth's energy budget out of balance. The planet is warming up, and this at an increasingly alarming rate. International action has led to agreements such as the Kyoto Protocol and the Paris Agreement, developed under the United Nations Framework Convention on Climate Change (UNFCCC), in which the parties commit to decrease carbon emissions (Rogelj et al., 2016). New strategies for low carbon growth are being developed and the reduction of fossil fuel consumption is an important factor in that process (Yamakawa, Qin, & Mussatto, 2018).

In order to try and leave fossil fuels behind as the main energy source in our societies, alternatives have to be found. Renewable energy has been coming up for that reason and is based on the idea that the source is either inexhaustible, or regenerable in the short term (Chum & Overend, 2001; Lund, 2007). Examples are sources like wind energy, solar energy, hydropower and of course bioenergy. Biomass is regenerable in the short term and is thus part of a short-term carbon cycle, which has no effect on our global long-term carbon cycle. It is a relatively efficient way to capture carbon out of our atmosphere to directly use as an energy source.

The growing importance of bioenergy and biofuels has attracted the attention of authorities around the world, including Europe, to support the development of the bioeconomy (O'Brien et al., 2017). Bioenergy has been recognized as an important factor for low carbon growth in the future (Tonini & Astrup, 2012). The interest for this form of renewable energy above other forms lies in its good performance in life cycle assessment (LCA) studies and the ability to directly make products resembling conventional energy dense, storable fossil fuel products like diesel or gasoline (Connolly, Mathiesen, & Ridjan, 2014). Europe has been developing its bioeconomy the last few decades, and biorefineries, which are industrial entities that produce a product based on biomass, have been appearing all over the continent. There are currently more than 800 refineries in Europe, of which 363 produce liquid biofuels (Parisi, 2018). However, the bioeconomy development faces challenges. Because of increasing demand, the limited amount of land there is at our disposal has to be managed in an efficient way in order to optimize this bioeconomy. That's why there is an increased interest in land use planning and monitoring. There is no question that the development of the bioeconomy serves for great opportunities to reach a more sustainable society, but for that to happen it needs to be carefully monitored (O'Brien et al., 2017). The first step in monitoring this development is creating an overview of the current situation of the bioeconomy.

Belgium, as a member state of the European Union and a party that signed the Paris Agreement, is also showing interest in the development of low carbon strategies (Berger, Bréchet, Pestiaux, & van Steenberghe, 2020). Understanding the current bioeconomy situation is an important step in that development. Moreover, Wallonia, as the largest region in surface area of Belgium's three regions, has been selected by the European Union as one of six model regions for the development of a sustainable chemical industry (European Commission, 2016). Also focusing on making the bioeconomy more sustainable, Wallonia is funded for research that will increase the use of renewable sources for the chemical industry and reduce carbon emissions. This goes hand in hand with the potential for bioenergy to play an important role in a low carbon strategy and increases the interest in organizing the bioeconomy in the Walloon region of Belgium.

Existing biofuel production technology

When thinking about organizing the bioeconomy with a focus on biofuels, it is good to know how far bioenergy technology has come. Currently there is a multitude of commercially viable options to turn certain forms of biomass into specific types of bioenergy using a wide variety of technologies (McKendry et al., 2002).

Bioenergy crops

Before taking a look at how biofuels can be made out of biomass, an overview of what crops are available to make these biofuels with will be given. This subject is very region specific, as every region is producing specific crops depending on local environmental factors like climate and soil quality. The crops that are grown in Wallonia are just a fraction of the crops that can potentially be used for bioenergy production (de Vries, van de Ven, van Ittersum, & Giller, 2010). There are three groups of bioenergy crops, which are first, second and third generation crops.

The first group are the first-generation bioenergy crops. These are crops that have either a high sugar, starch or oil content, which will be its main source of product used for the energy production. Sugar and starch are very valuable and efficient sources of energy which can be converted using little pre-treatment and fermentation. The main first-generation crops are corn, wheat or cereals, sugar beets, sugar cane, soybeans, rapeseed and linseed (de Vries et al., 2010). The downside of the use of first-generation energy crops is the fact that these crops are used for food production if not for energy. There is a direct competition between these two uses. That makes its use for energy production somewhat controversial, as it can reduce the availability of locally produced food and feed (Cassman & Liska, 2007).

A second group of crops are the second-generation bioenergy crops, which are crops that supply us with simple lignocellulosic biomass that can also be converted into energy but with more steps in between or a more intense pre-treatment (Molino, Chianese, & Musmarra, 2016). It is often the case that first-generation crop will also provide a portion of simple lignocellulosic biomass that can be treated like second-generation crops. Wheat for example has a big portion of straw that does not contain any starch. A good example of a pure second-generation crop is elephant grass (*miscanthus x giganteus)*, but also wood-based crops like short rotation coppice (SRC).

The last group of bioenergy crops are the third-generation crops, which contains mostly sea-based plants like seaweed. It is the most recently discovered group and efficient ways to turn this form of biomass into energy are being developed (Sharma, 2015).

Bioenergy production methods

Looking at the multiple methods to produce energy out of biomass, they can also be divided into three main groups. The first one being the direct combustion of biomass, which produces heat that can be turned into electricity following the principles of a classic thermal power station. The second group are thermochemical processes, which converts the biomass into more usable forms of energy like gas or oil with a higher calorific value. The third group are biochemical processes, using micro-organisms for the conversion (McKendry, 2002).

Direct combustion of biomass

The direct combustion of biomass is self-explanatory. After the drying and the partial gasification of the matter, it will be burnt to produce heat, turn water into steam and produce electricity. The main question is which kind of biomass has the highest caloric value on its own, and how to attain the optimal conditions for combustion. To reach these optimal conditions, specific methods were developed. Two examples of which are suspension furnaces and fluidized bed furnaces. In the first one, the biomass will be pulverized and brought into suspension in a pre-heated oven. This will maximize contact surface between the matter and the air, improving burning conditions greatly. The second example entails a boiling bed of sand in which the biomass is brought for combustion.

Thermochemical processes

There are four kinds of thermochemical processes and they are all some form of pyrolysis, differing in the specific conditions the reactions are taking place. Pyrolysis itself as a first one, brings the biomass in low oxygen and high temperature conditions. This degrades the biomass to single carbon molecules like carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4). Besides this gaseous mixture, called synthesis gas (syngas), there will be derivatives in liquid phase like tars, oils and methanol that are usable too. Syngas is an intermediate product that can be used for a wide variety of applications and is valued greatly for that reason (Lieuwen, Yang, & Yetter, 2010; Wilhelm, Simbeck, Karp, & Dickenson, 2001).

The second process is called carbonization, which is a pyrolysis process specialized to produce charcoal from wood. Carbonization will only be done with wood type biomass, which will then be upgraded to charcoal as an end product. Charcoal has a higher calorific value than the concerning biomass and will burn with higher temperatures, which means it is overall a better-quality fuel (Ruiz-Aquino, F. et al, 2019).

The third is gasification, which is focused on producing an improved syngas mixture using the same principles but a higher base temperature of around 800°C (Molino et al., 2016). There will be less tar, oils or biocrude as derivatives, which makes the process more efficient.

Hydrothermal liquefaction is a fourth variety on the pyrolysis process and shows a lot of promise which is why it is currently being studied heavily. Here the biomass will be put in lower temperature conditions, around 350°C, but under very high pressure of over 20 MPa in some cases. The main product from this process will be a liquid bio crude with a high energy content. This crude can be upgraded to usable hydrocarbons like biodiesel and -gasoline (Biller, Sharma, Kunwar, & Ross, 2015).

Biochemical processes

Biochemical processes are focused on the use of micro-organisms to degrade the biomass and produce mainly methane (CH_4) or ethanol (C_2H_5OH) as end products. The two main commercial methods here are ethanol fermentation and methanogenesis, which are two different forms of anaerobic digestion. Both of them will bring a form of biomass in contact with specific bacteria or yeast in absence of oxygen, allowing these organisms to break down the matter.

Methanogenesis, the most commonly used method for breaking down biomass with anaerobic digestion, will make use of methanogens to produce a high methane containing product (CH_4) called biogas. Methanogens are single-celled organisms (micro-organisms) that belong to the domain of Archaea. Methane production plants can be designed for treating specific compositions or blends of biomass. Some will digest a more fluid stream of biomass like animal manure and sewage sludge, others a more solid stream of biomass like energy crops (solid-state anaerobic digestion or SS-AD) (Li, Park, & Zhu, 2011). Biogas is used mostly to be turned into electricity by simply using it as fuel for internal combustion engines. Other technologies such as dry- and steam reforming (methane reforming) make it possible to use biogas for the production of syngas (Rostrup-Nielsen, 1984), a sought-after intermediate product with a series of industrial applications.

The other method, ethanol fermentation, is based on the principle of fermenting sugar to ethanol. First generation energy crops with a high sugar or starch content can be used for ethanol fermentation and the conversion is done by yeast in the absence of oxygen (Lin & Tanaka, 2006).

Biomass conversion products

When converting biomass to a usable form of energy, there are a lot of different products that can be aimed for. In order to get a good view of what is available, it is interesting to create an overview of what intermediate and end products there are. The end products are characterized by their ability to be directly used as fuel source for the transport sector or for energy production.

