

Louvain School of Management

Circular economy: Best practices and future perspectives for the beer brewing industry

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Academic year 2019-2020
Intitulé du master et de la finalité : INGM2M

Executive summary

This thesis is articulated in four distinct parts starting with the literature review of the brewing processes and knowledge developed over the last decades as well as its contribution to circular economy. This leads to the formulation of four hypothesis, to be answered on the basis of the information gathered in the second part which consisted in collecting internal inputs from Belgian brewers in the Walloon and Brussels region. This step revealed a very innovative sector already embedding circular economy in its DNA without sometimes even knowing what the actual economic concept is all about. The answers to the hypotheses can be found in the third part, and the key elements are the following. Firstly, financial investments are slowing the craft breweries down in their transition towards more circularity added to a potential correlation between an investment's price tag and its circular impact. Secondly, despite being a very innovative sector, there is room for improvements, as far as circularity is concerned. Especially for higher added-value brewer spent grain (BSG) revaluation alternatives, as well as regarding the origin of the barley and the whole circularity and logistics associated with primary packaging. Thirdly, the difference between craft and industrial brewers is established but with the reassuring thoughts that they are not competing on the same market and that craft brewers will benefit from the industrials' innovations once they have gone mainstream. Finally, brewers are well on their way towards circularity and are asking for external support to guide them through this process. Regarding the first and third hypothesis, financing alternatives have also emerged with circular economy, in the name of functionality economy. Long-standing and new public financing solutions only few are using, also represent solid alternatives to financially support a circular transition. Another summary has been created and is represented as a diagram, just before the conclusion. This scheme is the final result of this thesis and has been created to answer the guidance need coming from the brewers.

Acknowledgment

This thesis is by far the biggest research paper I have undertaken and stating that I was alone on this journey would be an open lie. With these few words, I would like to sincerely thank all the people that were involved in any way, in the making of what represents the accomplishment of my journey at university.

I therefore wish to deeply thank

Vincent Truyens, for his constant availability and support, as well as his thesis mentoring experience and more precisely, his advised comments and overall guidance throughout the entire redaction of this work.

All the interviewees involved in the qualitative analysis, Nicolas Declercq, Bruno Deghorain, Pierre Delcoigne, Marc-Antoine de Mees, Didier Hamoir, Alix Thiran, Rodolphe Paternostre, Hadrien Velge and Vincent Vanderveken, for their time and precious answers that directly served as valuable input.

La Binchoise and La brasserie de la Lesse, for introducing me to the entire brewing process and showing me around their facilities before I started working on my thesis.

Lara Hotyat, for her support and valued advice, as well as schedule flexibility leading to the deadline of the thesis.

My family and friends, for their continuous support over my entire academic journey leading to this thesis and for helping me make the best out of it. Special mention to my parents for giving me the opportunity to study, and in the best conditions during the past years.

Lisa Hamoir and her family, for providing me the best working conditions and hosting me during the lockdown, as well as for her continuous support and dedication.

Methodology

This thesis's construction revolves around four different parts that have been executed and are presented successively in order to get to the completion of this work.

After a thorough review of the existing literature, the structure of the thesis began to build up and this allowed for an appropriately divided presentation of the existing theory. The life cycle of a beer can be very long, and it passes through different processes that are geographically separated and often not managed by the same people. This obviously leads to a clear separation of processes, but they can all be looked at, no matter the nature of their activity, from four specific points of view. Starting with water usage, moving on to solid waste followed by energy consumption and finally the overall greenhouse gases (GHG) emissions. This is why I decided to present in the first section all the elements of the life cycle analysis (LCA), from these four different perspectives, while packaging will be given extra attention in addition to the four perspectives. The last two elements, GHG and energy, have often been used to assess the environmental performances, while the first one is particularly impactful for the brewing sector and the second one for circular economy. The intent is to get the general knowledge on this specific subject in order to confront the findings with the reality of the “on the field” data.

This data is collected in the second part of the thesis through semi directive interviews with several brewers from Belgium, a brief online questionnaire for the same audience and information collected on the internet. A first series of informal conversations with “La Binchoise” and “La Brasserie de la Lesse” took place during the exploratory phase to gain knowledge about the global process and get a sense of which direction to take, to help structuring the thesis. Then, a selected panel of craft breweries was chosen on the basis of their core values and circular practices. The interviews were conducted online because of the sanitary crisis and the imposed quarantine on the whole country from mid-March 2020 to early May. The exchanges were recorded when it was possible, and only notes were taken when the interviewees didn't accept to be recorded.

The third part of this study confronts the findings of the previous two sections in order to assess the feasibility of the theory on real-life situations and to identify the areas for improvement. To help with the structure of the analysis, the hypothesis formulated at the beginning of the second part will be answered and serve as guidelines.

Finally, the section four looks at the subject from a different perspective and offers a managing point of view including a support tool to be used and shared by the greatest number. Indeed, this thesis will be available to the public and the goal is to see breweries gradually implementing circular practices and push toward a circular transition.



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BEERFOOD - RODOLPHE PATERNOSTRE

List of abbreviations

°C	Degrees Celsius
AD	Anaerobic Digester
BBP	Brussels Beer Project

BMC	Business Model Canvas
BOD	Bio-chemical Oxygen Demand
BSG	Brewers Spent Grains
BSY	Brewers Spent Yeast
CE	Circular Economy
CHP	Combination of Heat and Power
CIP	Cleaning-In-Place
CO ₂	Carbon Dioxide
CO _{2e}	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
FU	Functional Unit
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GHG	Greenhouse Gas
hl	Hectolitre
KPI	Key Performance Indicator
L	Litre
LCA	Life Cycle Analysis
MBR	Membrane Bioreactor
MCI	Material Circularity Indicator
ML	Absolute water use
MRS	Material Reutilization score
OECD	Organization for Economic Co-operation and Development
PLA	Polylactic acid
SME	Small and Medium Enterprise
T	Ton
USA	United States of America
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

I. Introduction

This thesis's subject was born on one hand from a strong interest in the preservation of the environment and the underlying transition, and on another hand from the importance of the Belgian brewing sector. Furthermore, the actual environmental context is now well settled in, and it's no surprise that a change must occur. Indeed, given the pace we've set and with the global population expected to increase, by 2050 we'll be consuming the equivalent of three times what the planet can restore in a year, according to the United Nations (2020). This statement led to the creation in 2015 of the 17 sustainable development goals with a target of achievement by 2030. These goals are a call for action by all countries to promote prosperity while protecting the planet and are built around the environment, the social and the economic aspects. (United Nations, 2020)

Furthermore, OECD's previsions for 2050 are clear and proving to be accurate as time goes by. (OECD, 2012) And in order to fulfil our European goal of carbon neutrality for that year, we'll need to rethink our system and build a transition to a sustainable economy. This is where circular economy can play a major role. This belief is also shared by the European Commission who has just released in March of this year their circular economy action plan, which aims at accelerating the transformational change required by the European Green Deal. (European Commission, 2020) Many believe that circular economy is a part of the answer and nobody shares that belief more than the Ellen Macarthur foundation that has been a fierce supporter of this relatively new economic concept and is doing its best to further spread the concept by making this quest their reason for being. According to them:

“The circular economy completes the picture of what is required to tackle the climate crisis. It offers an approach that is not only powered by renewable energy, but also transforms the way products are designed and used. This framework cuts GHG emissions across the economy through strategies that: reduce emissions across value chains; retain embodied energy in products; and sequester carbon in soil and products. » (Ellen Macarthur foundation, 2019)

1.1 Importance of the brewing sector in the Belgian economy

The choice of the Belgian brewing sector is pretty straightforward since beer is one of the oldest and most widely consumed alcoholic beverages worldwide and is the third overall most popular drink after water and tea. (Restaurant supply, 2014) In 2018, the global beer production was recorded at 1.94 billion hectolitres with China, the United States and Brazil producing the most. (Statista, 2019) Next to these three countries, Belgium only produces 1% of the world beer production mainly due to its size, but it's the only country that brews ten times its demographic weight. (Belgian Brewers, 2018) Another reason for choosing the Belgian sector for this thesis, is the addition in 2016 of the Belgian beer culture to the representative list of the intangible cultural heritage of humanity. (UNESCO, 2016)

At a more domestic level, the impact of the 304 breweries is significant with numbers from the 2018 yearly report of the Belgian Brewers recording the production of over 1,500 different beers, a total investment of 251 M€ in the breweries and an additional 100M€ in the hotel and catering sector. Regarding the brewing sector, it employs both directly and indirectly 55,000 people and it has been determined that it contributes to 1% of the GDP, which equals to 4B€. The Belgian beer market has now seen the emergence of many new craft breweries, but the majority of market share are split among the leaders that account for most of the sales. It's hard to get exact numbers but in 2012, AB InBev owned 56.3% of the Belgian market. (AB Inbev, 2012) The reality of these two types of breweries is different and the majority of this thesis will be targeted towards craft brewers. This category concerns the breweries producing less than 100,000 hl every year. (Hébert & Griffon, 2010) The rest of the beer producers, making more beer than the milestone just mentioned will be referred to, as industrial brewers.

1.2 Environmental impact of the sector

There are several ways to assess the environmental impact and performance of a product. One of the most popular and widely used is probably the Life Cycle Analysis (LCA) which is based on a life cycle approach that takes into account the full supply chains of materials and energy. The LCA methodology allows for an assessment of potential improvements in environmental performance through the quantitative basis it offers. (Koroneos et al., 2005)

New Belgium, a brewery with great environmental concerns from the USA found in cooperation with the Climate Conservancy that the carbon footprint for a 6-pack of one of their

beers is 3,188.8 gr of CO₂e. This means that it would take 54 days for an average adult tree to absorb that amount of emissions. (Sestra Systems, 2017) Now, an American 6-pack holds 2.129294l and the 2018 global beer production was estimated at around 1.94 billion hl. This means that the gross estimation of CO₂e emissions for the world's beer production in that year is equal to 290,531,603 T. Now back with the tree perspective, this amount of emissions requires 13,344 billion trees to be absorbed in one year, knowing that rough approximation for the global number of trees on the planet is 3040 billion. (Crowther, Glick, & Covey, et al., 2015)

For the beer production, the full supply chain includes raw material acquisition, industrial refining, packaging, transportation, consumption and waste management. Earth toxicity, heavy metals, and smog formation are leading the charge in terms of most impactful categories taking all the perspectives into account and associated with this activity. Bottle production followed by packaging and beer production are found to be the subsystems that account for most of the GHG emissions. (Koroneos et al. 2003) These results are indeed confirmed by a Belgian study comparing the environmental impact of two packaging methods. In the paper, the LCA of one litre of beer shows that the packaging has by far the greatest impact (72% for bottles and 87% for kegs) when the container isn't reused and when it is, it's the barley cultivation that tops the environmental impact ranking with a contribution of 58% and 70% for bottle and keg packaging respectively. (Melon, Wergifosse, Renzoni, & Léonard, 2012)

Now, CO₂ emissions aren't the only factor to take into consideration, and while the LCA focuses mainly on this and the energy requirements, most of the breweries rely on four KPIs when it comes to assessing their environmental footprint. The water usage, the solid waste, the energy requirements and the CO₂ emissions. (New Belgium brewing company, 2020) (Sierra Nevada, 2020) (AB InBev, 2020) We'll use the same KPIs for this thesis and it's important to mention that each of the four categories is somehow interrelated. This means that a reduction in one of them can sometimes lead to an increase in another one therefore meaning no reduction at all but a transfer of impact. Now, this allows to choose which type of impact is the less harmful for the environment and which one is the easiest to thereafter tackle for the real reduction to happen.

1.3 Circular economy

The definition of circular economy will be mainly based on the Ellen Macarthur foundation's definition because of its easiness to apply to any sector and its simplicity to combine with other factors. Given the amount and importance of content and present in the general introduction, the definition coverage will be contained to the most important aspects.

Circular economy is defined as “a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.” (Geissdoerfer et al., 2017) One of the key thinkers of CE believe that in a CE, the objective is to maximize value at every step in a product's life, since the aim is to keep products, components and materials at their highest utility at all times. (Stahel, 2016)

The same authors emphasize on the importance of the work of the Ellen Macarthur foundation in the context of circular economy. In the foundation's eyes, circular economy aims at *“redefining growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: Design out waste and pollution; Keep products and materials in use; Regenerate natural systems. »* (Ellen Macarthur foundation, 2019)

1.3.1 Ellen Macarthur's three principles

As reported by the foundation, this new type of economy is based on three main principles that are then further detailed.

The first principle is designing out waste and pollution. This can be achieved through designing for circularity with products made for disassembly, repairability, modularity and biodegradability. Another path leading to this same goal is to eliminate waste by optimizing both the quantity of material and energy required, precisely forecasting the demand to avoid overproduction and designing for a specific need instead of profit. This refers for example to the concept of design thinking where the design is not initiated by profit but by the will to

address a real need/problem. (Sarwar & Fraser, 2019) Finally, the third approach leading to the same objective is about substituting materials, referring to the use of renewable, low carbon or recycled materials as alternative inputs for production. (Ellen Macarthur foundation, 2019)

The second principle is to keep products and materials in the loop by reusing products and components on one hand and recirculating materials on the other. This principle is dependent on the previous one because it's the design that allows for further reuse of products and especially materials and components. For the food system application, it's all about valorizing discarded organic resources and turning them into feedstock for the circular bio economy. (Ellen Macarthur foundation, 2019)

The third and last principle concerns the regeneration of the natural systems to sequester carbon in soil and products. A regenerative approach using renewable resources and returning nutrients to the soil provides opportunities for carbon sequestration. (Ellen Macarthur foundation, 2019)

1.3.2 Circular economy in Belgium

The principles just mentioned are starting to be acknowledged and adopted by many, including the Walloon Parliament that recently published a report on circular economy in Wallonia. This report further considers the circular economy as a quadruple opportunity.