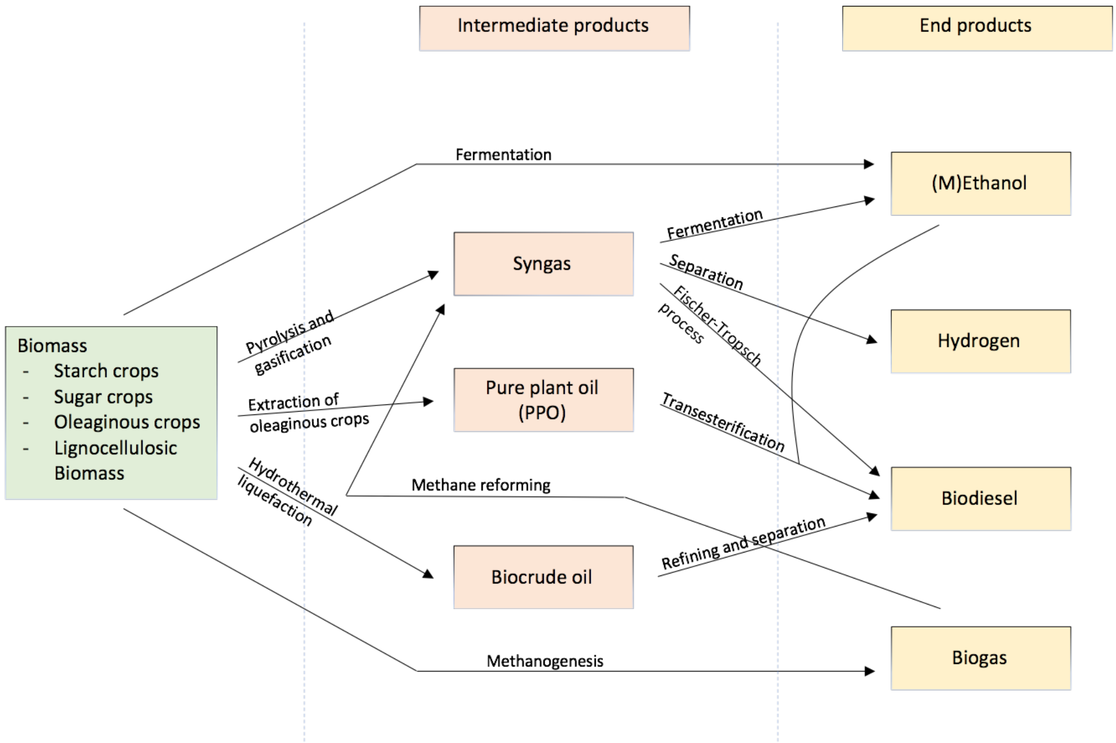

Figure 1: currently available biomass conversion products and how they can be made. (Molino et al., 2016)

There are three intermediate products to be distinguished, and four final energy products. The intermediate products are often used for the production of the mentioned end products but can also be used for a series of other applications like industrial processes. Syngas for example is a product that has many other uses, and pure plant oil can even be used for human consumption.

The three intermediate products are syngas, pure plant oil and biocrude oil, and can be obtained by pyrolysis or gasification, extraction and hydrothermal liquefaction of specific biomass crops respectively. The most versatile intermediate product has to be syngas, as it can be used for the production of three of the four mentioned end products. It can be fermented into bioethanol, separated to obtain pure hydrogen and converted to biodiesel using the Fischer-Tropsch process. This process will convert the gas mixture, under high temperature and pressure conditions and with the use of a catalyst, into liquid hydrocarbons. The main idea is that the compounds H_2 and CO that are in the syngas mixture will be split into ions and form CH_2 chains (Steynberg, 2004).

Biodiesel is the most versatile end product, as it can be obtained from no less than three different processes using the products in figure 3. Besides the Fischer-Tropsch process of syngas it can be produced using the transesterification of PPO and ethanol along with the purification of biocrude oil coming from hydrothermal liquefaction. The main idea of the transesterification process is to exchange the organic group of an ester with the organic group of an alcohol using a catalyst. In this example, the PPO is the ester and the ethanol is assuming the role of the alcohol in the process. This creates ethyl esters of fatty acids (biodiesel) and glycerol (Ma & Hanna, 1999; Steynberg, 2004).

Bioeconomy in Wallonia

There are a lot of possibilities when it comes to shaping a bioeconomy, and that is also the case for Wallonia. The interest and motives are clearly there to start developing the bioeconomy of the region. Above that, there is enough information available to know which of the above crops, technologies and final biofuel products are used and produced in Wallonia. None the less, all of this information has not been collected and structured before to create an overview of the current bioeconomy situation in the region. This thesis tries to give that overview, as a sort of reference that can serve as a base for future bioeconomy development, with a focus on the agricultural part of the bioeconomy and the production of biofuels. There are three perspectives that are selected to do so, which are three aspects that can potentially have a big influence on these future developments. The first perspective is the physical form, which is about what kind of crops that are used in Wallonia to make biofuels with, which kind of technologies are used and what final bioenergy products are produced. Also, with the goal on giving mass and energy balances of the current situation, showing where most of the energy comes from and which crops are grown in most quantities. The second perspective is an environmental perspective, attempting to calculate an environmental impact of the market based on greenhouse gas emissions. The third is the economic perspective which is selected to try and identify which crops are currently the biggest moneymaker, and which technologies might bring about the biggest yields. It remains the case that profit is an important drive for change, which will be no different for the bioeconomy.

While trying to give as much of a complete image of the bioenergy market of Wallonia, the decision was still made that the forest management sector and the livestock industry are not taken into account. The focus is on biofuel production, and these two aspects do not contribute to that market. Forest management does contribute to energy production when it comes to heat, but none the less it is omitted because other than heat the possibilities are slim for this resource when it comes to fuel production.

Methodology

In order to create an overview of the current situation of the bioeconomy in Wallonia, it is described in multiple perspectives, which are the physical, environmental and economic perspective.

Physical bioenergy market

The physical analysis of the bioeconomy in Wallonia seeks to answer the question how the agricultural sector looks like for the whole region. Based on the five F's as the main end use categories for agricultural crops, an analysis was done to determine which portion agricultural land is used for which purpose. This gives a general idea of how big the bioenergy market is compared with the other end uses. A second reflection that is made concerns the number of farms there currently are in Wallonia, their size and the evolution it has known the last few years. The analysis is done on the NUTS2 level, which are the five provinces, being Brabant-Wallon, Namur, Liège, Hainaut and Luxembourg. On this level it was still possible to structure the data in a clear way and it gives a good overall idea of what province is focusing on which end use. The data was also available on the level of municipalities, but an analysis on this level would be too detailed for the current research stage and will become more relevant when detailed land use planning would be done in the future. The data on which the analysis was based is data for the year of 2018 collected by Statbel (Statbel, 2019), which is Belgium's main hub for statistical data provided by the public authorities (Statbel, 2020). Excel was used for calculation and creation of figures. For this part of the analysis, values are exclusively expressed in the surface area occupied by a certain crop and only gives an idea of agricultural land use for that reason.

A second part of the physical analysis goes more in depth concerning the bioenergy market in Wallonia. It aims to show where crops are grown that will be used for biofuel or energy production, where and how the conversion takes place and what energy products are produced. A comparison is also made with fossil fuel consumption in Wallonia and the overall energy consumption of the region to put the significance of the market into perspective. The number of farms that produce a certain type of bioenergy crop was also added to see if there is a link between previous results. The used data was collected from direct contact with Valbiom and Biowanze. Valbiom is a government organization that focuses on the stimulation of biomass valorization initiatives and has a lot of information concerning the current bioenergy market (Valbiom, 2020b). Biowanze is the only large scale biorefinery plant in Wallonia and an interview has been conducted to get more insights on the market (Bio-based Industries Consortium, 2012; Biowanze, 2020). One big limitation in the detailed mapping of the bioenergy market was the fact that there is no possibility in laying a direct link between crops coming from a certain patch of land and their end use. Maps are given to show where bioenergy crops are grown, not knowing which crop grown in which location is actually used for biofuel production. The maps are made using QGis (QGIS Development Team, 2020) with data provided by Geoservices Wallonia (Géoservices Wallonie, 2016) from the year of 2016. The locations of bioenergy production plants are also identified and shown on the maps.

Environmental perspective

The goal of creating an environmental assessment of the bioenergy market of Wallonia is to see how much environmental impact there is to establish a baseline for the current situation. This could give an idea of how future development should be organized to limit possible negative effects of a larger bioenergy market. Being aware of which aspects of the current bioenergy market are pollution hotspots allows for more well considered decisions. As shown in the results (figure 5), two major bioenergy products were identified in the Walloon region, which are ethanol and biogas. To calculate the total impact of these two products in Wallonia, two steps are taken. The first step is to calculate the impact per unit of each product separately, and the second one is to multiply the total production of each product to calculate the total impact for the whole bioenergy market. The functional unit for ethanol is one kg of ethanol production and for biogas one m^3 of biogas production.

The used inventories (table 1) were extracted directly from Ecoinvent 3 database (Wernet et al., 2016) with 'SimaPro' software (Simapro, 2020). This study focuses on calculating a carbon footprint as a representation for global warming impact, for the bioenergy market in Wallonia. The greenhouse gas emissions per unit of product produced was calculated using the IPCC 2013 GWP 100a method. The exact processes that are used are listed in table 1. The processes are selected to approach the current situation in Wallonia as much as possible. For ethanol a process is selected for which the main resource is rye, which is the process the closest to wheat that Simapro could provide. The same goes for the biogas production process, for which corn and biowaste are used in reality while the selected process is for grass. There has been chosen for a Cut-Off approach, as the consumption lifecycle stage or recycling stages are not part of the scope, which makes this a cradle to gate assessment.

There are two scopes that are taken into consideration. One is the total production of biofuel products in the region, including imported crops, and one is the total production exclusively coming from crops that are grown on Walloon soil, excluding imported crops. The use of biowaste as main resource for biogas production is excluded either way, because the environmental impact for this process is not comparable with the production of a crop dedicated for the process like corn or grass.

Table 1: The full name of the Simapro processes used for the environmental analysis of the bioenergy sector in Wallonia.

Description	Name of SimaPro process
Production of ethanol	Ethanol, without water, in 95% solution state, from fermentation {RoW} │ethanol production from rye │Cut-off, U
Production of biogas	Biogas, from grass {RoW}│biogas production from grass │Cutt-off, U

The results show a value in CO_2 equivalents that represents the environmental impact and thus contributions to climate change. This is also compared with the impact for the production, using a well-to-tank approach, of the fossil fuel product gasoline. This well-to-tank approach is the equivalent of the cradle-to-gate approach that was selected for the assessment of the biofuels.

Economic perspective

Another dimension that could bring useful insights to the development of the bioenergy sector is its economic situation. An analysis was conducted to answer the question (1) which crops are currently the most interesting to grow for farmers from an economic standpoint. A second element that was looked into (2) is how the current bioenergy market holds up compared to other sectors and the bigger picture, being the GDP of the region. This comparison can give an idea of how (in)significant the market currently is on an economic level, and if it could attract investors in the future. A last comparison (3) that was made is between the market value of the crops and the end products, to show the added value of the biofuel production processes. To answer the first question (1), market prices of the most prominent crops are compared to each other to evaluate their potential, for which data collection is done. Assessment of production cost was not taken into account as this information was unavailable, which means that production cost is believed to be similar for all of the crops in question. The second question (2) is answered by calculation of a total market value of the market based on the economic value of the produced biofuel end products. The third (3) comparison is made with similar data gathering and analysis. Calculations were done in Microsoft Excel (Microsoft Corporation, 2020).

Results

Overview of the agricultural sector

To begin with, a comparison is made between the multiple uses for the crops that are grown today in Wallonia. There is a wide variety of crops that are currently grown as agricultural products in the region. Examples are crops that are grown in relatively large scales like corn and wheat, but there are also crops like vegetables, both in or outside of greenhouses, fruits on trees, flaxseed, miscanthus and a lot more. All of these crops are divided according to their end use sector. These end use sectors are the five F's, which are 'food', 'feed', 'fiber', 'fuel' and 'fine chemicals'. For the last one however, the fine chemicals, no information was found for crops that would be used for its production, which is why it is excluded out of the analysis. Two extra end uses are added, which are 'ornamental' and 'other'. The 'ornamental' end use speaks for itself, and are crops, plants and trees that are grown for ornamental purposes like horticulture. The category 'other' indicates greenfield areas and currently unused grass fields.

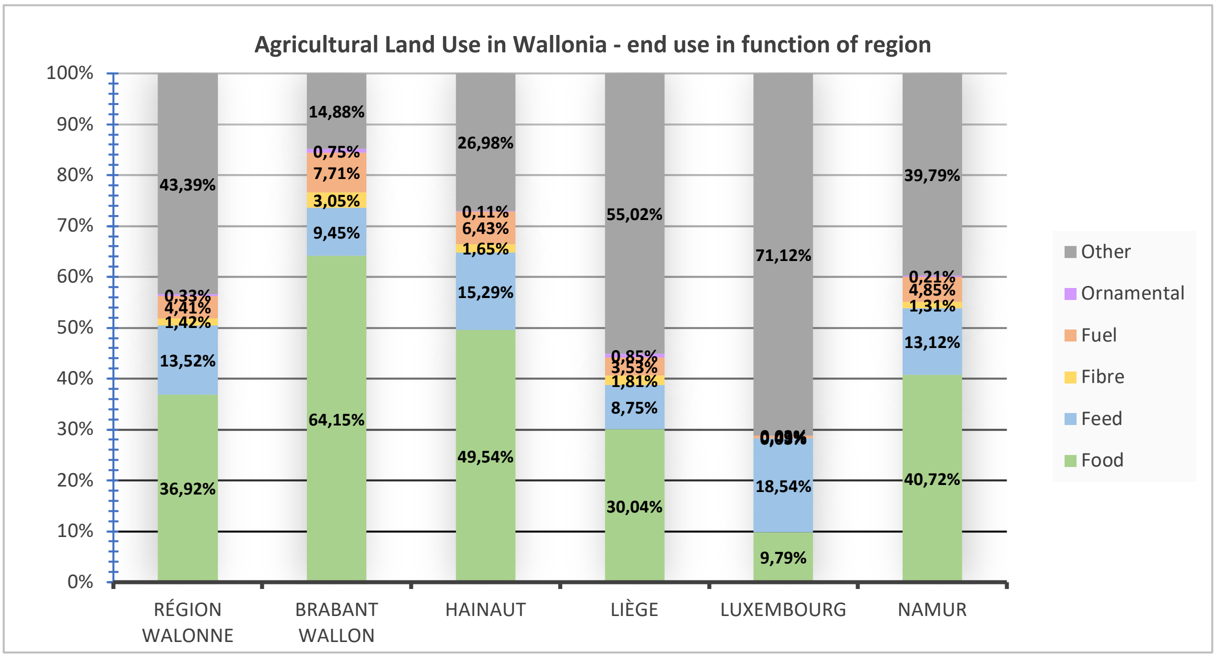

Figure 2: The agriculture land use in Wallonia, according to 6 categories which are 'food', 'feed', 'fiber', 'fuel', 'ornamental' and 'other', for the whole region of Wallonia and for each of the provinces (Statbel, 2019).

The crops represented by 'food' are a large group of products that are destined for human consumption, like wheat, potatoes, vegetables, fruits and sugar beets. The 'feed' end use is mostly represented by corn, beets and grazing land. The only two crops that are used for 'fiber' production are hemp and flaxseed. The crops selected for the 'fuel' section are already adapted to what portion of certain crops are used for the production of bioenergy, based on the detailed analysis of the market. Detailed information on these crops can be found in figure 4 and 6 in the next section of the results.

The total amount of available farmland in the Walloon region is 735.500 hectares, of which the biggest portion is in Hainaut and the smallest in Brabant Wallon. The other three provinces each have around 150.000 hectares of available farmland. The figure shows us that in most provinces there is a focus on food production, only in Luxembourg there is a focus on feed production. The 'other' category represents available but unused land, and the figure also indicates how a densely populated province has a much smaller 'other' proportion than a thinly populated province. This is very clear when comparing the results between Brabant Wallon and Luxembourg, which are respectively the densest and least densely populated provinces of the region (Statbel, 2016). The land used for biofuel production remains only a small portion in any of the five provinces and is almost directly proportional to the percentage of land used for food production. This is explained by the fact that for Wallonia, the only crops used for bioenergy production are first generation crops and are otherwise used for food or feed purposes (Heneffe C., personal communication, 17/02/2020). Fiber production follows a similar trend and crops grown for ornamental use have a slight concentration in Liège and Brabant Wallon.

To put this data in a different perspective, figure 3 is also given, showing for each end-use what portion is grown in which province. This offers different insights and shows in a clear way where most of the crops for a specific end use are located. It also gives an idea of the agricultural intensity of each of the provinces. The ones that are scoring low on most of the end uses can be seen as less agriculturally intensive as the provinces that have an overall high score.

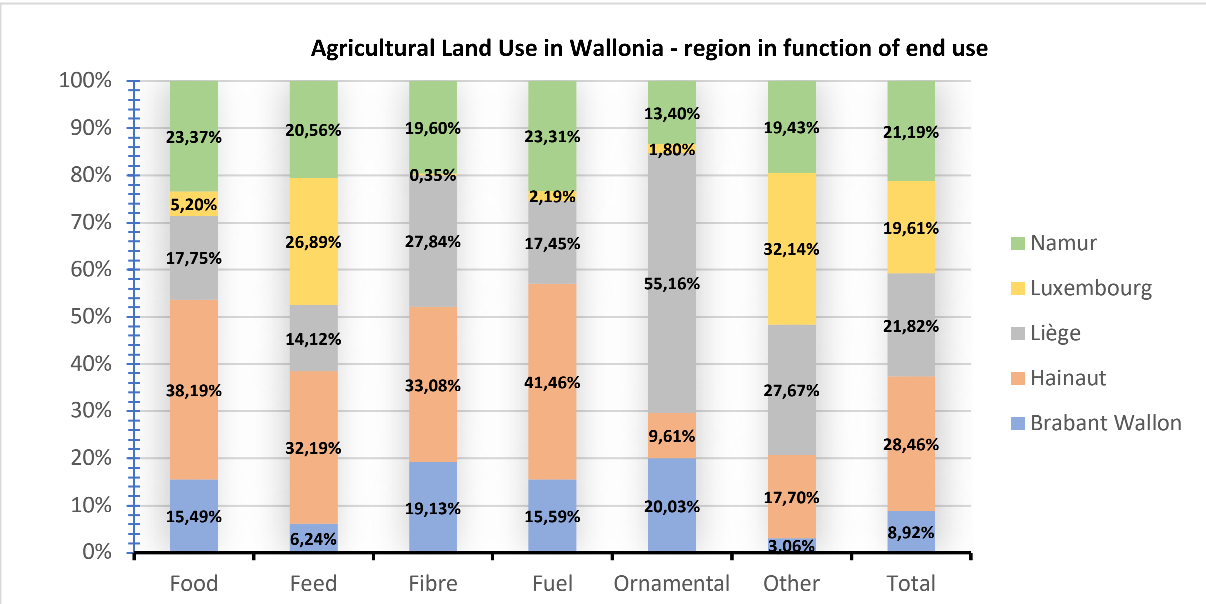

Figure 3: The same data as figure 1 is displayed but structured differently. For each end use it is shown what proportion is grown in which province (Statbel, 2019).

From figure 3 it is clear that the province of Hainaut is the most agricultural intensive province in Wallonia, taking care of 28,5% of agricultural land use. On the other hand, Luxembourg is dominating in unused grass field surface and represents a relatively large share for the feed production in Wallonia. For the other end uses the province of Luxembourg scores very low, which is explained by its natural riches.

The province of Brabant Wallon scores moderately to low on each of the end uses and scores the lowest in total. The main reason for that could be the dense population and the fact that the province is relatively small, which leaves it less surface area for agricultural purposes. The province of Liège is dominating on the ornamental crops, which is even more apparent here than in figure 2.

The number of farms that is producing all of these crops has been changing over the years in Wallonia. Since the industrialization of farming, the main tendency has been that farms are getting bigger and are decreasing in numbers. Productions on a bigger scale became more economically viable than a smaller scale of farming (RTBF, 2018). Whether that tendency is still going on can be seen in table 2, which is showing the number of farms between 2015 and 2019 for each of the provinces in Wallonia. It can be said that the overall number of farms is still somewhat decreasing, but fluctuations are noticeable as well.

Table 2: total number of agricultural entities over the years between 2015 and 2019 (Statbel, 2019).