- A social one that will provide 36,000 new jobs.
- Environmentally speaking and with a timeframe set on 2030, it could halve the carbon emissions, reduce by 30% the quantity of raw materials and lower down the cost of treatment for the collectivity emerging from negative externalities of the linear model.
- From the economic standpoint, it will boost the economy by +1.04% (points/year) while pushing for a local and durable reindustrialization.
- The governance opportunity could allow the development of a holistic vision to handle the complexity of our society and coordinate the multiple actors and initiatives to amplify the dynamic. (Parlement Wallon, 2019)

In Brussels the government adopted in 2016 the four-year regional program in circular economy with a budget of 12.8 million € for 2016. (Circular economy brussels, 2016) And the Flemish region has its own 2050 circular vision represented by “Vlaanderen Circulair”. (OVAM, 2020)

Nine breweries even signed in a Green Deal for brewers regarding their water usage reduction towards 2022. (Vlakwa, 2018)

1.3.3 Assessment tools

In order to quantify and assess circular economy, some tools have been created and two of them managed to stand out from the rest.

The Lansink ladder, chosen by the authors of the Walloon report to evaluate the life cycle, offers a normative framework to assess the efficiency of resources' use. The top of the ladder is to be realized in priority to eventually end up land filling products as the last option.



Figure 1 : Lansink ladder (Source : <https://www.sheeponwheels.com/about.html>)

The other tool is the Ellen Macarthur foundation diagram that is more complex and illustrates the continuous flow of technical and biological materials through the “value circle”. (Ellen Macarthur foundation, 2019)

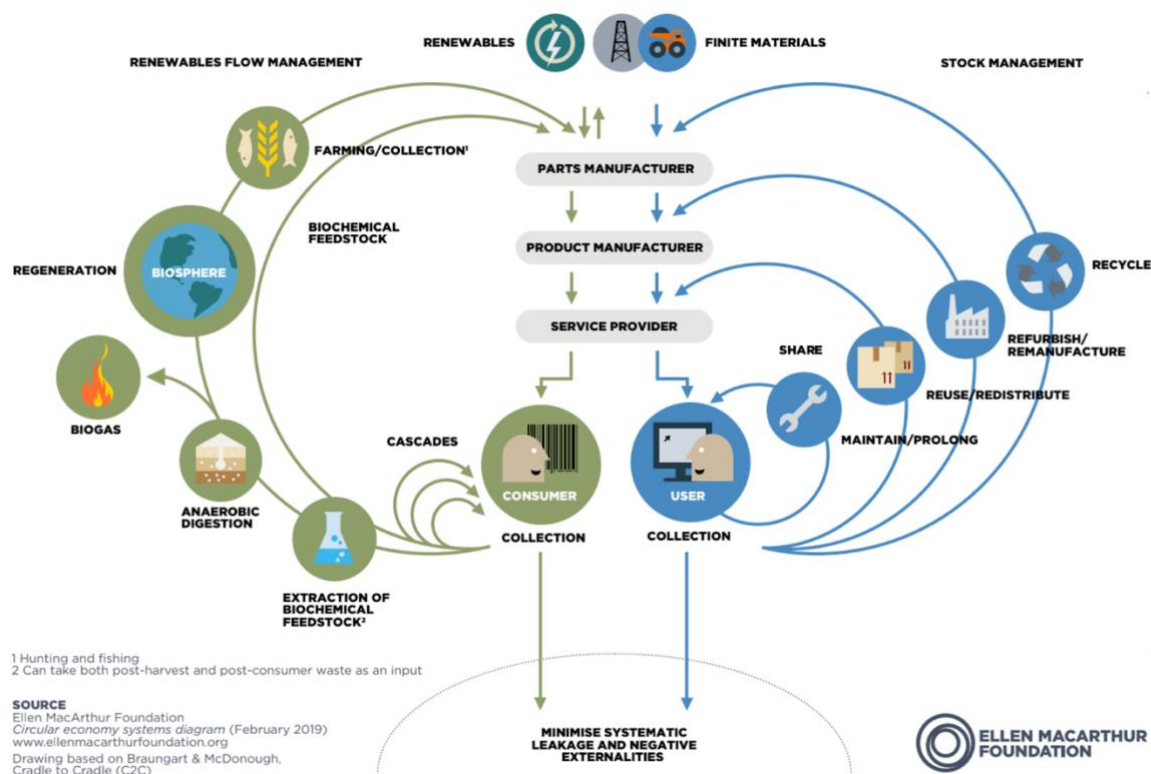


Figure 2 : Ellen Macarthur foundation diagram (Source : <https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail>)

1.3.4 Advantages of circular economy for the food system

The advantages of circular economy are numerous. Therefore, here is a quick view on the ones associated with the food system only, that interest us specifically since beer is part of that category. Being a consumption beverage, and – water aside – made from harvested ingredients mainly, we can safely assume it falls in that category. Among the advantages of circular economy, there is a potential emission reduction of 5.6 billion tons of CO₂e corresponding to a 49% diminishing in the projected 2050 total food system emissions. (Ellen Macarthur foundation, 2019) The three principles of circular economy defined by the foundation have been given a special treatment for food and agriculture. Every section presented in the next three paragraphs has been further detailed in one of their latest publications: “*Completing the picture. How the circular economy tackles climate change.*”

The first principle refers mainly to reducing food waste and it can be achieved by better matching the supply with fluctuating demands. This process is facilitated by digitalization and supporting policy initiatives. The potential for this change can contribute to reducing edible food waste by 50% by 2030 as well as an annual emissions reduction from across the food value chain adding up to 1.4 tons CO₂e.

Even if we consider the first principle accomplished, there will always be a surplus of organic materials. The objective of the second principle is to view this not as waste but as feedstock for other parts of the economy. Products can eventually be created, natural fertilizer used and even energy recovery via anaerobic digestion. The composting of by-products and green waste could amount to 0.3 billion tons CO₂e per year in 2050.

Finally, the third principle is about regenerating natural systems and it represents the greatest opportunity to turn the food system to a major actor in the solution to climate change. Regenerative agriculture could result in carbon sequestration, better water retention and less synthetic fertilizers. Managed grazing¹ and regenerative cropland² are estimated to represent a 1.4 billion and 2.5 billion tons of CO₂e per year respectively.

¹ Using livestock as a tool for building soil fertility by carefully controlling timing of grazing and resting of pastureland. (Ellen Macarthur Foundation, 2019)

² A set of techniques on arable land that reduce GHG emissions associated with different crop types as well as increase soil carbon capture. (Ellen Macarthur Foundation, 2019)

II. Part I

This section covers the entire chain involved in the brewing process from an academic point of view. It gathers all the relevant knowledge on the subject found in several scientific reviews in order to get a strong understanding of the already available literature and potential solutions.

2.1 Decomposing the beer LCA

The lifecycle analysis of beer can vary from one study to another, often due to the scope that is chosen. The full supply chain can go from the hops harvesting process up until the conditioning of the final product and even the disposal by the end consumer. The sly part associated with this decomposition of the process is that throughout their journey, the raw materials are transferred amongst several actors before reaching the stage of final product. As a result, the focus is sometimes only put on a single process when looking at the environmental impacts.

A Belgian study (Melon et al., 2012) performing an LCA on an artisanal blond beer ended up with six steps represented on Figure 3. A calculation of the impact proportion on the whole process is represented in percentages on the step's line in the table. The steps are namely barley cultivation; brewing; wort boiling; guard; spent grain washing; packaging. This means that the logistics part regarding the transport and conditioning has been put aside, as well as the disposal by end consumers. This common practice is also known as “cradle to gate” (of the factory).

Steps	Bottle		Keg	
	Single use	Reuse	Single use	Reuse
Cultivation barley	<u>21.83</u>	<u>57.52</u>	<u>10.52</u>	<u>69.99</u>
Brewing	0.2	0.52	0.1	0.64
Wort boiling	3.79	9.98	1.82	12.14
Guard	1.97	5.2	0.95	6.32
Washing spent grain	0.04	0.11	0.02	0.13
Packaging	<u>72.17</u>	<u>26.67</u>	<u>86.59</u>	<u>10.78</u>
Total	100.00	100.00	100,00	100,00

Figure 3 : Beer LCA (life cycle assessment of an artisanal Belgian blond beer, 2012)

However, as it's important to bear in mind the entire supply chain, here's a schematic representation of the whole system.

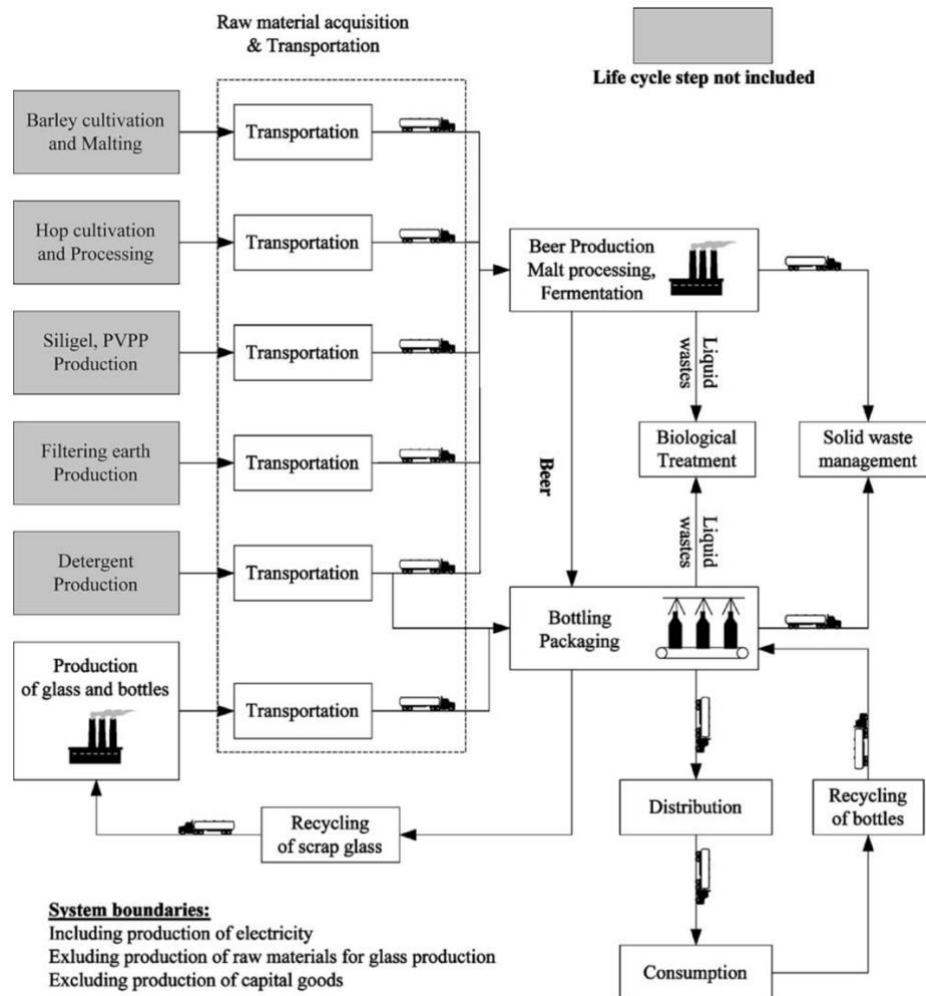


Figure 4: Schematic presentation of beer supply chain (Source: life cycle assessment of beer production in Greece, 2003)

2.2 Analysis of the brewing process

Despite the actual brewing process only being the third responsible in terms of most impactful activities related to the production of beer, it's important to have a look at what the core activity of this production process. The next paragraph will focus on the beer-making process only, also known as brewing.

The first step is the milling, which consist of extracting the flour out of the malt grains through a flour mill. The flour is then transferred to the mash tun for the mashing. This is the process of mixing flour with hot water for one hour and a half at specific temperatures ranging from 55° to 72 °C. It's called mashing because the mixture obtained from this process is the mash, and it contained the sugar extracted from the starch of the malt. Up next is the lautering that is done to separate the mash into wort (extracted sugary liquid) and spent grain (the main solid waste of the brewing process). The wort obtained is what will be used for the boiling process that

follows the lautering. For one hour and a half, the wort is boiled at 100 °C in order to sterilize it, to clarify it, to adjust its sugar level and it's also when hops and flavouring is added. Before entering the fermentation tanks, the wort is filtered to remove what has been added in the previous operation and is cooled down from 95 °C to 25 °C with a plate cooler during what is called the cooling. This step is also the occasion for the wort to be oxygenated with the use of a spark plug, which facilitates the start of fermentation. For five days, the yeast added to the wort at the beginning will transform the sugars into alcohol and carbonic gas. The beer is cooled down close to 0 °C at the end of fermentation, which results in the yeast flocculation and floating down to the bottom of the tanks. This is the flocculation and it happens just before the beer can start maturing. The maturation takes place at 2° C for ten days and here the young beer will ripen, clarify and become gas saturated. Then finally comes the conditioning where mature beer is put into bottles or kegs. There are two ways to operate the bottle conditioning, the artisanal and the industrial one. The first one consists of adding sugar and yeast for another ten days fermentation to happen in a warm room in order to give the beer its fizz. This extends the production time by ten additional days, and that can be avoided by capturing the extracted carbonic gas from the fermentation process and putting it straight back in the bottle to give it its fizz. This second process requires the use of expensive machines which is why only the industrial beer production is concerned by this method. (Brasserie La Binchoise, 2020)

The figure 5 pictures very precisely all of the inputs and outputs involved in the aforementioned brewing process. This is one of the first steps to execute when performing an LCA analysis of a product.