	Région Walonne	Brabant Walonne	Hainaut	Liège	Luxembourg	Namur
# farms 2015	12.872	1.033	3.956	3.187	2.352	2.344
# farms 2016	12.854	1.024	3.957	3.171	2.347	2.355
# farms 2017	12.632	987	3.941	3.258	2.264	2.282
# farms 2018	12.739	1.032	3.908	3.123	2.327	2.349
# farms 2019	12.733	1.027	3.927	3.091	2.346	2.342

Table 3: number of farms for each size of farm for the whole region (Statbel, 2019).

	<5ha	>5ha to <10ha	>10ha to <15ha	>15ha to <20ha	>20ha to <30ha	>30ha to <50ha	>50ha
# farms 2015	756	857	820	721	1.321	2.318	5.862
# farms 2016	695	847	841	722	1.289	2.314	5.916
# farms 2017	683	884	831	708	1.270	2.277	5.782
# farms 2018	663	885	796	732	1273	2.301	5.911
# farms 2019	682	902	799	718	1.263	2.255	5.878
Net change	Decrease	Increase	Decrease	Constant	Decrease	Decrease	Increase

Table 3 shows us the evolution over the years concerning the size of the farms in the Walloon region. We can see that over the years the number of the smallest size farms have decreased significantly, and the biggest size farms have increased slightly. However, categories in-between show the varying patterns so it cannot simply be concluded that the smallest farms are disappearing and big farms are multiplying in the last few years. The situation is fluctuating but the overall number of farms for each size is remaining more or less constant. This reflection can give us insights on how the agricultural landscape is changing, if large farms focusing on mass production are would still be favorited over small farms for example, this would have an impact on how fast this agricultural landscape can change in the future. To see that small farms still get opportunities in the sector, is a sign that small scale initiatives have a chance and mass investment is no requirement to start agriculture activity. This could make the market more flexible for developments in the bioeconomy.

The bioenergy sector of Wallonia

The overall structure of the bioenergy market in Wallonia is displayed in figure 4. Shown in green is the production stage of the market, and thus the production of the crops that are used for the conversion towards biofuel products. In red are the biorefineries, which are the market actors that are occupied with the actual conversion. In yellow are the final bioenergy products that come out of these processes and in blue are the actual manners in which these products are consumed. Some aspects are partly or completely left out of the scope of this study for detailed analysis and are indicated in grey. The partly leaving out of the scope has to do with different approaches that are worked with, in one approach they are included and in another they are excluded (table 4).

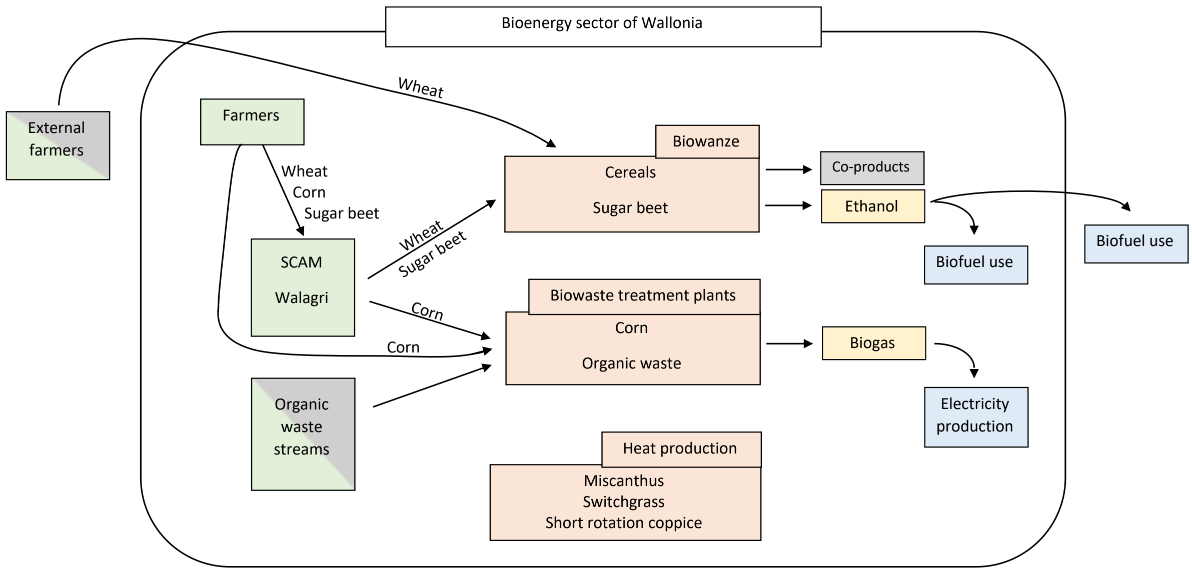

Figure 4: structure of the Walloon bioenergy market (Statbel, 2019; Valbiom, 2020a) (Florence C., personal communication, 28/10/2019; Heneffe C., personal communication, 17/02/2020)

Wallonia currently has three main processes for biofuel production, which is one big bioethanol production plant called Biowanze, a series of 51 methanogenesis plants scattered across the region and a very minor amount of heat production using second-generation crops (Heneffe C., personal communication, 17/02/2020). Besides these second-generation crops, the two other processes use wheat, sugar beet and corn for their corresponding biofuel production. In total, Wallonia produces around 292.500m^3 of ethanol and 113.366.667m^3 of biogas per year, and corresponding energy values can be found in table 4 (Biowanze, 2020; Heneffe, 2016). The total energy consumption in Wallonia for 2017 was 125TWh (Julien & Iweps, 2019), which means that the bioenergy sector makes up for 1,5% of the region's total energy consumption or 0,4% if only the crops grown on Walloon soil are calculated. Figure 10 gives more info on the energy balance and goes more in depth on what portion comes from which crop.

Table 4: The yearly productions for two approaches. The first approach is for the total bioenergy production sector in Wallonia, including product coming from imported crops and the use of biowaste for biogas production. The second approach excludes these factors, calculating only crops grown on Walloon soil. (Biowanze, 2020; Engeneering Toolbox, 2003; Heneffe, 2016)

	Ethanol	Biogas
Yearly volume approach 1	292.500 m3	113.366.667 m3
Energetic value approach 1	1.712,4 GWh	417 GWh
Yearly volume approach 2	89.797,5 m3	15.871.333m3
Energetic value approach 2	525,71 GWh	58,4 GWh

Based on figure 4, a more detailed overview will be given for each of the main steps. Beginning with the end products that are provided for the Walloon market, then proceeding to how these products are made with a description of which technologies are used, finishing with the crops that are grown and used for the production of these biofuels.

1) The biofuel end products

Figure 4 shows that there are two biofuel products coming from the bioenergy market in Wallonia, being ethanol and biogas, besides heat production. A detailed description will be given what end products there are, including co-products. It has also been looked into how these forms of bioenergy are used and a comparison with conventional fossil fuels is given. Looking at Biowanze, there is a series of products that come out of the ethanol production process. Using mainly wheat and a minor amount of sugar beet, there is a portion of ethanol, feed, gluten, fertilizer and electricity being produced.

Table 5: the co-products produced at Biowanze, both for one metric ton of wheat and a calculation of their yearly production (Biowanze, 2020).

Product	Produced per ton of wheat	Produced yearly
Ethanol	325l or 256,5kg	292.500m3 or 230.782,5t
Feed	425kg	382.500t
Gluten	80kg	72.000t
Fertilizer	20kg	18.000t
Electricity	5kWh	4,5GWh

To bring this into perspective, Biowanze's yearly production comes down to about 0,6% of the European ethanol production (European Biomass Industry Association, 2004) and besides that they produce enough electricity to provide power for 1250 families for the year. The electricity is used by the company itself to provide the power needed to keep the process going, making the plant almost self-sufficient. When it comes to the ethanol, most of it is used as additive for fossil fuels destined to be used for transport. The goal is to replace a portion of the fossil fuel products like diesel and gasoline by the bioethanol, to create a greener fuel. Today this is done by simply mixing the two, often in a 5% bioethanol to 95% gasoline ratio (E5) or a 10% to 90% ratio (E10) (FOD Economie België, 2020a). Other than a gasoline additive, it can also be used in cosmetics like perfume, it can be added to alcoholic drinks for human consumption or used for cleaning products (Florence C., personal communication, 28/10/2019).

By comparing the bioethanol production in Wallonia with the total gasoline consumption of the region, a view can be created on how significant this production actually is. Displayed in table 6 are the yearly consumptions of the two main fossil fuels, diesel and gasoline. Based on these numbers it can be said that there is enough bioethanol production in Wallonia to provide for the whole of Belgium enough product for converting all of its gasoline to a E10 formula. However, at the same time are using the equivalent of 90% of the total wheat production in Wallonia to convert into bioethanol, which ultimately represents a market share for vehicle fuel of 8% for Wallonia exclusively. In practice it is not possible to make sure where the ethanol is going to specifically, and what it is used for exactly. This is information that only Biowanze can provide, and that is deemed confidential by them. If only the wheat and sugar beet produced exclusively on Walloon soil that is actually used in the process is taken into account to make this comparison, providing 89.797,5m^3 of ethanol, that market share would only be 2,6% even.

Table 6: comparison of bioethanol production in Wallonia with biodiesel production (FOD Economie België, 2020b).

	Yearly for Belgium	Yearly for Wallonia
Consumption ethanol	/	292.500 m^3
Consumption gasoline	2.400.000 m^3	800.000 m^3
Consumption diesel	7.800.000 m^3	2.584.000 m^3

The methanogenesis plants are a different story. The biogas that is produced with those will always be directly turned into electrical or thermal power using an engine. The total installed capacity for the methanogenesis plants in Wallonia is 39,6MWel and 43,7MWth (Heneffe, 2016). The electrical power is mostly generated by agricultural plants and a few treating landfill leaks, whereas the thermal power mostly is produced by industrial wastewater treatment plants, which is a setting that has more use for the type of energy. Other types of methanogenesis plants represent around 10% of both electrical and thermal power generation in total (Heneffe, 2016). On a yearly basis the totality of biogas plants brings 135GWh of electricity on the market for sale, after the operator's own use, and 95% comes from the mentioned agricultural and landfill treatments plants. These 135GWh of electricity is enough to provide power to 37.500 families every year, which makes it quite significant. The 51 plants together produce around 113.366.667 m^3 of biogas per year, providing 188GWh$_{el}$ 229GWh$_{th}$ of energy (Heneffe, 2016). The conversion rates are typically 6kWh of thermal power or 2,5kWh of electrical power per cubic meter of biogas (Jørgensen, 2009; Uddin et al., 2016).

2) The bioenergy production processes

The biofuel products are produced using fermentation and anaerobic digestion. Here is a closer look at the production processes. Biowanze, the company that produces ethanol from wheat and a small amount of sugar beet, uses adapted technology with which they focus on creating as many co-products as possible. Their strategy is about diversification to increase their economic feasibility. Besides producing ethanol, they produce a big portion of animal feed, a portion of gluten, some fertilizer and electricity that they use on site. Figure 5 gives an overview of the process.

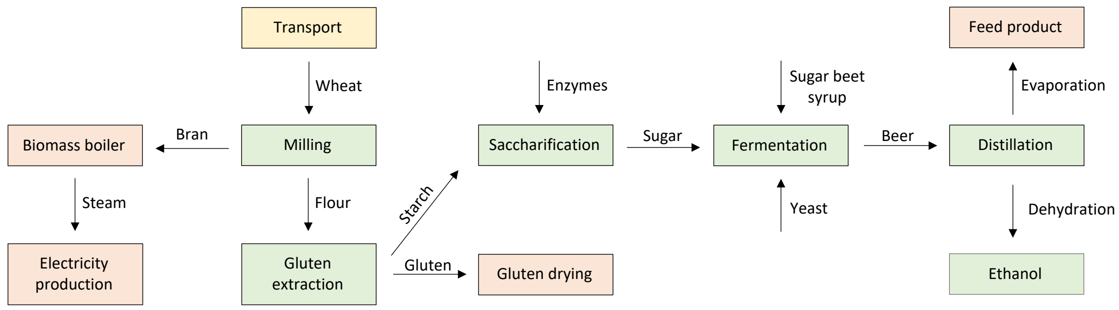

Figure 5: The production process for ethanol and co-products as done in Biowanze. In green is the main process for the production of ethanol, in red are the co-products, yellow is the start of the process (Biowanze, 2020).

The fact that Biowanze tries to create as many co-products as possible also reduces their waste production. They try to find a good use for anything that leaves the production process. The first step is the pre-treatment for the wheat, which is the milling where they also separate the wheat flour from the bran. The pure flour will be the base product used for the ethanol production, whereas the bran is currently used in a biomass boiler for the production of electricity. The biomass boiler is one of Biowanze's unique features and provides them enough energy and heat for them to be almost completely self-sufficient. Currently Biowanze is also supporting research that is focusing on extending the use of bran for other applications, and at the same time they are looking into miscanthus as a replacement for the bran used in the biomass boiler. When the flour is separated from the bran, it gets separated again and this time from the gluten to increase the product's starch content as much as possible. The next step is the saccharification of the flour using enzymes, to turn the starch into fermentable sugars. For the fermentation itself there is a relatively small amount of sugar beet syrup (1%) added to make sure that the sugar content is high enough for an efficient process. After the fermentation, Biowanze is left with a sort of beer-like product from which the bioethanol is distilled to an almost pure form. What is left is used for animal feed after evaporation, and is a high protein containing product that they call 'ProtiWanze'.

The processes for methanogenesis that is used in the 51 plants across Wallonia, are of four different types. Almost all of them treat a mix of different types of biomass, except a few treating landfill gas discharges. The most represented one (1) is a vertical reactor in which a fluid biomass blend kept homogeneous by placing mechanical agitators inside. The blending can also be done with pumps that move the biomass around the reactor. This is the case for the plants treating agricultural waste and some treating sludge coming from communal wastewater treatment. A second type of plant (2) that is used mostly for industrial wastewater treatment, is the upflow anaerobic sludge blanket (UASB) plant. Here there is no mechanical agitation needed, as the water polluted by organic matter is brought in from beneath in a continues process. Inside of the tanks, the micro-organisms that take care of the digestion are added in the form of granule that stay in suspension. The continuously added wastewater and formed methane going in an upward movement, make sure that there is enough agitation for a continuous purification of the wastewater. At the top there are slats that ensure the separation of the purified water, the methane and the leftover sludge. The third type (3) of methanogenesis is a dry one, which is a process that is comparable to composting. The big difference is the absence of oxygen which makes it possible for biomethane to form. This technique is used for the one household waste treatment plant there is in Wallonia. The last technique (4) used is the one specifically for landfill gas discharge treatment. The anaerobic digestion process will happen naturally within the landfills in this case, and the gas only has to be taken from underground and treated for electricity or heat production. This is done by simply drilling holes in the landfills to free and capture the gas (Heneffe, 2016).

3) The raw products for bioenergy production

Currently there are three main bioenergy crops in use in Wallonia, which are wheat, corn (or maize) and sugar beet. These three are used for only two processes which are the production of bioethanol and biogas. Besides these main crops there are small amounts of miscanthus, switch grass and short rotation coppice that are grown for heat production in industrial processes (Valbiom, 2020a). Because these crops are only grown in these very small amounts of which a large portion are only pilot projects, they will be mentioned here but won't be included in other analyses.

Table 7: Biorefinery plants producing biofuels in Belgium (Bio-based Industries Consortium, 2012).

Name of the plant	**Location**	**Main activities**
Wallonia		
Biowanze	Wanze	Bioethanol production
Flanders		
Syrial	Aalst	Bioethanol production
Alco bio	Gent	Bioethanol production
Oléon	Gent	Biodiesel production
Bioro	Gent	Biodiesel production
Proviron	Oostende	Biodiesel production

When it comes to biorefinery plants, there is only one major production plant in Wallonia (table 4). This is plant is Biowanze and uses around 900.000 tons of biomass product per year of which 99% is wheat and 1% is sugar beet for the production of bioethanol (figure 6). The sugar beet that is used is already in the form of a syrup, which comes from the Tiense Sugar Factory just next to the plant and is only used to stabilize the process. Big portions of the wheat used in Biowanze comes from neighboring countries or the Flemish region. Only 45% comes from Belgium, of which 15% from Flanders. 25% comes from France, another 25% from Germany, and 5% is from the UK (figure 6) (Florence C., personal communication, 28/10/2019). Besides Biowanze, there are 51 methanogenesis plants scattered around the region, but these are all relatively low-scale and are mainly used for organic waste management. In total they convert around 475.000 tons of organic material per year into biogas, of which 440.000 tons is biowaste and 35.000 tons (or 7,4%) is corn. The corn is added to ensure that the mix of organic material can efficiently be digested.

For wheat and sugar beet it is already known that with one kg of product, 0,325kg of ethanol can be produced. That would mean that around 3kg of wheat is needed to produce one kg of ethanol. This calculation can also be done for biogas, and the results say that for the production of 1m3 of biogas there is a need of 3,32kg of corn or 6,78kg of biowaste on average.

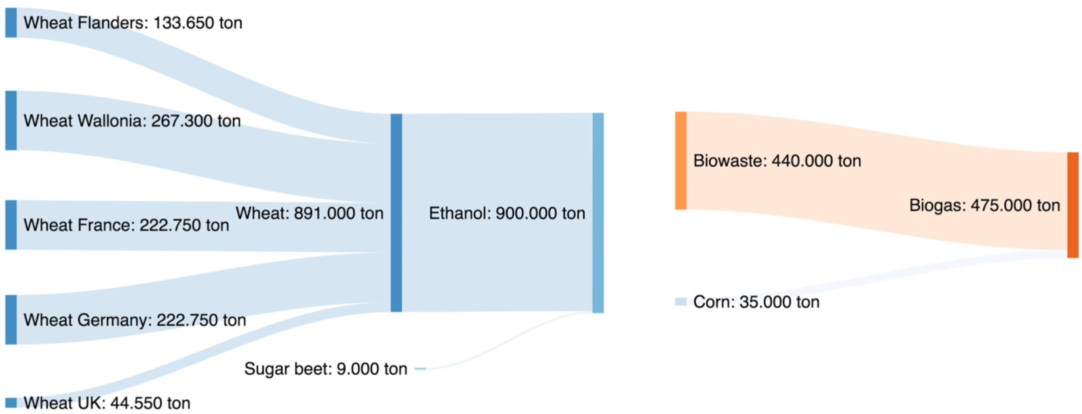

Figure 6: portions of energy crop used in each of the processes, with a distinction of where the crops are coming from for wheat. In blue is the ethanol production process, in red is the bio-methanogenesis. Florence C., personal communication, 28/10/2019; Heneffe C., personal communication, 17/02/2020)

Comparing the total productions of these crops for the whole region with the portion used for biofuel production, gives us the results shown in table 8. The portions for sugar beet and corn are relatively small and don't impact the market all that much. However, concerning wheat production no less than 25% of all wheat produced in Wallonia is used for the biofuel market.

Table 8: overview of total crop production on Walloon soil and the fraction that is used for bioenergy production in Wallonia. (Statbel, 2019)

Crop	Total production per year	Production for bioenergy	%
Wheat	1.043.262 tons	267.300 tons	25,62%
Sugar beet	3.597.562,30 tons	9.000 tons	0,25%
Corn	2.071.583,38 tons	35.000 tons	1,69%

The question remains where these crops used for biofuel production are grown exactly. It was not possible to create a direct link between the plots of land where crops are grown and its end use because of the structure of the market. Like shown in figure 4, crop farmers will never directly sell their products to biorefineries in Wallonia, but they will pass through an intermediate actor on the market that collect the crops for further distribution. These market actors are Walagri and SCAM. For that reason, maps are given that show the plots of land where the crop is grown for the whole region, and thus not exclusively the portion used for bioenergy production. For reference, the production plants that use a portion of the crop for bioenergy is also shown on the map. Crops coming from the vicinity of the plant have a higher chance of being used for bioenergy production than crops coming from further away. Figure 7, 8 and 9 show these plots of lands for wheat, sugar beet and corn respectively. A map is given for each of the crops for clarity.