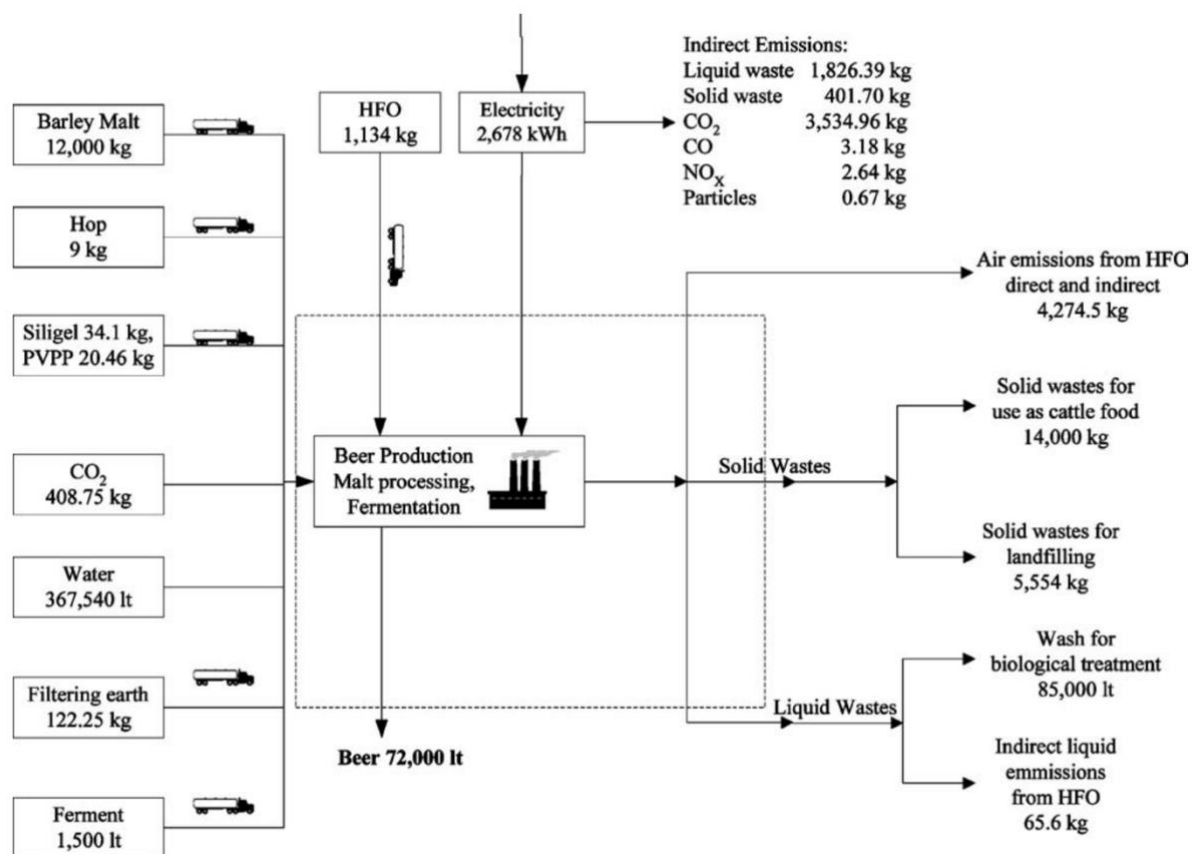


Figure 5: Inputs and outputs in the beer production for one batch (Source: life cycle assessment of beer production in Greece, 2003)

The following sections will deeply analyse the four types of inputs and outputs throughout the complete life cycle of beer production. However, packaging has been left out of each section on purpose. Due to its importance, a dedicated section will be focusing on this aspect exclusively.

2.3 Focus on water usage and circular solutions

“I am convinced that, under present conditions and with the way water is being managed, we will run out of water long before we run out of fuel.”

Peter Brabeck-Letmathe, Chairman Nestlé Corporation

The world population is growing every year by roughly 83 million and expected to reach the ten billion marks by 2050. (United Nations, 2017) With a limited amount of water on our planet and an increasing population, the battle for water is only going to get tougher as we move on. Even today as there is still enough water for everyone yet, more than 2 billion are living with the risk of reduced access to freshwater resources. The actual problem is that 80% of the wastewater resulting from human activities is dumped back in the seas and oceans without a proper treatment to remove the pollutants. (United Nations , 2017) Most of the water is not used by the population for a day-to-day usage, but 71% is what the agriculture requires, and another 16% comes from the industries' consumption. (MarketWatch, 2012) This is why people are turning to vegetarian diets and agriculture to more regenerative practices avoiding pesticides and resulting in way less water consumption. Now what industries are doing can be separated into two main actions happening upstream and downstream. The first one consists of reducing the global usage of water that can be achieved through innovation of new and more efficient processes, or simply by implementing a water stewardship program inside the company. Now downstream what they're aiming at is to treat their wastewater in order to reuse it and not to contaminate the surrounding environment it's released it.



2.3.1 Upstream agriculture

The numbers and facts presented above only account for the brewing process but there is more to it than just that. Mekonnen & Hoekstra (2011) estimated that upstream, around 1 600 m³ of water would be necessary for the production of one ton of cereals. The requirement in terms of grams of barley for a litre of beer is roughly 100 to 200 grams and with a simple calculation we reach a total of 150 to 300 litres of water just for the production of a litre of beer. Next up before reaching the brewery under the form of malt grains, the barley is malted, and this also consumes water. The maltsters' association of Great Britain estimates that 4.5 to 5m³ are required for each

ton of malt produced. (The Masltsters' association of Great Britain, 2011) This adds up another 0.75l of water per litre of beer. Downstream now, the conditioning also involves the usage of water and Korneos and al. (2003) have found that 60 litres of water was necessary to produce one ton of glass. The same study shows that a 0.5 L bottle requires 0.546kg of glass to be produced which means that a ton of glass allows for the production of 1830 bottles, or an additional 0.03 L of water for half a litre of beer.

This means that overall the real water to beer ratio is around 5.31 without the barley cultivation, and an astonishing 230 when we include it. This number is at the opposite of what was presented earlier in this part about the water scarcity to come. This is why breweries have made it one of their main concerns and improvements are being witnessed but there is still room for improvement.

In order to find these improvements, it's interesting to have a look at the different cultivation methods. A study by Wheeler et al. (2015) has already compared organic and conventional agriculture and the results show that organic farms perform better in terms of absolute water use (ML), water use as a percentage of allocation received (%) and water-use productivity (ML/\$), that is the most relevant water measure for individual farms. However, evidence was also provided about conventional irrigated farms being more water-use efficient. For the specific case of cereals and barley production. As far as water consumption is concerned, it's pretty easy to choose the least impactful between organic and conventional cultivation since barley is rain-fed and doesn't require additional water. (Tricase et al., 2018)

Barley is the main type of grain used to brew beer, but it's not the only one. In order to reduce the water usage in the beer production process, switching up the type of grain might be a solution. The Land Institute (2019) developed a perennial grain called Kernza that Patagonia provisions uses to brew its own beer. (Patagonia provisions, 2016) This type of grain has long growing roots that retains much more water and more efficiently, which results in better soil quality and less water consumption. The study from de Oliveira et al. (2019) highlights the high water-use efficiency of Kernza throughout the growing season which mitigates water stress and increases the resilience to climate. More information on Kernza is provided in the analysis of CO2 section.

A comparative LCA between organic and conventional barley production was conducted by Tricase et al. (2017) and the results suggest that a lot of importance should be given to the methodology and the functional unit (FU) chosen, because different FU can actually lead to different results in terms of efficiency. Overall, organic barley cultivation can be considered the most durable for the environment but the conventional one is more efficient with better yields. The study suggests a choice for one of the two methods according to the purpose of the request, and since we're looking at the barley in the context of beer production, we should consider the mass functional unit that favours the most efficient production technique: the conventional one.

In 2012, Seufert, Ramankutty and Foley published their work about barley cultivation and the yield differences between the two methods, in "Nature". They ended up with the same general result as Tricase et al. (2017) suggesting lower yields for organic cultivation compared to the conventional way of doing things. Three years later in 2015, Ponisio et al. suggest looking at the different types of management practices instead of comparing organic and conventional methods. They think that appropriate techniques could significantly reduce the actual yield gap and even increase the organic yields to obtain similar or better ones. The two practices retained for their yield reducing action are two diversification techniques, multi-cropping and crop rotation.

On a side note, hops and spices aren't taken into account because of their insignificant importance comparatively with the rest. (Cimini & Moresi, 2016)

2.3.2 Brewing process

Beer production accounts for a fair share of the 16% representing the industry water consumption. Apart from hops, grain and yeast, beer is made out of more than 95% of water. But that's not it, water is also needed to rinse and clean countless pieces of equipment and containers which results in a water usage to beer production ratio that is not efficient. However, this has been a major focus for the entire sector and over the past 25 years, water consumption has been reduced from ten to twenty litres down to an average of 3.2 to 6 litres of water per litre of beer. Despite the improvements realized in this part of the process, the ratios are still too high and need to be lowered down even more with the help of innovative processes or the circular economy. Today, brewers can reuse up to 70% of their wastewater and mainly use this amount for secondary use such as cleaning, rinsing and cooling. (Belgian brewers, 2018)

2.3.2.1 Water sourcing

Since beer is a consumption beverage, the quality standards and safety measures associated are strict because it's a matter of health of the consumers. This is probably one of the reasons why no recycled water is used as the main ingredient of beer. But if we get back to the definition of circular economy, is what is true for products and materials also true for water? This means that if we can avoid using virgin water as much as possible, we'll de facto integrate more recycled content back in the loop.

2.3.2.2 Optimizing the use - Brewing

There isn't much existing literature on ways to optimize the consumption of water inside a brewhouse. However, the Brewers Association from America has written a volume reduction manual targeted at water and wastewater which will be used in order to get inspiration and a taste of what's already been done over there.

Before even getting started with more insights, the Brewers Association evaluated the cost of water. It's equal to the sum of costs related to incoming water, sewage service charge, energy and chemicals needed to process it and the labour and other costs associated with wastewater treatment. (Brewers Association, 2013)

Foremost, in order to reduce the quantity of water used for the beer production, it's vital to have a proper data collection system. This will allow for benchmarks, to define appropriate KPIs, to set objectives, detect leaks and much more. Pagoropoulos et al. (2017) support this claim when

Water saving measure	Possible application	Typical reduction in process use (%)
Closed loop recycle	Fermentor cooling	>90
Cleaning-in-place (CIP)	New CIP set	60
Re-use of wash water	Cask washer	50
Countercurrent rinsing	CIP set	40
Good housekeeping	Hose pipes	30
Cleaning-in-place	Optimisation of CIP set	30
Spray/jet upgrades	Cask Washer	20
Brushes/squeegees	Fermentor cleaning	20
Automatic shut-off	Pump cooling water	15

Figure 6 : Typical reductions in water use (Source: Brewers association)

they say that digital technologies play an important role in the transition to circular economy by optimizing forward material flows and enabling reverse material flows. In parallel, a water stewardship program seems to be a relatively easy measure to implement that can turn out to generate almost an immediate payback. Giving the opportunity to employees to suggest improvements, whatever they may be, can also prove to be rewarding.

As far as the technical optimization techniques are concerned, a similar ranking to the Lansink ladder is used in order to prioritize action over others.

In this specific case, the priority is to adjust the flow, then to adjust the current equipment followed by changing to new equipment, reusing or recycling water and finally shifting to a low water or waterless process.

The typical reduction in water use is hereby presented along with the percentage of reduction use on figure 7. What immediately stands out from this table is the closed loop recycling that generates over 90% reduction, as well as the implementation of a cleaning-in place (CIP) system.³

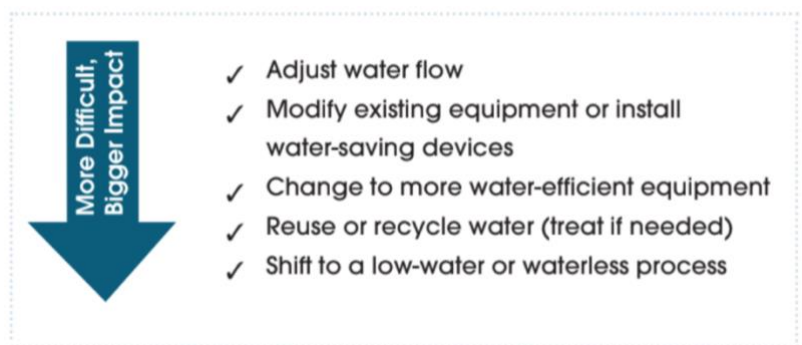


Figure 7: Moving from simple to more complex actions (Source: Brewers Association)

2.3.2.3 Disposal

It is estimated that three to ten litres of wastewater are generated for every litre of beer produced. The effluents are characterized by their high concentration in sugar and alcohol mainly, alongside with solid organic content, high temperature and low ph. Brewery wastewater needs to be treated properly because the sugar and alcohol it contains result in a liquid up to 500 to 1000 times stronger than domestic wastewater. The strength is calculated in terms of chemical or biochemical oxygen demand (COD or BOD, respectively). This imposes more energy and costs to treatment plants which translates into expensive fees for the brewery wastewater and

³ Cleaning-in-place (CIP) : “The cleaning of complete items of plant or pipeline circuits without dismantling or opening of the equipment and with little or no manual involvement on the part of the operator. The process involves the jetting or spraying of the surfaces or circulation of cleaning solutions under conditions of increased turbulence and flow velocity”. (Society of Dairy technology)

can become a competitive disadvantage for some breweries. As far as the environment is concerned, the discharge of untreated wastewater causes nutrient pollution. (Ferreira, et al., 2019)

Biological solutions

There are two main ways to treat brewery processed water and they're called aerobic and anaerobic treatment. The microalgae treatment is more experimental and less common.

Aerobic Treatment

The goal of this method is to convert BOD into biomass, CO₂ and water. The treatment involves adding oxygen to processed water in order to facilitate the biological degradation process from which the aforementioned elements stem from. There are here two options to choose from, ranging from low cost but highly energy demanding treatment ponds that accomplish only low effluent levels, to advanced membrane bioreactors (MBRs) and activated sludge processes. The largest cost drivers regarding this decision are energy, operations labour and sludge disposal.