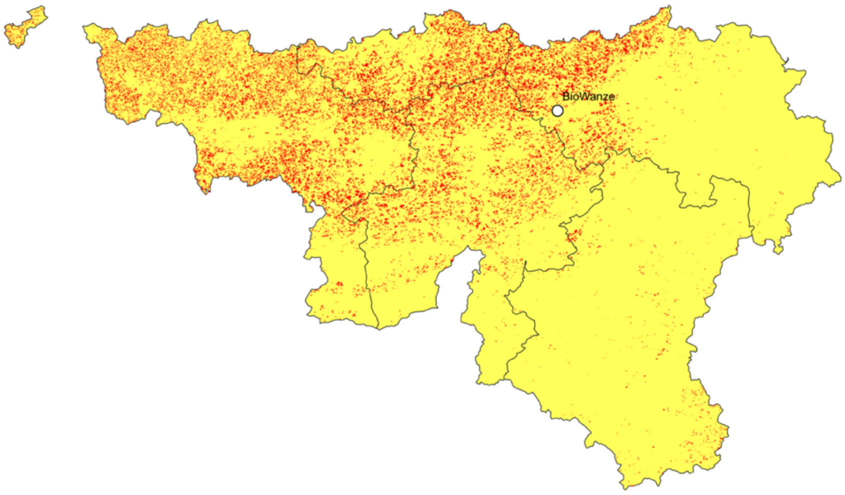

Figure 7: wheat production in Wallonia with the location of Biowanze as reference, using the wheat off of 31.264,52ha of land per year or 25,62% of the area that is marked in red (Biowanze, 2020; Géoservices Wallonie, 2016).

When it comes to wheat, it can be said that the crop is most intensively grown in the provinces of Hainaut, Brabant Wallon, the north and center of Namur and the west of Liège. Biowanze is located in an area where wheat production is present, and it could be assumed that most of the Walloon wheat that they use is coming from Liège, Namur and Brabant Wallon, as these areas are closest to the production plant. The total hectares highlighted here are 121.954ha of which 31.264,52ha is used for bioethanol production.

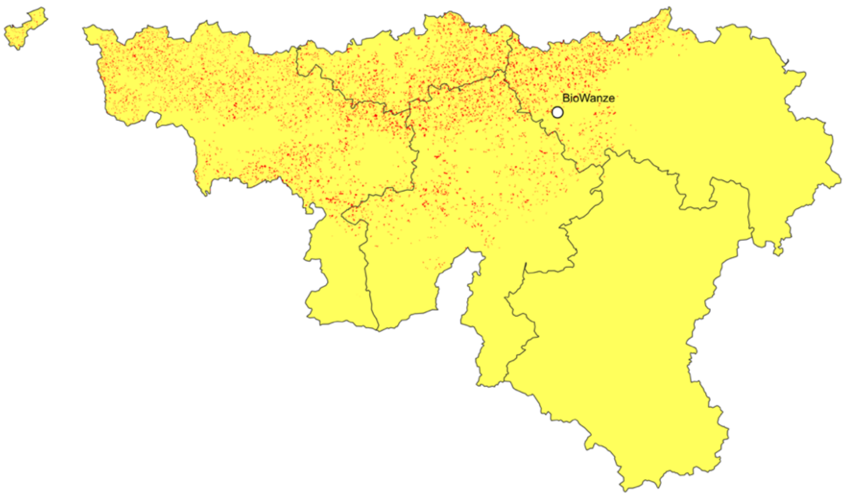

Figure 8: sugar beet production in Wallonia with the location of Biowanze as reference, using the sugar beets off of 106,60ha of land per year (Biowanze, 2020; Géoservices Wallonie, 2016).

Sugar beet production in Wallonia follows a similar pattern as its wheat production, with concentrations in the provinces of Hainaut, Brabant Wallon, the north of Namur and the east of Liège. However, in totality the crop is les intensively produced overall compared to wheat. The portion used for energy production is very limited with only 106,60ha from a total of 42.610ha, but the fact that the sugar beets get to be processed at the Tiense sugar factory before their use in Biowanze, makes it hard to track what area the beets are coming from. This because the Tiense sugar factory is attracting sugar beets from all over Wallonia. However, because the Tiense sugar factory claims on their website that they only process sugar beets that are grown not further than 50 kilometers away from their factories, it can be assumed that this proposed rule of local production is respected (Tiense Suikerraffinaderij N.V, 2020). Although, 50km remains a large distance on the scale of Wallonia, which means that the sugar beets used for bioethanol production could still come from about the same area as for wheat, so that would be the provinces of Liège, Namur and Brabant Wallon.

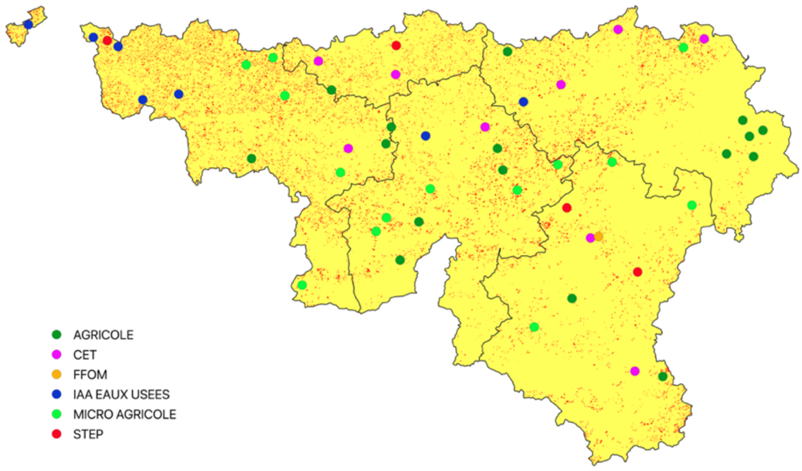

Figure 9: corn production in Wallonia with the approximate locations of anaerobic digestion plants as reference, using all together the corn off of 918,39ha of land per year. (valbiom) 'Agricole' is for agricultural waste, 'CET' is for 'Centres d'Enfouissement Technique' which are landfills, 'FFOM' stands for 'Fraction Fermentes cible des Ordures Ménagers' or household waste, 'IAA' are 'Industries Agro-Alimentaires' or the agricultural food industry and 'STEP' is 'Station d'Epuration' which is a wastewater purification station (Géoservices Wallonie, 2016; Heneffe, 2016).

Unlike wheat and sugar beet production, corn production, 54.358ha in total, is more evenly divided around the whole region, and so are the methanogenesis plants. There are 6 different categories of methanogenesis plants to be distinguished based on the specific kind of waste product that is treated. The biggest group, representing 30 out of 51 plants, are those used on farms for the treatment of agricultural waste products, shown in the colors dark and light green on the map. The second biggest one is treatment of gas coming from landfills, under 'CET' in the color pink with 9 plants. Then in the color blue there are 7 industrial wastewater treatment plants, in red there are 4 treatment plants for sludge coming from communal wastewater treatment, and then there is just one plant for the treatment of household waste in the color yellow on the map. The scale of these methanogenesis plants varies greatly, from as much as 3MW to less than 10kW. Some are used for co-generation of electricity and heat and others exclusively for the generation of either electricity or heat from the produced biogas.

Figure 10 shows the total energy balance of the market based on the complete analysis. Based on these numbers, a value can be calculated for how much one ton of each of these crops represent in the whole balance. For wheat it can be said that 1ton represents 1,9 MWh of energy, which is the same value as for sugar beet. One ton of corn represents around 1,67MWh of energy, which is comparable to wheat and sugar beet and differs mostly because of the different technology that is used. Biowaste on the other hand can produce on average 0,81MWh per ton with methanogenesis, which is less than half compared to corn (Heneffe, Gossiaux, & Schmitt, 2019). These values are calculated by dividing the total energetic values of the end products by the weight of the crops used for their production.

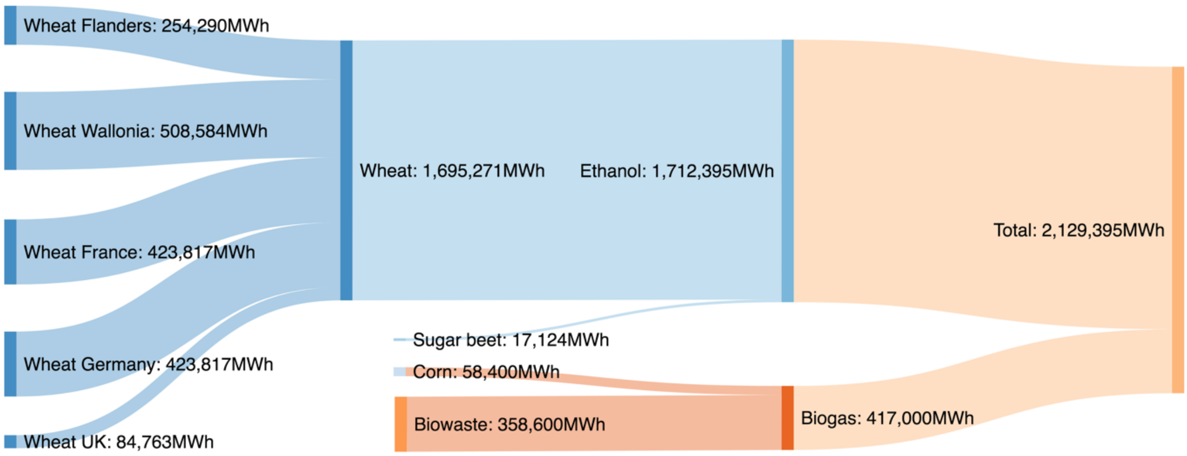

Figure 10: the total energy balance of the bioenergy market in Wallonia (Engeneering Toolbox, 2003; Heneffe, 2016; Heneffe et al., 2019).

Taking a quick look at the number of agricultural entities in the regions compared with the number of farms growing wheat or sugar beet (table 9), there are some parallels to be made with the maps that are shown above. 82% of farmers in Brabant Wallon produce wheat which makes it a main wheat production hub in Wallonia. Looking at the map showing the areas where wheat is being produced in the Walloon region, it can be seen that there is a dense wheat production in Brabant Wallon that corresponds the statement. The opposite can be said for Luxembourg and a big part of Liège. The number of farmers producing sugar beet per province follows the same pattern. The percentages are slightly lower which is explained by the lower density compared to wheat production as can also be seen on figures 7 and 8.