Anaerobic Treatment

The anaerobic digestion treats water by removing its BOD (up to 80–90%) while producing energy-rich biogas, possibly converted into electricity and heat with a cogeneration system. Carefully designed reactors allow a diverse microbial community, to degrade organics in the processed water, simultaneously treating solids and/or BOD while generating biogas. Anaerobic solutions offer many opportunities and the potential for wastewater treatment is significant. However, this requires an important initial investment that is compensated by lower operating cost and the production of renewable energy. Despite the obvious long-term advantages this option presents, the capital needed to make it happen, is often the reason why breweries decide to choose an alternative solution.

This type of treatment is widespread amongst the large breweries and for example the Sierra Nevada brewery in the USA uses a methane-rich biogas that they generate to power their boilers. (Sierra Nevada , 2019) One anaerobic treatment solution was developed by Cambrian Innovation under the name of EcoVolt Reactor. What's interesting here is that it's specifically designed for scaling, which allows incremental expansion to better match the growth. On top of that, they introduced in 2015 a financing plan that offers wastewater treatment as a service.

This is exactly what new circular business models are about with the general idea to optimize the use of products and services to the fullest. This plan is particularly addressed to small breweries which don't have enough capital to invest in a treatment operation or that simply do not have enough wastewater to run that reactor at full capacity. The water energy purchase agreement (WEPA) allows breweries to focus on their core business while Cambrian owns and operates its EcoVolt solutions for its customers who are charged by gallons of wastewater treated and by kWh of clean energy and gallons of water returned to the facility. (Master Brewers, 2017)

Microalgae

The circular bio economy is an emerging concept that relies on the exploitation of waste as a feedstock for different biotechnological processes to obtain a huge spectrum of biochemical components through a biorefinery platform. (Ferreira et al., 2019) Just like circular economy, it focuses on creating added-value products from a thought through production, conversion and utilization of renewable resources. The versatile and eco-friendly properties of microalgae make it a solid candidate for developing closed-loop systems both contributing to the economy and the environment. (Shahid, et al., 2020) The algae can be used to produce biofuels, biopolymers, biofertilizers, etc. and the remaining water can be reinserted back in the loop for agricultural or industrial purposes. (Mohan et al., 2019)

Innovative Solution

In Colorado, it's the city of Boulder found a way to use weak wort. They partnered with a local brewery to use the sugary liquid in order to help reducing the nitrogen runoff from on the city's water-treatment facilities. The trial turned out successful and opened up the path for new innovative solutions. (Modern Farmer, 2015)

2.4 Focus on solid waste and circular solutions

“There is no such thing as ‘away’. When we throw anything away it must go somewhere.”

Annie Leonard, Proponent of Sustainability

Solid waste is what is usually referred to when talking about circular economy, and rightfully so. Even though the scope of the definition is broad and it's not the only category matching the definition, it's nonetheless a very important one and the beer sector is no exception to the rule. However, it's important to mention that the sector is already very active and amongst the most innovative ones in terms of resources reuse. The well-known relationship between brewers and farmers concerning the brewers spent grains (BSG) is the best example of that. The combination of a rising global demand for healthier diets on one hand, and the focus on diminishing food waste on the other, places the recovery of the brewing sector's waste as an ideal candidate with a lot of potential. Aside from BSG, the other two main types of waste are spent yeast and spent hops and trub. The last category mentioned is the least represented in terms of waste quantity. The table extracted from the study of Fărcaș et al. (2017) gathers the main solid waste of the brewing process.

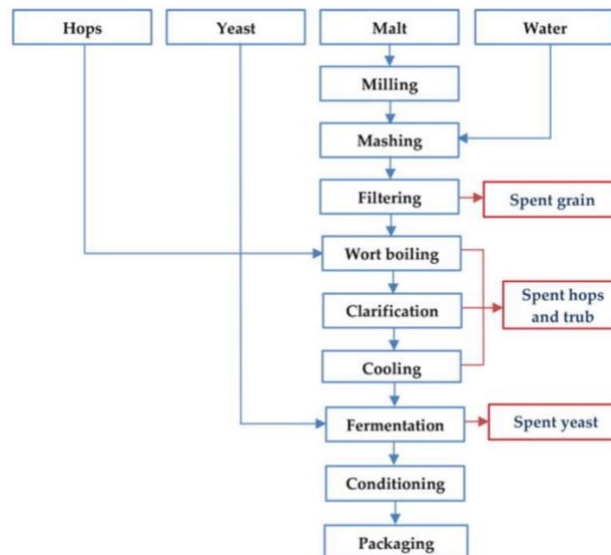


Figure 8: Schematic representation of the brewing process and points where the main by-products are generated (Source: Fărcaș et al., 2017)

2.4.1 Spent grains

BSG is the by-product that is by far the biggest source of waste for breweries. A study for Interreg commissioned by the European Union looked at the Orval brewery and its BSG for the year 2018. Their annual beer production was 72,600 hl and the amount of BSG associated was 897.14 tons. With a quick calculation, we obtain a ratio of 1.236T (70–80% water) for every 100 hl of beer which represents a substantial amount of waste to dispose properly at an estimated €14.9/T worth. The amount of money this resource represents is probably what leads most of the breweries to find a way to reinsert this material back in the loop at the best price possible. (Interreg Bioval, 2019) Fărcaș et al. (2017) believe in converting the brewing waste into functional ingredients and see it as an area with huge potential and opportunities.

Composition and use

BSG is made out of six different materials that can be used as resources for a circular purpose. The main component accounting for 40% of the composition is cellulose and hemicellulose. It can be used to make second-generation biofuels and bio composite, as well as prebiotics and plastic additives. The second most represented component with 20%, is proteins that can serve as additives both for plastic and food, as well bio-based energy and fertilizer with the help of a biodigester. Lignin represents 15% and is a material used to manufacture bio-based materials or carbon nanotubes. (Gindl-Altmutter, et al., 2019) The remaining two identified components are lipids and polyphenols that are both accounting for 10% of the mix. The use for these two components concerns the chemistry sector and cosmetics goods in particular for which they play a role in the manufacturing formula. All of the aforementioned are contained in the solid residue obtained following the initial press of BSG. But the liquid that is obtained and accounts for 70% of the total mass, can be fermented to produce acetic acid and also probiotics through a yeast production. (Interreg Bioval, 2019)

2.4.2 Spent yeast and trub

The second major by-product is generated approximately in the range of 2 to 4 kg for every hl of beer, which becomes substantial once we look at a yearly production. (Hellborg & Piškur, 2009) The BSY, mostly made of liquid (85–90%) is difficult and expensive to handle. This is a concern for its management and often results in a concentration through increasing the dry matter up to 22–25%. (Mathias, de Mello, & Sérvulo, 2014) In terms of application, BSY can

be used in the food sector as well as for cosmetic products using the inner layer. (Araújo, et al., 2014) It's consumption for humans as a protein source is limited because of the increase level of uric acid in both blood and tissues caused by nucleic acids. Its source of high-quality proteins makes it a serious alternative for soy proteins, and the glutamic acid it contains can provide the food industry with a typical “umami” aroma. (Mathias, de Mello, & Sérvulo, 2014) The β -glucans also present in BSY have potential applications as food thickeners, fat replacers, dietary fibres and even more, for the food industry. (Zechner-Krpan et al., 2009) Since the direct use of spent hops as feed supplements is not desirable, they are mostly used as fertilizers and soil conditioner, or sent to animal feeding when mixed with spent grain. (Fărcaș et al., 2017)

2.5 Focus on energy consumption and circular solutions

“We simply must balance our demand for energy with our rapidly shrinking resources. By acting now, we can control our future instead of letting the future control us.”

Jimmy Carter, American President

Energy can be characterized by many different forms and can be generated from many different sources. The main method to generate a continuous and consistent input of energy is through the use of fossil fuels. This is one of the most linear and harming practices on our planet due to the CO₂ emissions associated. In the environmental context that is ours, the renewable energies are getting more popular and rightfully so, because they generate energy without releasing any particles in the air during their use. Just like for the water section, there are three aspects that require attention and that are crucial to a circular and sustainable use of energy. It all starts with the source of energy, that determines how clean the flow we're working with is. It's followed by the process optimization that will aim at reducing the total energy demand. Finally, it's about capturing the energy in order to reinsert it back in the loop because like Lavoisier said, “Nothing is lost, nothing is created, everything is transformed.”



The use of thermal energy in a brewery is considerable given the temperatures needed for some processes and the rapid changes that need to be operated. It is reported by Pettigrew et al. (2015) that beer brewing is energy intensive and that energy costs may constitute up to 8% of total production costs. Muster-Slawitsch et al. (2011) mentioned the brew house mashing, the wort preheating and the wort boiling as the most energy-intensive steps. But they also pointed out that the technology and operational parameters applied in the brew house, the brew volume, operating schedule and the ratio of brewing/packaging capacities influence the energy demand significantly. The study from Muster-Slawitsch et al. (2011) has shown an annual saving potential of over 5000 T of fossil CO₂ emissions derived from thermal energy supply of the three breweries considered in the study.

To lower the energy requirements, several solutions appeared to be working. A detailed work in thermal energy management elevating the sensibility of on-site workers and managers is one of them. What stands out from the study is the high potential for process optimization, heat integration and the integration of renewable energy. However, all production methods aren't

similar and it's therefore very hard to provide one "fits all" solution for the brewing process. Even though larger companies already benefit from energy efficiency improvements due to various and often costly technologies, there is still high potential in SMEs (Sturm et al., 2013).

2.5.1 Process optimization

The observations from Kubule et al. (2016) indicate that what greatly influences the energy consumption in small breweries, is the batch processes and the non-continuous production. The last point mentioned can eventually be solved by a circular practice which consists of sharing the machinery and can be interpreted as functionality economy.

During the brewing process, 93% of the heat losses are due to evaporation of water during wort boiling, and according to Kubule et al. (2016), reduction of water evaporation heat loss represents a huge potential to reduce the overall energy consumption. The implementation of additional heat exchangers could reduce thermal losses by recovering steam energy, and then using it to heat water in an accumulation tank, for example. This eventually results in recovering both the heat of water vaporization and the additional heat difference between tank water and steam, for an estimated payback of 1.1 years.

2.5.2 Heat integration

Hot water management has been identified by Muster-Slawitsch et al. (2011) as the key factor for integrating waste heat or new energy supply technologies. The hot water needs to be intelligently integrated, such as the heat available at high temperature needs to be reused at similar temperature and the exergy⁴ should not be destroyed by mixing with cold water. For one of the breweries they studied, 25% of the energy could be recovered with a payback of 1.5 years by reusing wastewater from the brew house CIP and the keg plant, waste heat from vapours at boiling start-ups and subcooling of steam condensate. This means it could potentially fuel itself with the remaining thermal needs being covered by the production of biogas from biogenic residues and wastewater. Figure 9 allows a visual representation of the economical savings the three aforementioned techniques offer.

⁴ The exergy parameter is defined as the temperature difference between the source and the sink.

Heat integration for process water generation	Possible energy savings kWh/week	Savings €/a	Payback years
Waste water brew house CIP	8,380	16,760	1.2
Vapours from boiling start-ups	10,821	20,850	0.9
Subcooling of steam condensate	11,173	23,826	0.8

Figure 9: Estimated payback period and savings (Source: Muster-Slawitsch et al. (2011))

The study and figure 10 below suggest that a large amount of waste heat can be recovered and it's already in application in most of the breweries. The wort cooler that preheats incoming fresh brewing water is well widespread along with mechanical and thermal vapour compression. The last one is the vapour condensation connected to a heat storage to preheat the wort before boiling. (Kunze, 2007) Additional practices are often performed, and it became a standard for brewers to reuse heat in any way, according to their brewing method and the machines at their disposal.

Waste sources		Potential for heat recovery				
Please state which heat sources are already included to heat recovery (yes = already included)						
		kWh/week	°C	HIGH	MEDIUM	LOW
waste heat contained in spent grain	no	26,315	75	x		
vapour losses at boiling start-ups	no	13,196	100	x		
vapour condensation	yes	97,890	100			
vapour condensate recovery	yes	14,759	95			
wort cooling	yes	182,139	95			
Waste water brew house CIP	no	9,164	70	x		
waste water bottle washer	no	10,475	30			x
waste water tunnel pasteurizer	no	not installed				
waste water CIP packaging	no	3,259	70		x	
waste water bottle rinser	no	385	70			x
waste water crate washer	no	1,862	40			x
waste water keg outside cleaning	no	663	30			x
waste water keg washing	no	21,672	70	x		
waste water CIP keg plant (pipings)	no	436	75			x
vapours from keg steaming	no	2,854	70		x	
waste heat cooling compressors (de-superheating)	no	17,676	110	x		
waste heat cooling compressors (condensation)	no	92,626	30			x
waste heat pressurized air compressors	no	16,657	70	x		
boiler flue gas	no	15,519	130	x		
other waste heat (e.g. from CHP) if applicable	no	not applicable				

Figure 10: List of heat sources and corresponding heat integration potential calculated for a specific brewing site in the Green Brewery Concept (Source: Muster-Slawitsch et al. (2011))

2.5.3 Integration of renewable energy

Biogas is not commonly referred to when the subject of renewable energy is brought to light, but in the case of breweries it has never been so logical to use this type of fuel produced from BSG. The study from Ortiz et al. (2019) shows that with the gasification of BSG, it is possible to cut down the fossil fuel bill by 22% when the syngas produced is used for heat generation.

The biogas can be generated with different methods that have their own efficiency and costs associated. The anaerobic digester (AD) outlined for water treatment represents a costly alternative but is more efficient than the rest when it's properly combined with a steam boiler or a combination of heat and power (CHP) system. (Sturm et al., 2013) A cheaper alternative would be the combination of a boiler or CHP with an absorption chiller, this time. If the initial investment is substantially a lot smaller and therefore more adapted to a small brewery, this also means a reduction of additional income by roughly 30%. A recent study from Siqueiros et al. (2019) also shows the results of anaerobic digestion being able to make up for 65% of a steam boiler energy requirement, while pointing out the mono digestion of hops not being ideal.

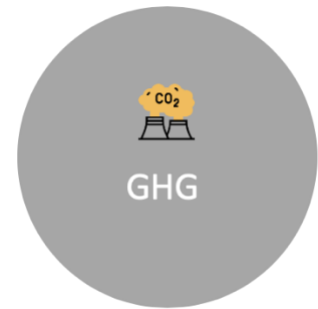
Muster-Slawitsch et al. (2011) outline that the main criteria highlighted for the use of renewables is the importance of exergetic considerations of the energy supply system. Because all the processes except conventional wort boiling runs below 100 °C and flat plates or vacuum tube collectors meet these temperature requirements well. The use of a solar energy system has proven to have a particularly large potential for breweries, especially in packaging and mashing, on a long-term perspective.

2.6 Focus on GHG emissions and circular solutions

“The pace of global warming is accelerating and the scale for the impact is devastating. The time for action is limited – we are approaching a tipping point beyond which the opportunity to reverse the damage of CO₂ emissions will disappear.”

Former Governor of New York

The CO₂ emissions are often used to refer to GHG. This paper does the same, alternating back and forth between the two. CO₂ emissions are commonly referred to when it comes to measuring the environmental performance because of the direct relation they have with the ozone layer depletion. Furthermore, this can also be applied to all the sectors of activity combined. It's estimated that around 4 kg of CO₂ is emitted for every hl of beer produced, and that the same quantity of beer requires 3 kg of CO₂ to be added for the fizzing. This means breweries have the potential to be carbon self-sufficient and even find a use for the surplus produced. The payback period is on average two or three years. (Atlas Copco, 2020) The beer production can be divided into different categories as far as CO₂ emissions are concerned. Packaging accounts for most of it with 40% of the total emissions being associated with this part of the process. Agriculture is second with 17% and in third, with the same proportion of 14%, are the brewing process and the distribution. Finally, the refrigeration and the malting account for 9% and 6% respectively. (Carlsberg group, 2019) The following section will look at how to tackle the CO₂ emissions and reduced them down as much as possible.



2.6.1 Upstream agriculture

Agriculture is amongst the most harmful sectors to the environment. This is nowadays not a secret for anyone who has looked into the subject or is aware of what's going on in terms of environmental degradation.

The scientists at the Rodale institute (2019) talked about a solution to climate change in their white paper, it's called organic regenerative agriculture. According to them, it has the potential to store enough carbon in the soil to reverse climate change. Even though beer is made out of 95% of water, it's also made from grain and hops which makes it an agricultural product. One well-known company for its environmental activism is aware of the agricultural impact of beer production and also believes in regenerative organic agriculture. This is why Patagonia

launched its very own beers with the long root Pale Ale and long root wit, both brewed from a new perennial grain called Kernza. (Patagonia provisions, 2020)

Kernza is a perennial grain which means that no yearly tilling is required. The absence of tilling avoids the usage of tractors that run on fossil fuels. It also lets the roots grow up to three metres deep into the ground. As a result, more carbon will be sequestered into the ground which will contribute to reducing the amount of emissions released into the atmosphere. In 2019, de Oliveira emphasized on the high evapotranspiration and net carbon uptake rates in comparison with other non-perennial grains. However, Vico and Brunsell (2018) performed a study that suggests the use of perennials only reduces yield variability, especially in dry land and rainfed agriculture. They also mention the lower average yield and water productivity when compared to annuals. In Belgium, Kernza is studied as a solution to fight droughts. The phenomenon has been hitting the country more frequently over the last years and causes damage. (Dumont, 2020)

It's generally thought that hops don't have a significant influence on the beer production process. It represents less than 1% of the solid entrants in the brewing process, and only one study took its cultivation into account to estimate the CO₂ emissions it generates. The impact in terms of GHG emissions was approximated by Cimini and Moresi (2015) at around 0.391 kg CO₂e for conventional hops.

2.6.2 Recovery

The CO₂ generated during the fermentation process can either be vented out or captured to be reused. From a circular economic point of view, it makes no doubt that this excess should be captured and reinserted back in the loop at some point. There are different systems available to operate that recovery and they will depend on the operation, the size and physical footprint of the brewery, as well as the purchase price of CO₂ in a given region. The recovery takes place during the fermentation process where the gas is collected, cleaned, dried and in some cases compressed for later use. (Brewers Association, 2013)

The advantages for CO₂ recovery are mainly the low operating cost, the lower environmental impact and the risk reduction related to the quality and supply of third-party gas. On the other hand, the disadvantages include a long return on investment period and an important initial investment. The limited production and the abundant supply of third-party offer are also part of the discouraging factors influencing the decision.

2.6.3 Transport

The transport of materials or finished products is mainly operated by engines running on fuel. This means that the CO₂ emissions associated depend on the distance travelled and the capacity of the vehicle. The distance is an independent variable that can just be shortened by sourcing and delivering more locally. The capacity, however, can be improved with modular packaging that allows for a more efficient storage, and lighter packaging that increases the capacity that can be carried and decreases the energy requirements to move the vehicle.

When most of the transportation is done through the road network, it's undeniable that the rail and waterway represent more sustainable options with a lesser impact on the environment.

2.7 Packaging

“If it can’t be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled, or composted, then it should be restricted, designed or removed from production.”

Pete Seeger, Folk Singer & Social Activist

Packaging accounts for a large proportion of the environmental impact of beer production. Especially when it’s not returned and reused. (Melon et al., 2012) Packaging is too often limited to the container of the beverage. This is the primary packaging we’re actually referring to. In most cases, there is a secondary and even a tertiary packaging. The secondary packaging holds a small quantity of individual containers together and can be represented by cartons or trays. Tertiary packaging is used to hold large quantities at the same time, usually for transportation using wooden pallets among others. For the primary packaging, there are three ways to condition a beer and they’re all commonly used and discussed about whether one would be better for the environment than the others. Kegs, glass bottles and cans really are at the core of all discussions when it comes to selecting the best option for our planet. The reason why everybody can’t agree on a common answer, it is because the answer differs depending on the factor we’re taking into consideration, as well as other variables specific to each situation. What everybody agree on, is that because of the major use of one-way packaging, there is a great potential for closing the loop in the brewing sector. The selection of the best solution is material and context dependent. (Niero & Hauschild, 2017) To analyse this critical part, all three packaging types will be studied separately, followed by a transversal opinion. Secondary and tertiary packaging won’t be studied in this paper.



2.7.1 Kegs

Beer kegs are usually made of stainless steel and sometimes aluminium or PET. The PET version is more recent and represent a lightweight and one-way alternative. Except for the PET version, the kegs are reusable up to 53 times according to Melon et al. (2012), which gives them a long-life duration. Once it reaches the end of life status, up to 99% of the stainless steel can be recycled and reinserted back into the loop. (Niero & Kalbar, 2019) The kegs are generally used for B2B because it requires a beer pump in order for the beer to be chilled and served on tap. A keg holds a substantial amount ranging from 20 L to 50 L. It’s true that more recently,

the domestic use of smaller kegs has been made possible and they're now available starting at 5 L.

2.7.2 Glass bottles

Glass bottles are the typical craft beer container and are therefore widely used. They make up for almost 50% of the total type of beverage in which beer is consumed. (Belgian Brewers, 2018) The glass bottles can be brown, green or made out of clear glass, even if the tinted glass is preferred for its opacity. Melon et al. (2012) estimated that a returnable glass bottle was reused approximately nine times, but there also exist lighter one-way glass bottles. The bottles are 100% recyclable and can be recycled endlessly without any loss of quality. Approximately 80% of recovered glass is turned into new bottles as fast as in 30 days. (Brewers Association, 2013)

2.7.3 Cans

Aluminium is known to be recycled endlessly while keeping untouched the properties that make it a great packaging. The fact that it's around twelve times lighter than glass bottles and at the same time very resistant is one of the key reason decision makers choose the cans over any other type of packaging. The opacity of the can is even better for beer because it shelters the beverage from oxidation in order to keep the taste and colour unchanged. (Brewers Association, 2013)

In 2012 it represented the second major packaging format (30%) at European level for beer, and nearly half of all cans produced in the EU were destined for the brewing sector. (Berkhout, et al., 2013)

Key actions to improve the environmental performances are to reduce the weight of the lid, to develop methods to separate the body from the lid and to investigate a closed-loop supply chain. Most importantly, the collection rate needs to be drastically improved. (Niero & Olsen, 2016)

2.7.4 Side by side

According to Niero & Kalbar (2019) and as far as the LCA indicators are taken into account, the stainless-steel keg is the least impactful for the environment compared to Aluminium cans and one-way glass bottles. But surprisingly, when the material reutilization score (MRS) and

material circularity indicator (MCI) are considered, it becomes the most impactful. The same study compared returnable glass bottles and aluminium cans circulating in India. The glass bottles seem to be better for the environment both from the LCA and CE indicator perspective. When the two types of indicators are combined, it appeared in the study that LCA indicators have a much stronger influence compared to the others. Still, it's essential that companies improve their circularity and assess it on a scale of absolute sustainability in order not to do it at the expenses of environmental performances. (Niero & Hauschild, 2017)

This first conclusion we can draw from this previous paragraph is that performance varies according to the factors taken to assess it. The difference between CE-related factors and environmental ones seems to be evident despite the environmental ones accounting for more when they're both combined. Overall, the study suggests that stainless steel kegs are the least impactful for the environment and glass bottles are the most adapted to circularity.

The results are further confirmed by other studies proving the positive influence on the environmental impacts of reusing beverages such as glass bottles and bigger packaging size. (Amienyo et al., 2013) (Detzel & Mönckert, 2009) This is essential in our study of circular practices, specific to the brewing sector.

Finally, an interesting figure shows the differences in electricity consumption by packaging type. The figure doesn't include cans, but here again, the supreme efficiency of kegs is once more demonstrated.

Electricity consumption shares for bottling equipment.

	Consumption for direct purpose, %	Consumption for cleaning or repairs, %	Other consumption, %
KEG filling	86.4	7.8	5.8
Glass bottling	3.4	84.8	11.8
Glass labelling	14.9	85.1	—
PET bottling	13.6	64.8	21.5
PET packaging	11.7	42.1	46.2 ^a

^a Consumption for packaging of manually bottled beer.

Figure 11: A. Kubule et al. / Journal of Cleaner Production 138 (2016) 275–286

2.7.5 Solutions

More sustainable packaging design include the development and selection of eco-friendly packaging design solutions, as well as the standardization of packaging. (Meherishi et al., 2018)

III. Part II

The second section is more practical than the first one and is dedicated to what came out of the semi-directive interviews as well as from the best practices found on the internet. Apart from the formulation of hypotheses preceding the content, the overall structure followed is similar to the first section in order to stay coherent and better absorb the content.

3.1 Exploratory research

The analysis of this section is built up on two different sources of information. On one hand, there is the public available general knowledge found on the internet, and on the other hand, the results coming straight from the semi-directive interviews conducted remotely.

Qualitative Analysis

The analysis was conducted on the basis of semi-directive interviews in which the interviewees were the central speaker of the conversation, while the interviewer stood behind. (Giannelloni & Vernet, 2015) The initial purpose was to meet people and interview them live with the help of an interview guide that I had prepared beforehand. The sanitary crisis due to Covid-19 had other plans and I had to adapt my method accordingly. In total, nine individuals were contacted and interviewed either via internet or by telephone. The conversation was recorded and transcribed when the agreement of the interviewee was given. When, they wouldn't agree on being recorded, I took notes that I restructured afterwards. Everything can be found in the appendix of this document. The choice for a qualitative analysis resides in the nature of its purpose that is *"to focus on naturally occurring, ordinary events in natural settings, so that we have a strong handle on what "real life" is like"*. (Miles, Huberman, & Saldana, 2014) This is exactly what was needed for this specific thesis and qualitative data has also often been advocated as best strategy for exploring a new area and for developing hypotheses. (Miles, Huberman, & Saldana, 2014)

Among the nine persons interviewed, there are five craft breweries namely: Brasserie La Binchoise, Brasserie Leopold 7, Brussels Beer Project, Brasserie Brunehaut, Brasserie des Légendes. All these breweries except for the first one, have stated environmental concerns, and therefore adopt a solution-oriented behaviour. One interview is with the co-founder and CEO of Ginette Beer, that is an organic beer brewed both at La Binchoise and Bellevue. A circular economy consultant that has extended knowledge in the brewing sector is also part of the

interviewees. These two different points of view offer the managerial perspective of a changing brand with a transition purpose, and the holistic approach of an external actor. Two additional interviewees have developed their own activity in the revaluation of BSG in the name of: Le Champignon de Bruxelles and BeerFood.

Two separated interview guides helped orientating the conversation both with the brewers and for the BSG revaluation. Besides that, an online survey was sent out after the interviews in order to collect the brewers' thoughts on a specific topic. Once the transcription of all the interviews was over and the answers from the questionnaire were gathered, the analysis was performed and later presented in the Part II following the same structure as in Part I.

3.2 Formulating hypotheses linked to the research questions and qualitative analysis

After collecting an important amount of knowledge and content on the subject, here is the formulation of the hypotheses. These are directly linked to the exploratory question, and carefully thought through with the following reasoning. The first one is a contextual hypothesis. The second one refers to the abundance of foreign literature – especially in the USA – that would suggest circular economy in Belgium is settled. The third one is more practical and aims at defining the targeted population for the final output of this paper. The fourth one seeks to know if the target population for the previous hypothesis is actually in need of such output. The hypotheses were elaborated on the basis of the content gathered in Part I of this work, as well as based on my general knowledge and understanding of the topic and the reality of its surrounding environment.