Table 9: number of total farmers producing wheat and sugar beet and their percentages for each province (Statbel, 2019).

	# farms	# wheat producers	%	#sugar beet producers	%
Région Walonne	12.739	6.340	49,77%	4.061	31,88%
Brabant Wallon	1.032	855	82,85%	654	63,37%
Hainaut	3.908	2.860	73,18%	1.961	50,18%
Liège	3.123	1.058	33,88%	705	22,57%
Luxembourg	2.327	229	9,84%	8	0,34%
Namur	2.349	1.338	56,96%	733	31,20%

Environmental analysis

Based on the described processes for biofuel production in Wallonia, a small environmental analysis was made. The processes selected from Simapro contained all of the information for a cradle to gate approach, which means that the included stages range from the production of the used resources, to the production of the energy needed for the process, to the treatment of waste products coming out of the process. This means that a lot of aspects are taken into account, and for the purpose of displaying the results, the three most contributing aspects will be shown (figure 11). For both the ethanol and biogas production processes, the electricity and crops needed are two of these three aspects. The third aspect for ethanol was the heat that is used, and for biogas the wastewater treatment. For each of these aspects it is also shown which amount is needed for the production of one unit of ethanol or biogas, together with their corresponding environmental impact in CO_2 equivalents.

For ethanol production it is clearly the rye production that is dominating in environmental impact compared to other parts of the process. When it comes to biogas production however, the production of the main resource, which is grass in this case, is particularly low. According to Simapro there is only a need of 316 grams of grass for the production of $1m^3$ of biogas. This is also very little compared with other results, like the fact that there is a need of 2,2kg of corn for one m^3 of biogas in Wallonia on average. This is an important nuance that has to be made.

Table 10: The total impact of the bioenergy market, following two approaches (figure 4). Approach 1 includes imported crops and approach 2 excludes them. Biowaste use for biogas production is not taken into account as its impact is not comparable to biogas produced from corn or grass.

Process	**Unit**	**CO2-eq**	**Market approach 1**	**Total CO2-eq**	**Market approach 2**	**Total CO2-eq**
Ethanol production	1kg	3,54 kg	230.782,5 tons	816.970 tons	69.234,8 tons	245.091 tons
Methanogenesis	1m3	0,285 kg	15.871.333 m3	4.523 tons	15.871.333 m3	4.523 tons

The total environmental impact for the two approaches can be found in table 10. It can be said that the bioenergy market of Wallonia emits 821.493.280 tons of CO_2eq per year, and the fraction that is a product of exclusively locally produced crops is 249.614 tons of CO_2eq per year.

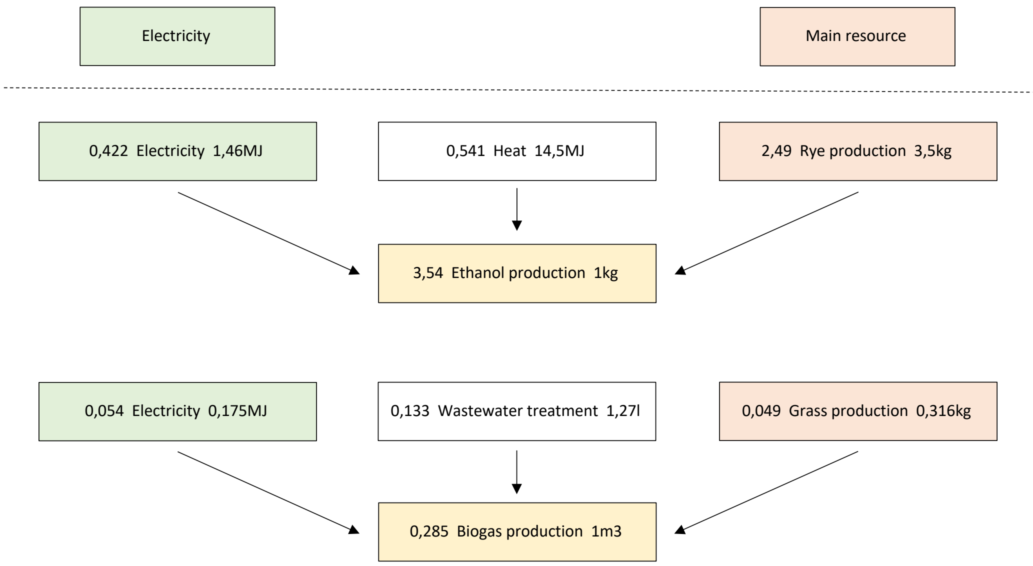

Figure 11: flow diagram of three most important steps for the production of one unit of end product, for both 1kg of ethanol and 1m^3 of biogas. Each of these steps are part of the used Simapro processes. The first value in each box is the corresponding environmental impact for the specific part of the process in kg CO_2eq, the second value is the amount of that specific product needed for the production of one unit of end product (Simapro, 2020; Wernet et al., 2016).

A comparison can also be made between the environmental impact of ethanol production and gasoline production too. From the Simapro results, it is known that for the production of 1kg of ethanol there is an emission of 3,54kg CO_2eq. For gasoline this would come down to 0,54kg CO_2eq, which is more than one sixth of the carbon footprint for bioethanol production (Eriksson & Ahlgren, 2013). It must still be said however that the ethanol production is based on renewable energy sources, which is not the case for gasoline, and if the consumption stage would be included the impact for gasoline will be a lot higher. None the less it remains the case that the environmental impact is significantly higher for bioethanol and can therefore not simply be ignored.

Economic analysis

The comparison between crops to see which ones are the most interesting to grow can be seen in table 9, and it is clear that corn is the crop that has the most potential. For the same surface of land used, it can bring a farmer more than four times the profit than wheat or sugar beet.

Table 11: the price per hectare of crop production for wheat, sugar beet and corn (Wallonie Agriculture SPW, 2019).

	Price per ton	Ton per hectare	Yield per hectare
Wheat	€185	8,55	€1.581,75
Sugar beet	€26,29	84,43	€2.219.66
Corn	€185	38,11	€7.050,35

The value of the total amount of wheat, sugar beet and corn produced exclusively in Wallonia comes down to €670.826.308, and the amount used for energy production has a market value of €56.162.110. The market value of the end products is for ethanol €48.262.500, which is only the ethanol produced from the wheat and sugar beet grown in Wallonia. The imported crops are left out of the analysis as prices of these crops may differ. For the produced biogas that market value is around €6.376.875, calculated based on the price per kWh_{el} of €0,0225 and the idea that all of the biogas would be used to generate electricity with a conversion factor of 2,5kWh/m3 (Uddin et al., 2016; VREG, 2020). The use of biowaste is included here, as this is a significant part of the process and the cost of this resource is considered to be 0.

When the total value of the raw crop products is compared with the value of the final biofuel products, which is €56.162.110 to €54.639.375, it is clear that the production of biofuels by itself is not enough to be profitable. Above that, these figures are pure turnover, and an operational cost should be calculated in order to have a full economic analysis of the process. This means that the industry is relying heavily on the co-products that are produced with the same process, and for biogas there is government funding to make the practice of green energy production with methanogenesis profitable.

When comparing the total value of the bioenergy market, including crops that are imported and the use of biowaste for biogas production, with the GDP of Wallonia, getting to €167.027.574 to a GDP of €90.371.200.000 which makes for almost 0,16% (European Commission, 2019).

Discussion

From this physical, environmental and economic analyses of the bioenergy market in Wallonia, it can surely be said that the market is fairly limited for the moment. Despite them being selected as a model region for the development of a sustainable chemical industry based on the use of biomass in Europe, there is still a lot of room for growth. In fact, currently there are no large scale chemical biorefinery plants in Wallonia, and Biowanze is the only refinery producing biofuels (Bio-based Industries Consortium, 2012). Compared with the Flemish region to its north, being a true biochemical and biofuel hub in Europe, the current technology and production there is in Wallonia is very minor. This is no surprise however, as Wallonia has not been able to develop its industry the last few decades as Flanders has. There are no ports and there is a lot less of an adapted infrastructure (De Standaard, 2003). None the less there is potential, and mostly because there is a lot of agriculture in the region, which means that there is a potentially large amount of product that can be worked with for the development of the bioeconomy. The fact that the market is currently rather small, can also be seen as a good thing. That means that it might still be flexible, and a planned development could relatively easily be obtained. A well-developed bioeconomy, regardless whether it would be developed in a positive way or not, is more difficult to change and push in a different direction.

The importance of planning a growing bioeconomy is surely not to be overseen. A large issue nowadays with the use of biomass as a source of energy is the food vs fuel debate. This debate argues that the land that is available to us for agricultural use, should not be used for fuel production but for the production of food products. Feeding the people around the world should be the number one priority, and the idea that people would starve from hunger because the land is used for energy production surely is controversial. In Wallonia too this argument can be applied, as no less than 25% of the wheat produced in the region is used by Biowanze. Thanks to our neighboring countries that doesn't mean that there is a shortage of wheat, but the idea that we need to import wheat because we use ours to produce biofuels can still be an issue. However, these are all facts that have to be put on the table when planning our land use and being critical towards the current situation is necessary for building a bigger and more sustainable bioeconomy.

There is a large series of further steps that can be taken towards that goal. The main subject being research that should be done concerning crop growth efficiency depending on where it's grown in Wallonia. This thesis is written as a step in a PhD research project at the Université Libre de Bruxelles (ULB), executed by Tianran Ding and Wouter Achten, where propositions for land use planning will be given as its main goal (Ding, Bourrelly, & Achten, 2020). Based on territorial LCA principles, the ULB is looking into which crops should be grown where to increase agricultural efficiency. This means that environmental and economic arguments are combined, which are two aspects that are very important and which are only touched briefly in this thesis. After agricultural efficiency has been looked into, decisions can be made based on these results which kind of bio-based products are most interesting to produce for the region. After that, investment could be attracted.