The first hypothesis regarding this section and the subsequent interviews is that the environmental concerns and the circular economy is not a priority for the craft brewers that are slowed down in this process, mostly because they think about being profitable and growing their business instead.

Then, according to the information gathered in the first part, it appears that the brewing sector is already ahead of the pack compared to other industries in terms of circularity and that it cannot but further improved.

The next hypothesis establishes the huge gap between industrial and craft brewers that can't compete in terms of circularity because of the size and financial differences.

The fourth and final hypothesis is formulated to state that brewers want to actually embrace the circular economy concept, but they don't have any external help to support them toward a transition of their business to a more circular approach of their activities, despite being willing to receive one.

The following exploratory research will enable me to assess and respond to these hypotheses in the Part III of this research paper.

3.3 Water usage

3.3.1 Source of water

The source of water used is essential in the brewing process. Representing a mere 95% of the beverage, it's not very surprising to hear the brewers interviewed talking about its importance in the production. There are two main trends resulting from the interviews and it's apparently a generality for Belgium if we stick to the brewers' word.



The first technique to source the water is to simply get it from the grid by connecting to the country's operated network. This results in a chlorine content but that evaporates rapidly since its evaporation temperature is lower than the temperature needed for the first process to take place. The price varies according to the consumption, which can result in expensive yearly bills for a brewery. However, the price includes the water treatment at an acceptable level of organic content, but more information on this will be detailed further in a dedicated paragraph.

The other technique consists of drilling and digging a well from where the water will be pumped back to the surface. The cost for such infrastructure often requires a sufficient production estimated by the owner of La Binchoise at 25.000 hl, in order for it to be amortized more easily. This solution offers a relative unlimited supply of water but requires energy as well as pre-use treatment depending on the intended use. The "Brasserie des Légendes" likes to use it "as it is" to brew its beers because of the taste and character it brings to the beverage. However, they need to use a softener as well as reverse osmosis in order to use it their steam boiler. This doesn't come for free and we can understand the brewer mentioning a sufficient amount of production required for using this source of water.

While water is known for its natural lifecycle, and therefore considered circular, brewers mostly use pure water in order to maintain consistency in their production. Doing so, they are also reducing to a minimum the risk of infection or contamination of their beverages destined for human consumption. A brewery located in San Francisco tried brewing out of greywater using a NASA water recycling technology. It ended up with surprisingly positive results in a blind taste test where people couldn't tell the difference with normal water beer. (The Guardian,

2016) The legal barriers to the use of such water for human consumption still remain to this day, one of the main barriers to seeing this type of project expanding to a bigger scale.

3.3.2 Optimizing the use

The common reference used to assess water consumption is the ratio of litres of water used to brew a litre of beer. It can range from a very good three times the amount of water, up to more than ten times the water requirements to brew a unit of beer. While it goes without saying that perfecting this ratio also rhymes with considerable economic gains, some brewers have made it a priority to lower it down as much as possible and become water experts for environmental purpose or any other worthy motive.

3.3.2.1 *Traditional methods*

A part of water consumption that doesn't seem that obvious when we think about beer production concerns the cleaning of the entire production line. The chemical reaction taking place during the brewing process is laying the ground for bacteria to develop. The machines as well as the entire place therefore requires a careful wash. A brewery that doesn't own a bottle washer will spend half of its water consumption cleaning the floor and for the first rinse of the tanks.

What breweries can do, is collecting rainwater in order to reuse it for the two aforementioned applications. This low-cost practice is easy to set up and for a rainy country like Belgium, can be very beneficial.

Another cleaning related application is the implementation of an automatic CIP system. This costly implementation proves to be extremely efficient with yearly savings of 450.000L of water for a brewery producing 20.000 hl per year. Alongside this 90% reduction of water presence in the cleaning solution, another 60% and 40% were saved regarding the use of chemical products and thermal energy respectively. With the subsidies of the Walloon government, this €150,000 investment can have a payback period of 5 years.

The cleaning that results from the strict hygiene standards is one of the main reasons the toxicity of its activities is often pointed out whenever the brewing sector is brought up. Alternative solutions exist and a brewery that is conscious of its impact that I interviewed chose an

environmentally friendly alternative to the traditional heavy polluting chemicals. At the Brunehaut brewery they opted for enzymes cleaning, which avoids the use of chemicals and reduce the water consumption. Although, it's important to note that this alternative is more expensive and less efficient than the chemical products, especially in very warm parts where sugars caramelize. Leopold 7 is another Belgian brewery that surprisingly enough has a cleaning technique that allows them to directly release their wastewater in the nearby river. They do not use any sequestering agent nor surfactant but instead, they use sodium that is then neutralized by natural acids and results in completely non-damaging compounds.

At the end of the production process, the beer needs to be put in a container that is generally a glass bottles, and this is called the bottle racking. If the bottle is new, it needs to be rinsed first and that is best done using a rinse block. Once they're filled, the bottles need to be rinsed and the water that is used to do so often gets reused for rinsing racks or hydrating the conveyor belts.

There is this debate among the brewers regarding the choice between one way or reusable glass bottles. The reason is that washing the bottles involves even more water consumption as well as chemicals. In a sector that is already targeted for the two mentions, it can be difficult to choose which decision is the best. This question will be further detailed in the packaging section but from a water consumption point of view, one way is better even if the water used to wash bottles can also be reused to clean the floor, which we said earlier was a major source of consumption.

3.3.2.2 Breakthrough innovations

A somewhat recent innovation developed by the giant AB InBev is said to successfully limit the need for water and energy used in the brewhouse. The "Simmer & Strip" technology simulates gas bubbles without the need to boil the liquid and get at a high temperature. This technique suited for industrial brewers has been made available for free to all the small breweries asking for it. (AB InBev, 2018)

"Leopold 7" brewery found a way to drastically reduce their water consumption by choosing not to put any label on their bottles but instead to use a screen-printing technique. This is a paint that is heavy metals-free and that washes away during the cleaning process without polluting the water. This uncommon technique seems to be very efficient.

3.3.3 On site treatment

The high organic content and the chemicals found in a brewery's wastewater are subject to norms that vary according to the geographical location and the agreement found with the local authorities. To illustrate that, all the breweries interviewed ended up telling a different story regarding the treatment of their wastewater. Some are allowed to release their water in a nearby water flow following very strict norms, while others use the public sewage to get rid of it. Despite the different levels of treatment, none of the breweries reuse their cleaned water and instead, prefer to dump it back into the environment.

3.3.3.1 Decantation

This process was found to be common for all breweries and generally takes place in massive twenty cubic metres settling tanks. The settling can be done in one or two steps, with the first step taking place in the first tank. This is where the real settling happens with the removal of all the materials in suspension. The second tank aims at clarifying the water a little more but isn't necessary, depending on the regulations you're forced to comply with.

3.3.3.2 Treatment plant

Only the brasserie des Légendes had its very own onsite treatment plant because the norms they have to respect are excessively tight and this requires the highest degree of attention. After the settling, the water is sent to the treatment plant where an underwater anaerobic treatment takes place as well as an aerobic one on the surface. The water takes up to two months to be cleaned and then returns to the rivers downstream. The maintenance and mud evacuation cost the brewery around 10 to 15.000€ a year but they have no other choice. The mud evacuated is actually a resource that is used to produce biogas by another company. The rest of the brewers either pay a small yearly fee that they arrange with the local treatment plant or, have the treatment taken care of if they are connected to the grid.

Even if they invested in the necessary infrastructure, it seems like the small Belgian breweries we interviewed are not keen on reusing the water they purified and therefore closing the water loop onsite. It seems to be the case as well in the United States, but breweries over there have taken the matter at hands by exploring the opportunity to generate power during the purifying process. A large American brewery called "New Belgium" invested in an onsite anaerobic

digester resulting in a water-cleaning process as well as a methane production, that is then converted into electricity and used again in the brewing process. (University of Washington, 2014) Such investment can't be supported by any brewery, and this is where Cambrian innovations stepped up. They launched the construction of a modular onsite treatment plant housed in a container and that can be scaled up as the production evolves. The same reaction is taking place but the format of the offer that the American start up is selling is what differentiates them from a conventional onsite plant. The circular design was then further completed with the addition of a financial payment system. It is based on the functionality economy and clients only pay for the water cleaning service and the energy provided by the reaction. (The Guardian , 2016)

3.3.3.3 Other techniques

There are numerous ways to purify water and that includes natural solutions. Since the planet has found ways to purify the water for so long now, the methods are vastly mimicking the planet, also known as bio mimicry. The natural purification cycle is where aquaponics founds its origin and inspiration. Brewer monks in the Netherlands decided to explore this natural alternative and reached out to a specific company in order to help them doing just that. The principles are simple yet, they sound surprisingly ingenious. The system combines the purification of water alongside the growing of plants and vegetables and sometimes the breeding of fishes. The nutrient-rich water is just what plants needs to grow faster and absorbing that, purifies the water. On top of that, the bacteria in the water contribute even more to purifying the water. (De Koningshoeven brewery, 2020)

This is also what the circular Italian farm “Radici a Moncalieri” (2019) chose to do with their wastewater. They use it to grow salads at a fast pace, as well as a breeding of fishes that help purifying the water by eating the nutrients and feed the plants with their excrements.

To close this section on the water use, here is an example of a circular practice that showcases Eco conception from a Belgian cleaning brand. Interestingly enough, “Ecover” found a way to create soap out of brewing waste. They state that at least 25% of the soap's ingredients is coming from the beer production by-products, mainly water and ethanol.

3.4 Solid waste

The main solid waste resulting from the brewing process are the BSG and BSY. Both of them account for the majority of the by-products generated by the production process. This part will describe the actual revaluation methods performed by the farmers, as well as evaluate the existing alternatives.



3.4.1 A second life for BSG

It's nowadays obvious for most of the breweries that their BSG are valuable and that they should enhance their stock by keeping it in the loop. The numerous components that made up this product allow to explore so many different ways to use it. But given all the possibilities associated, it's important to somewhat establish an order of priority since all the applications don't have the same added value. If a brewer gets to choose from at least two options, he should know how and what to prioritize. The Lansink ladders⁵ seems to be once again, accurate enough to compare and assess the different options. Talking about options, all brewers don't have the same constraints and opportunities so let's take a look at that.

Rural and urban breweries

Farmers are trying to feed a large number of animals at the lowest-cost possible. This makes them huge fans of BSG, that just fits the requirements of highly nutritive food at a low cost. This is what pushes them to go and get themselves the precious feedstock from the close by breweries. At the same time, they are getting the brewers rid of the spent grains and rewarding them financially for the materials provided. This is exactly what the majority of the breweries interviewed chose to do because it represents the easiest option, logistics wise. The farmer comes when the wort is extracted and picks it up right away. Doing so, the brewery avoids dedicating a storage room while at the same time avoids having to support the odour coming from it. All the breweries that opted for the cattle feed option are rural breweries that have it very easy to get in contact with local farmers.

⁵ See *Introduction to circular economy* in this document for more information.

The breweries located close to the city centres don't have the same easiness of access to a nearby farmer. Nor often do they have a sufficient production to benefit from economies of scale and pay for the transport of their organic matter. They're therefore looking for high added-value activities to sell their BSG to and make the most out of their spent resource. This is where business opportunities emerge for other industries to fill the gap and close the loop for a circular economy.

Now that the difference between urban and rural breweries has been pointed out, we can start looking at the applications and try to compare them according to the Lansink ladder.

3.4.1.2 Back to Lansink with the four "F rules"

The ladder usually works in accordance with the "R rule", but there is an adaptation of the ladder for the BSG revaluation. The environmental consultant Vincent Vanderveken is specialized in circular economy, and he introduced me to the "4F rule", destined for BSG. The 4F rules are usually used in the bio economy sector. They are also mentioned as guidelines to follow in anticipation to the rising population and the expected land use efficiency, to sustain a large number of individuals. (The forests dialogue , 2012) (European Commission, 2019) The rule states that the activities should be prioritized in this order: food, feed, fibre and fuel.

Food

The food is understood here as food for human consumption, and therefore as a substitute to conventional ways of feeding ourselves, which is one of our physiological needs. There are many human food alternatives made from the use of BSG and here is a summary of most of them.

The humid BSG often need to be dried in order to be used and this requires energy, while releasing odours and carbon dioxide. One way to avoid it and use the BSG "as it is", was found and developed by the "Champignon de Bruxelles". The Belgian start up located in the basement of the centre of Brussels, grows shiitake mushrooms and others types, from BSG and wood. They either buy the BSG at €30/T or receive it for free from a nearby brewery in order to use it as a resource. The reason they can receive it is because brewers need to get rid of the BSG as organic waste, and this represents a costly solution. A market gardener that needs BSG as a source of feeding will come and pick it up from the brewery and will drop some by the

mushrooms production site, to give them the percentage they need for the mushroom culture and keep the rest for himself. Once the mushrooms have grown and the substrate is of no use anymore, they're given to the same market gardener in order to spread it over his soil as compost. This solution only requires little human labour and the appropriate humid and chilled growing environment, which makes it a high added value activity and one to prioritize.

Mushrooms are hardly shared with friends and consumed around a refreshing beer like snacks are. This is why many have gone to explore this alternative like “regrained” in the USA, “brewsticks” in France and more locally, “BeerFood” in Belgium. The Belgian producer told me about the workforce and human labour required to get to the final product and he pointed it out as the main constraint. They had to rethink their production process towards a concentrated production every, one to two months through an industrial producer in order to lower down their costs. The final product is comparatively more expensive than the range of traditional snacks and the taxes every actor of the supply chain takes is proportional which makes it tough for the end consumers to understand such a gap. Hopefully, they target a public that is already aware and understands the reality behind the product. The next step will be to widen their audience. This high added value activity still finds it hard to justify the high price tag due to the labour involved but surely represent an opportunity at an industrial level to involve circular economy.

Those who consider beer as a complete meal will probably be thrilled to learn that they can have it for breakfast. “Instock” is a Dutch company producing granola from the BSG they collect. Once the BSG is dried and associated with the right ingredients, it suddenly becomes a breakfast very rich in natural fibres. (Instock, 2020) And if they prefer to skip breakfast, a French entrepreneur decided to make her own ramen noodles from the precious spent grains. After drying them and grinding then in flour, the noodles can be produced when adding the appropriate ingredients. (Ramen tes drêches, 2020)

Finally, the BBP, whose BSG are destined for local bakeries making bread out of it, invested €13,000 in an oven and also in an electric mill. They sell their dry BSG unground or as flour, for €6 and €8/kg respectively. This allows them to break even on the human labour and investment payback. Overall, the general food consumption of BSG requires the BSG to be dried and grinded into nutrient-rich flour that can be used for many applications. This means that a dryer and a grinder are becoming essential to an efficient revaluation of the materials.

Feed

This other revaluation method is probably the most commonly used with cattle feed and rightfully so. Indeed, the simplicity of this alternative in terms of logistics is what drives most of the brewers to partner with a local farmer that will use the spent grain to feed his cattle. This doesn't require any transformation of the grains and they can be used in their wet form. However, the amount of energy, water and food needed to feed animals and the nutritive value of the final product has already been proved extremely inefficient and is considered a waste of resources by many. Despite the proof being exposed, people continue to eat meat and dairy products because it's deeply rooted in our culture.

Another type of feeding that is certainly less obvious than the previous solutions is what the “Brunehaut” brewery decided to explore. They chose to sell their BSG for €12.5/T to “Pur Ver” that uses the material for vermicomposting. The brewery chose this solution for its BSG in order to stay coherent with their core values. Being the only producer of organic BSG in the area, it didn't make sense to sell this precious material to a conventional farmer that would just mix it with the rest of the cattle feed. Composting is also an alternative for BSG, but it requires space and emits carbon dioxide as well as smelly odours.

Finally, I learned that a recipe had been developed by and for homebrewers mostly, in order to bake dog food with the leftovers from their home brew. The BSG are once again dried and mixed with other ingredients to serve the animal feeding purpose. This solution, however, has no proof of industrial application and remains a domestic practice not much widespread.

Fibre

The use of fibre-rich spent grains is less common, but the real-life applications found represent very attractive alternatives to other harming practices, or at least very linear ones. This is mostly the case of single-use plastics that have been the target to many criticisms over the past years due to the negative impact they have for such a small period of use. “Glass & More” is a student project born in Belgium where the idea was to replace single use plastic drinking cups with reusable cups made out of spent grains. (Glass & More, 2019) They imagined a cup produced with a 3D printer and that would use the biodegradable “buzzed” material developed by “3Dom” in order to print. (Primante 3D, 2015) Another type of single-use material concerns dishes and cutlery for eventual parties with plenty of guests, or getaway lunch in nature where

traditional heavy tableware is not practical. “Do Eat” invented the edible tableware of food containers that comes in very handy for takeaway services. (Do eat, 2015)

Finally, a study from Boulder University in the Colorado, USA proved that window insulating could be manufactured and that a part of the formula includes BSG. They developed an aerogel that possesses impressive isolating characteristics, but the colour proves to be an issue. This is where they teamed up with local breweries, to use the cellulose left from the brewing process to mitigate the issue and therefore allow light to pass through but not heat. (Spirits hunter , 2019)

Fuel

The remaining and last type of BSG revaluation concerns the production of raw power. Leftover food is known to release methane while it decomposes, and this can be a source of power using anaerobic digestion. The process is similar to the one mentioned for the onsite water treatment plant by American New Belgium brewery. Such infrastructure represents an important investment to recover gas, and further requires the machinery to be adapted to the use of the natural fuel. All in all, this type of investment is definitely reserved for high capacity breweries. Indeed, one brewery interviewed had an energy audit realized for them, and it came out that in order to be profitable and to produce its own energy out of BSG, it would have to produce one ton of the by-product per day in order to feed a micro bio methanation process.

3.4.2 What happens to the BSY?

The second most important by-product of the brewing process is the spent yeast collected after the fermentation. The majority of the brewers I interviewed didn’t have any particular use for it, nor didn’t seem to be interested in finding any revaluation solution. They all either leave the spent yeast running with wastewater to get treated or mix it with BSG in order for it to be edible by animals. Only the Brunehaut brewery mentioned its will to find a solution for BSY and even contacted a company producing insect food out of yeast but with no answer. However, the BBP⁶ is currently experimenting the production of beer with spontaneous yeast that can apparently be reused for another beer production-related reaction afterwards.

After some research, it appeared that BSY can be sold as a dietary supplement because it is high in nutrients. The deactivated yeast contains mainly proteins and carbohydrates as well as vitamins from the B group. (L'Express, 2017) The nutritious but dead bodies represent the perfect ingredient for making pollen substitute for feeding bees. (HoneyBeeSuite, 2020)

Bees and beer seem to have actually more in common than three letters out of four composing their word. The circular farm “Radici a Moncalieri” found out that spent hops can be recovered and used to fight a major bee sickness called “varroa”. (Radici a Moncalieri, 2019)

The Australians are very fond of “Vegemite” which is a spread they put on hot toasts or just bread. In Britain, where it was first invented, it’s called “Marmite” and the spread that is as successful as in Australia, is actually made out of a brewing by-product, yeast extract. This is actually how the German scientist Justus von Liebig came up with the spread when he discovered brewers’ spent yeast could be concentrated and eaten. (The spruce eats, 2019) Despite trying to reach out to them, I was unable to get any return on if they were actually using spent yeast to manufacture the products or if they had changed the original recipe.

3.4.3 Other by-products

It’s very rare for craft brewers to offer non-alcoholic beverages. The reality is that this range of products is booming, and industrial breweries are trying to keep up with the increasing demand that is expected to increase by 7.5% from 2016 to 2024. (Global Market Insights , 2019) The Belgian giant AB InBev also joined in on this new segment and as a result started witnessing every week 75.000l of alcohol being evacuated from the site. Hoping to find a better alternative for this resource, they partnered with a Belgian manufacturer of biological fuels to produce 18 l of fuel with 100 l of alcohol. The beer manufacturer is no stranger to the revaluation of residual alcohol, since in Australia they’re already producing high quality vinegar from it. (La Libre, 2019)

Regarding the same issue, the BBP came up a solution of their own and developed a non-alcoholic beverage called “Pico Bello” that doesn’t require alcohol extraction. This means they’re able to keep it a craft practice and to maximize their use of water by using yeast that barely eats sugar and therefore barely transforms it into alcohol.

3.5 Energy consumption

The consumption of energy is associated with a negative impact on the environment because most of the energy available is produced using fossil fuels. This allows a stable and continuous flow of energy at a relatively affordable cost compared to other solutions. Like for the other sections, the following paragraphs will take a look at solutions brewers have come up with, to reduce the need for energy by optimizing its use, as well as to source from cleaner energy sources.



3.5.1 Machinery and source

Running a brewery involves energy requirements at all sorts of different levels. I decided to split these categories into two, on the basis of the data collected during the interviews.

3.5.1.1 *Brewing process*

The entirety of the brewers interviewed use a steam boiler for the specific purpose of heating during the brewing process. The boiler runs on fuel oil, known to be particularly harming for the environment. When confronted to this fact, half of the owners mentioned studying the possibility of installing a wood-fired boiler but had to resign themselves because of a too expensive price tag, up to three times superior to an oil-fired boiler. One brewery that I couldn't get in contact with, managed to get the support of a local cooperative to make use of the functionality economy and power itself with natural wood. They only need to pay for the heat they use, and the rest of their fee includes the maintenance as well as a financial purchasing plan for the boiler. In other words, they pay the heating service instead of the equipment, and this is said by the cooperative to be cost-effective on the medium term. (Le Soir, 2019)

3.5.1.2 *Building and offices*

This part of the energy requirements of the breweries is often less energy intensive and can be partially taken in charge with fewer harming technologies. All of the breweries interviewed are, or are going to be equipped with solar panels, with one of them even equipped with thermal ones. The capacity of the roof allows them to cover up 80% of their electricity requirement depending on the size of the roof and on the production capacity. Some breweries get their

energy from a “greener” source for the rest of the energy requirements like a biomass boiler, for example. The brasserie des Légendes even recovers the energy from the fermentation tanks to warm up the offices, the warm rooms as well as a bottle warmer before bottling. They invested massively, around 300–400.000€ with the help of the region, to recover the energy by regulating the temperature instead of releasing it outside with unit heaters. Without taking the brewing into consideration, it allows them to satisfy up to 80% of their energy needs and have estimated a return on investment of five years.

3.5.2 Recovery and optimization

The aforementioned example of energy recovery from the fermenter is definitely nice to hear but far more difficult to put into practice taking into consideration the investment it involves. However, an energy practice that every brewer is now doing and at a low cost, is recovering energy during the cooling before the guard. All the brewers use a buffer tank in order to heat the next brew.

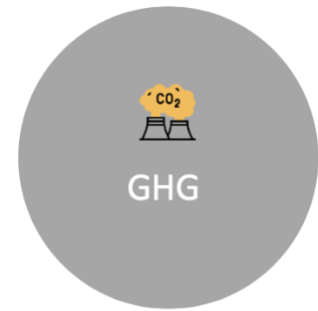
Another interesting implementation that Leopold 7 and the brasserie des Légendes put in practice, is the recovery of steam. A system of tube heat exchangers enables to pick up around 500L of clean water at 85°C in a hot water tarp, resulting in a chimneyless roof.

Automation

Just like the use of an automatic CIP system for cleaning the brewery, the implementation of an automated heating system brings along many optimizations and savings. A brewery decided to implement three main automations that allows them to decrease their energy requirements. The brewhouse software controls water flow between hot and cold tarp as well as the transfers inside the brewhouse. The boiler is automated and regulates itself the desired temperature. Finally, the controller handles the energy recovery system on its own, which means it automatically opens up the valves for the water to flow and the heat to be transferred.

3.6 GHG emissions

Earlier on, we saw that the two most impactful activities releasing carbon dioxide in the beer supply chain are the agriculture and packaging. There is a dedicated section for packaging, but this section will take a look at if and how breweries capture CO₂ coming out of the brewing process, as well as how they mitigate the impact of barley cultivation.



3.6.1 Recovery and reuse

When I brought up the subject of CO₂ emissions with the brewers, it was obvious that it's not a primary issue. This doesn't represent a major concern for them, and a brewer told me his activities only produced 2.4 T of carbon dioxide yearly. This is mainly used for kegs filling and such a GHG capture system requires sufficient quantities of production in order to invest. According to one of them, from 200,000 hl on, it becomes interesting with a couple of pilot projects started at 100,000 hl. Furthermore, since most of the Belgian brewers are characterized as craft brewers, they actually don't need CO₂ for bottling their beverages because they prefer the second fermentation in the bottle, that gives the fizz and the distinctive taste to the beer.

However, Leopold 7 brewery got involved in a three-year project with the UCLouvain to study the possibility of recovering CO₂ in order to grow algae destined for dietary supplements. This involves the installing of tubes on the roof that can house the growth of the algae but they're only in the testing phase which is why no more information is available.

3.6.2 Capturing carbon dioxide unknowingly

Whether this decision is purely economic or just common sense in trying to avoid food waste, using discarded food to make a new product is a concept known as Eco conception and many brewers have started using discarded bread to make fresh beer out of it.

The "Brussels Beer Project" started exploring this ancient brewing technique when they found out that 12% of Brussels's food waste was actually bread. (Food and Wine , 2015) They decided to partner with the supermarket "Delhaize" that would reach out from their unsold stock to provide them the bread they need to make the "Babylone". For the same reasons, "Ginette"

partnered with “Le Pain Quotidien” in order to recover the unsold bread and sell beer partially made out of it, directly to the restaurant’s customers. The master brewer of “La Binchoise” brewery, where the “Ginette Old Bread” is brewed told me that discarded bread represents a significant amount of the quantity of ingredients found in the beer recipe. While the exact proportion remains a secret well kept, he told me that malt was still needed for the chemical reaction to take place, but that using bread allows to combat food waste, save on malt and give the beer a singular taste.

Other similar projects have been developed by several breweries which are not worth repeating. However, “Instock” in the Netherlands has an innovative approach. Together, with an Amsterdam-based brewery, they started brewing not only from discarded bread but also reusing unsold potatoes. They rescue a part of the 340 million kg of potatoes that go to waste each year to come up with the “Pieper bier”. (Instock , 2020)

Agricultural focus

The “Brasserie des Légendes” is one of the breweries interviewed and their motto is the following: “De la terre au verre”. This means from the ground to the cup and it refers to their core values of using Belgian only, certified barley. Most of the malt Belgian brewers buy, comes from Belgian maltings but the maltings actually source most of their grains from foreign countries. This is where the aforementioned brewery decided to step up and produce its own malt, in the family farm and in partnership with other local farms. This means that the trucks delivering the malt do not travel more than 50 km, cutting down on the CO2 emissions.

Finally, the last example to offset CO2 emissions associated with the barley culture, concerns Patagonia. The worldwide famous clothing company known for its environmental activism, has launched “Patagonia Provisions” whose goal is to tackle the negative impacts created by the agriculture. As part of this programme, they produced a beer called “the long root”, because of the malt they’re using to brew the beer. The perennial grain called Kernza is particularly suited for regenerative agriculture. It uses less water and sequester more carbon out of the atmosphere than regular wheat. (Patagonia provisions, 2020)

3.7 Packaging

The biggest impact for the brewing supply chain is packaging. Luckily enough for this thesis's purpose, it's concerns products which means circular economy practises can more easily be applied to it. For all of the breweries included in the panel, the question of packaging takes different paths and leads ultimately to different answers. Overall, it's fair to say that when there is a focus other than the economic one, it's directed at the primary type of packaging.