This thesis can provide a base for that process, although it has many limitations. Besides giving a good view of the current situation of the biofuel market, extending on environmental and economic level, nothing is said about the social level. Although at the start of the thesis this was the intention, due to the inability to plan the required interviews this part had to be cancelled. Every industry also has a social impact, and to assess that impact, guidelines for a relatively new kind of LCA is in development, which is the S-LCA. The goal is to see what negative or positive impact the production of a certain good can have on a social level, like contributions to education of the population or providing fair wages for example (Sureau, Lohest, Mol, Bauler, & Achten, 2019). An aspect that is interesting to add to an impact assessment, to give an incentive to industries to also better themselves on a social level. A very good tool to put globalized companies on the spot and make them think about production in low-income countries. Ultimately this aspect would be less applicable for the bioenergy sector in Wallonia in any case, as there are no globalized entities and their negative social impact would be limited.

LCA's are a great concept for any kind of impact assessment, and mostly so on the environmental level. When it comes to the environmental analysis that has been done in this thesis, some LCA principles were also used to get as much of a holistic idea of the bioenergy market. Although, fact remains that a real LCA analysis takes time to develop and goes in great detail to include as much environmental aspects as possible. The time needed for a full LCA was not provided for this thesis, but it remains an interesting idea to use life cycle thinking to assess an impact of a whole sector. Currently the concept is mostly used for separate entities like companies, to assess their impact on the environment. Would there be potential in using LCA's to step up in scale and compare sectors with each other? Maybe, although that might ask a lot of work for the potential insights it could bring.

Another aspect that is important to mention, is the fact that for this work the forest management sector is not taken into account. This is a big deal for Wallonia, as the sector for wood production makes up for a fairly large part of their bioeconomy. When talking about forms of energy coming from a biological source, the burning of wood actually represents the most used energy source for the region. As of right now there is an installed capacity of almost $400MW_{th}$ which is almost five times the capacity of the biogas plants, calculating both their electric and thermal capacity. This installed capacity is divided over 149 plants that use wood for heat production for all sorts of industrial activities (Bombeck & Gossiaux, 2016). Besides industry there is also a big portion of domestic heating that is done using this form of energy and which is also of great significance. Just as the use of wood as an energy source, sources like miscanthus and short rotation coppice are not really talked about in this thesis as well. However, these are new sources of bioenergy that have a lot of potential but are currently not used in great quantities. They also fell out of the scope because they are not really competing with first generation crops concerning land use, as they are mostly grown on patches of land that do not have sufficient requirements for crop production. None the less these are crops that have to be included when planning bioeconomy design and can play a big role. Currently they are very promising for heat production, but in the future, they could also be used for biofuel production once the technology has reached that point.

For the environmental part, which was based on LCA principles, it could be noticed that allocation is not taken into account. Despite the fact that this is an important concept for lifecycle thinking, it was decided to leave it out because the selected Simapro processes could not approach the actual processes closely enough. Allocation being done on these processes would only give a false image of the actual situation. However, it must be said that Biowaze specifically focusses on diversification, which means that they try to produce as many co-products as possible. If an LCA would ever be developed based on Biowanze, this is surely an aspect that cannot be overseen. This also means that for this environmental analysis, the environmental impact that is attributed to the bioenergy market is probably an overestimation. Some parts should be attributed to the feed market or the fertilization market.

Critical remark concerning bioenergy products and technologies

Following the created overview of which biofuels or bioenergy products are available, a few reflections can be made (figure 1). It has been mentioned that syngas is the most versatile intermediate product and that biodiesel is the most versatile end product. This is based on how many ways there are for their production. When designing the bioeconomy and thinking about attracting investment for one of these technologies, this also has to be taken into account.

Syngas is an interesting product because it has many applications. It can be obtained from biomass using multiple technologies, but it's also a product of a series of other processes. Carbon capture technology is also something that has been coming up, and when capturing carbon, one of the products that it is most easily turned into is syngas. That is one reason to invest in this product, as more ways for using it might be developed in the future. When it comes to biodiesel, it is also a product that has to be kept an eye on. Compared to ethanol there are not only more ways to produce it, it is also more efficient and less polluting in its production (Hill, Nelson, Tilman, Polasky, & Tiffany, 2006).

The interview at Biowanze

One aspect of information gathering that was supposed to be one of the largest sources of information for this thesis, were the interviews with important actors on the bioenergy market in Wallonia. Due to a difficult situation caused by COVID-19, there has ultimately been one single interview with the largest biorefinery in Wallonia, Biowanze. Although some of the insights that was gotten from that interview are used in this work, some were not but are still interesting enough for them to be mentioned here.

A first one is regarding the use of sugar beet as a resource for biofuel production. Currently there is a small fraction used at Biowanze, but that is only 1% of the total amount of crops going into the process. When asking the question why they are not using more sugar beet, the answer was that it's not cost-effective at all. Sugar beet has a higher industrial value on its own, because of how easy it is to extract pure sugar from the crop. Sugar has a high base value, which makes it a lot more interesting to simply use sugar beet for sugar than for ethanol production. Another particularity about sugar beet, is that the price is influenced by a quota, keeping it 'artificially' at 26 euros per metric ton. This is done to keep the farmers interested to grow the crop so that enough sugar can be provided on the Belgian market. This could also influence whether it is interesting for a company like Biowanze to produce ethanol from sugar beets, as the price of the crop is kept higher.

During the interview, the food vs fuel debate was also briefly touched. For Biowanze it was a slightly sensitive subject, as they have had some resistance in the first years after their opening because of that. This was mainly the case because they had a big influence on wheat prices the first few years they became operational. None the less they explained that in Europe it is not as big of a problem, as only a few percentages of the wheat produced in Europe are used for ethanol production. Compared to the US, where that figure is close to 50%, the European situation is surely doable. However, it still remains a fact that when looking locally, they still use 25% of the wheat production of Wallonia and a big portion of the wheat produced in Flanders too. Above that, these amounts are still only 45% of the total amount of wheat that they use. This shows that the issue is still something to look into, despite the argumentation of Biowanze.

A last point concerns their insights when it comes to the future of biofuels and bioenergy. The technology for using second generation crops as resource for biofuel production is coming near, but they would not suspect it becoming economically viable before the year of 2030. That means that for a current development of the bioeconomy, the focus should remain on first generation crops. Although it would be a good idea to keep an eye on these upcoming technologies, as they show great potential to not having to use food crops for energy production. The company is also investing in different technologies to increase their diversification, focusing on the valorization of products derived from wheat. Extending their ethanol production or a switch to other bioenergy products is not in their interest at the moment.

Conclusion

The objective for this thesis was to provide an overview of the bioenergy market of Wallonia, to serve as a reference for future research. This is done by showing how the market is physically organized, both when it comes to how much volume is produced of what product and their corresponding energetic values. It has also been attempted to bring these numbers as much as possible into different perspectives to make the interpretation of them easier, by expressing the market in an environmental and economic sense. If an idea is looked after of how big the bioenergy market is nowadays in Wallonia, this work can provide a complete image of the current situation.

The current market is limited, with only two forms of bioenergy being produced, which are ethanol and biogas. There is only one major biorefinery that uses 25% of the wheat being produced in Wallonia, above huge portions coming from neighboring regions and countries. This makes for a very one-sided market dominated by only one actor which might complicate bioeconomy development in the future. None the less there is surely more room for a strategic use of biomass for industrial, chemical or energetic purposes. The total land used for fuel production, taking the whole agricultural sector into account, remains very limited with only 4,4% of the total land that is destined for agricultural use in Wallonia. Above that, the chemical sector is not even represented, so for its development there is also more room in the future. A strategic way of doing so is definitely what should be envisioned.

Also, when it comes to environmental and economic factors the future for biofuel production will be challenging. The economic value of the resources going into the process is sometimes even higher than the economic value of the product coming out. Economic feasibility of current technologies is difficult, relying on the production of co-products or governmental aid for the activities to be profitable. This will have a big influence on future development of the bioeconomy and might be the reason why the current market is so limited. When it comes to environmental factors, the environmental impact, when having a cradle to gate assessment, for one unit of biofuel is much higher compared to conventional fossil fuels. This might be an argument for environmentalists to oppose the technology, even with the consideration that biofuels are a renewable source and fossil fuels are not.

Despite that, biofuels and bio-based products have an important role in the sustainable development of our societies. Their potential for leaving fossil fuels behind that are a major cause for global warming is not to be ignored. A strategic planning of which biofuel, which technology and which crops to focus on, specialized for the Walloon region, will ensure a strong bioeconomy that can last for decades.

Reflection concerning COVID-19

During the writing of this thesis, the world was hit by a global pandemic, which was the COVID-19 virus. For a period of time, around three months, the economy in Belgium had to slow down its pace because of a strict quarantine. These measures that were taken on a national level to try and contain the spread of the virus as much as possible also had an effect on this work. The means and resources available to students and researchers during that time were reduced. To make this thesis as complete as possible, a reflection is given on which levels these impacts are noticeable.

A first one that has already been mentioned is the impossibility to extend the social assessment part that was initially planned for this thesis. The idea was to have interviews with a series of market actors that are active on the bioenergy market. Selected interviewees were producers of bioenergy, farmers that possibly grow bioenergy crops, research facilities that focus on the bioenergy market and possibly a governmental institution that works on the subject. The goal was to get an idea of their take on how the bioeconomy is evolving, both in a positive or a negative sense. Because of the quarantine these interviews could not take place in the second semester, and the only actor that was interviewed was Biowanze. The fact remains that Biowanze, as only biorefinery in the region, has a key role in the bioenergy market, which means that their view on the matter would surely dominate and have a big influence on bioeconomy development. None the less, these other market actors also have a big influence on the market, and their opinions would have been valuable.

Besides these interviews there was also an interest in using software provided by the ULB for the environmental assessment, which was the Simapro program. Eventually the software has been used for a short carbon footprint, but the initial interest was to use it for a much more extended environmental analysis. The ULB was kind enough to provide the license login to work with Simapro from home during the quarantine, but the computer available was not sufficiently powerful to run the program in a smooth manner, which had an influence on how the program could be used. The initial intention was for both the environmental and the economic analysis to be described more extensively for this thesis. These parts were to be focused on during the second semester, but because of the difficult situation ultimately these parts were less developed.

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