3.7.1 Primary

As far as the interviews of this paper go, the debate between bottles and cans is won by glass bottles. This is mainly due to the fact that they're all craft brewers which implies that the glass bottles are necessary for the second fermentation as well as represent the craft symbol.

3.7.1.1 Kegs

Of course, kegs are used by all the breweries but here again, some choose to opt for one-way kegs when other use steel ones according to the type of use. For the national consumption, the majority uses stainless steel and only Leopold 7 decided to transport beer in plastic kegs produced by "Eco draft" with a removable and independent inside pocket. This means the outer layer gets reused and it offers better conservation performances. The pollution associated with stainless steel kegs washing as well as the necessity to buy upfront a large quantity of kegs to have a sufficient fleet and no bottleneck, were the decisive factors.

The export and the long-distance associated with it, is the reason why the brewers choose to pack with one-way kegs that are much lighter and don't bring any logistics trouble. The company "Keykeg" was mentioned as part of the suppliers that sell the PET kegs.

3.7.1.2 Glass bottles

The container of choice for all the craft brewers but not only, is broken down into two variants that once again are a favoured source of debate. Should the bottles be reused or not? From the answers collected, it seems like they should and the use of a caution to ensure the return is well set up in the breweries. The returnable option also includes the requirement for a bottle washer,

valued around €150,000 or in the case of “La Binchoise”, a selling contract to other breweries wishing to buy the dirty bottles.

This brewery is also not very keen on using returnable bottles for several reasons that are:

- The bottles “fleet” requirements in order to have enough bottles to fill the beer while the rest is in circulation, making its way back to the brewery. This is a considerable investment and for one of the breweries producing 3,000 hl a year, the requirements are an astonishing 500,000 bottles.
- The pollution associated with the cleaning process. Whether it is related to the water consumption or the chemicals required. It is true that this process is energy intensive.
- The glass needs from the glassware to produce brand-new bottles. The bottle manufacturers need a sufficient amount estimated at 80%, of recycled glass in order to run the ovens used to make the new bottles.

An interesting lead to explore and probably follow is located in the Netherlands where in the '80s, the “Nederlandse Brouwers” developed a standard returnable glass bottle of high quality that would be shared among the brewers of the country. They established well-thought rules for the brewers wishing to join the movement and this allowed a circularity operating at a greater scale. (Nederlandse brouwers, 2020)

Industrial Innovations

The size and eventually the financial power that comes with it, allow industrial brewers and market leaders like Carlsberg to be ahead of competition by allocating resources to their R&D department. The “Carlsberg circular community” is a proof of the dedication the company shows towards changing the rules of the packaging games of the beer supply chain. They believe in a loop that includes the optimization of the inputs, as well as the engagement of the retailers and customers, and finally the end of life protocol. (We-economy, 2020)

They’ve for example developed the first of the concepts with the creation of a paper bottle prototype made out of sustainably sourced wood fibres. The prototype is broken down into two different versions, one with a thin recycled PET layer and the other with 100% bio-based PEF polymer film barrier. (Carlsberg group, 2019)

3.7.1.3 Cans

Only the BBP and Leopold 7 are using cans as a container. The latter set an ambitious target for themselves that is a maximum of 185 gr of CO₂ emissions for the transport of 33 cl of beer. The reasoning behind this concerns their exportation of beer that can therefore only reach Paris when it's contained in a glass bottle but can go as far as Bordeaux contained in cans because of the significant weight difference. The BBP's mindset is more foreign and future driven. Their inspiration comes from outside Belgium, from the USA for example where cans have become mainstream, even for craft brewers. *"The can is the future and we're even thinking of having a 100% can packaging line for our new brewery."* This statement from the BBP interviewee says it all, and on top the conservation, lightweight and modular characteristics, they also believe cans allow for more creativity on the design.

It's true that cans have undeniable performing characteristics, but they also carry a fake ecological container image. "La boucle verte" is a French start-up that set out to tackle can-recycling in their native city, Toulouse. After three years they had to stop their non-profitable business and with that came the conclusions they were able to take back. The 60% recycling rates announced for French aluminium cans actually means 40% of cans are buried or landfilled, 22% used for roads under layers and 38% are recycled as secondary raw materials. The 38% apparently can't be reused to make cans again because aluminium coming from French sorting centres is unusable according to recycling engineers. The 100% recycled ratio can't even theoretically be reached because of the different materials composing the can. The thin internal plastic layer and the external varnish make it a non-100% metal product that would be otherwise easier to recycle. On top of that, heat is lost when melting metal which, once more proves the recycling ratio is actually just an illusion. (La Boucle Verte, 2020)

With that pessimistic overview of the recycling cans system, also came their deep thoughts on the system itself and the false hope they sold to people, removing some of their guilt concerning their consumption practice. They believe that the promotion and development of the recycling industry as a whole, is driving people towards even more and guilt-free consumption. The solutions must be found upstream and in the conception of our consumption system. (La Boucle Verte, 2020)

3.7.2 Secondary

There is no room for secondary packaging among the breweries I asked my questions to. The use of beer crates is applied to everybody and that's where it ends. "Ginette" is the only brand using a secondary packaging to sell its bottled beers and it's a four-pack paper one out of recycled cardboard. The same cardboard is used for a six-pack of cans of the same brand.

Once again, the industrial sector is a step ahead with the example of Carlsberg's snap pack, that holds six cans of beer using glue instead of plastic. (Carlsberg group, 2019) One of AB InBev's most famous brand Corona, launched in 2018 a 100% plastic-free fibre six-pack ring from plant-based biodegradable fibres. The fibres even consist in part of spent grains and other compostable materials. (Weather, 2018)

3.8 Additional information

3.8.1 Industrial ecology

When asked about potential synergies, or just during the course of conversation, two brewers mentioned both past and potential synergies. The owner of the "Brunehaut" brewery talked about the historic combination of breweries and carbonated beverage plants. The latter would recover and use the excess CO₂ from the brewing process for its own production.

Another use for CO₂ recovery was brought up by the master brewer of "La Binchoise" who said that in the case of an eco-zoning, a brewery could be located next to a tree nursery in order to use the carbon dioxide to help trees and plants grow.

3.8.2 Circular farm

The previous example connects the brewing process with the growth of natural elements, and this is exactly the mindset of the founders and workers at the circular farm in northern Italy. They developed a brewing activity inside their farm and are reusing almost everything from the process. The wastewater is used for aquaponics in the greenhouse of the farm, the yeast is apparently reused to make beer and bread, and they even found that hops could be used for bees in the fight against a serious disease called "varroa". The farm is a complete circle that follows the Lansink principles as guidelines. When a product can be reused, they make sure it's done. If the reuse opportunity isn't available, they will want to transform the product in order to find

a new use for it, and finally if it's not possible they will use it to feed the animals or for composting. (Radici a Moncalieri, 2019)

3.8.3 Decreasing beer consumption

Another way to decrease the impact of an activity can also be to slow down its growth and question ourselves about the actual worldwide consumption. As part as our non-physiological needs, drinking beer is above all else a refreshing beverage partly contributing to our social interactions. It's therefore not vital to us and it has been proved several times to have negative side effects on our general health. The effects on the liver and the brain are the most important and shouldn't be taken lightly. (Jéquier, 1999) However, some positive health benefits associated with a moderate consumption of beer have also been stated, like a cholesterol reduction, diseases prevention due to the antioxidant properties of alcohol, reduced risk of rheumatoid arthritis. (Norman, Biff, & Margo, 2000) Despite the health benefits, the general feeling about beer is that its intake is generally harming your body, and it has a lot to do with the amount of intake.

Since it has a non-neglectable impact on the planet and on our bodies, why do we keep drinking beer? And why is our consumption even increasing over the last twenty years? (Statista, 2019) A solution to diminish the environmental impacts of beer would then be to limit our production. Just like it happened globally during the COVID-19 pandemic, a shutdown of the activities has an immediate effect on the environment. It's very likely that an overall reduction of the activities would result in a reduction of the environmental impacts, but there are obviously other dimensions associated with beer production. The amount of people employed in this sector and the revenue it generates are too important to be ignored and to force them to step down. Moreover, the worldwide need and demand from the world population for beer is also too strong not to be met. It would require a coordinated inter-governmental action, backed by the environmental and health factors, to try to drive the consumption down.

IV. Part III

This section of the thesis will address the three hypotheses formulated in anticipation to the exploratory research executed in part II. Answers will be provided on the basis of the “on-the-field data” presented in the previous section of this paper.

4.1 Hypothesis 1

The first hypothesis regarding this section and the subsequent interviews is that the environmental concerns and the circular economy is not a priority for the craft brewers that are slowed down in this process, mostly because they think about being profitable and growing their business instead.

The way I see this hypothesis is split in two parts, with the environmental concerns on one side, and the actual reasons slowing them down on going toward more circularity.

I will start addressing the environmental concerns of craft brewers on the basis of what I heard and saw. It's important to note that the panel of craft brewers I chose to interview are relatively prone to the environmental impact of their activities. This means that apart from La Binchoise, all of the beer brands interviewed do have environmental concerns that they identified and acknowledge and ultimately, try to address. Whether it's a dedicated area on their website, integrated in their core values, transferred through dialogue or all the mentions together.

There exist many different environmental concerns, and each concern can be solved in different ways. Leopold 7 set a particular focus on water stewardship to become a reference in the area, while the brasserie des Légendes is known for its local ingredients sourcing. Among the innovative solutions found by the interviewees, the Brunehaut brewery decided to switch to enzyme cleaning instead of using chemicals. It turns out that this is actually more expensive and less efficient than the previous and polluting technique used. The local barley sourcing of the brasserie des Légendes also bears a higher cost than imported and mainstream barley. The motive for such implementations is, of course, not economic but what is it really then?

In the case of local barley at the brasserie des Légendes, or for the Brussels beer project's “Babylone”, it represents a marketing investment in addition to being an environmentally friendly practice. From being barely profitable, to even representing a source of cost to the

brewery, the decisions allowed them to either directly promote the new aspect of their activity or to benefit from external publicity through press articles mentioning their business.

For the brasserie des Légendes, the implementation of such practices also represents a valuable asset in a public subsidy file. Especially today, when the environment is at the centre of public concerns and debate, the image carried by financing organizations is essential. Ultimately, the goal is to become more efficient and benefit from economic gains on the long-term period. This is why the majority of the breweries invested in new equipment and recovering techniques. However, these investments come at a cost, but does it slow down the adoption decision? There are two distinct examples that are relevant among the information collected when I think about the financial aspect slowing down circular practices.

The first one is the most obvious one since all the brewers I asked the question to have exactly the same opinion about it and it has to do with the way they produce heat for the brewing process. They all use oil-fired boilers because wooden ones are simply three times more expensive and completely out of budget. To their regret, the economic factor took over and they all decided to use oil as their source of fuel. However, a new concept that is part of the CE and called the functionality economy, appears to be an appropriate solution to this very specific heating source problem. The Bertinchamps brewery decided to do so and went into business with a cooperative valorizing local wood resources named Coopeos, that would sell heat instead of a boiler. (Le Soir, 2019) Similarly, in the USA, the start-up Cambrian innovations launched a financing programme similar to Coopeos' but this time for wastewater treatment and electricity generation associated with it. (The Guardian, 2016)

The other element slowing circularity down concerns the packaging and the choice for reusable containers. The circular option that uses reusable glass bottles requires on top of added logistics, a bottle washer and a sufficient number of bottles to have enough in circulation and for bottling. This isn't an insignificant investment, even more so for a small brewery. This is also true for stainless steel kegs valued at around €70, often associated with a €20 caution only. Which means in the case of exportation and/or no return that a lot of money is lost doing things this way. (de Mees, 2008)

To conclude this first hypothesis, I would say that indeed for most craft breweries, the economic factor still rules the game and that it does slow down breweries in their transition, especially for impactful practices often associated with a higher price tag.

The financial aspect associated with circular economy implementations is slowing craft brewers down but new financing models part of circular economy present alternatives.

4.2 Hypothesis 2

Secondly, according to the information gathered in the first part, it appears that the brewing sector is already ahead of the pack compared to other industries in terms of circularity and that it cannot but further improved.

The brewing sector and breweries particularly are one of the most innovative sectors and have now for many years absorbed this in their very own DNA. Just like the water ratio going from 12 to 20l down to 4.5 l over the last 25 years demonstrates it. The widespread heat recovery between two successive batches and installation of solar panels is another proof that this sector is always up to date on the best practices and on the hunt for new implementations to be done. However, there are areas that seriously haven't much evolved over the years or/and are and that are subject to improvements.

The first one concerns the long-lasting relationship between brewers and farmers. For many years now, farmers have been collecting the BSG to feed their cattle since it's very rich in nutrients on top of being extremely cheap and available in large quantities. The problem is that doing so, it doesn't exactly bring the highest quantity of added value to the society. In the order of priority established the 4F rule, feeding animals only comes second behind humans. This is because the loop is bigger with an added actor processing the nutrients. It's obvious that raised animals are fed for a later human consumption whether it's meat or dairy, and just as the Ellen Macarthur diagram shows it, the smaller the loop the better.

The other area of improvement concerns globalization and the origin of ingredients as well as the final destination of finished products. For Belgian beers, most of the barley comes from

abroad varying from neighbouring countries to far eastern Europe. The problem is that the barley is malted in Belgium which can mislead some brewers, or at least not wake their conscience up. At the other end of the spectrum, Belgian beer is exported throughout the entire world since we brew up to ten times our national consumption. This means that the transportation associated with such practices has a negative impact on the environment and on the circularity. The time a keg takes to return from Hong Kong to its brewery of origin differs massively than the usual circulation time of a keg. The Brunehaut brewery said some of their kegs could take up to nine months to return from San Francisco where they were consumed, which lead to the switch from stainless steel returnable kegs to PET one-way ones. (de Mees, 2008 & 2020)

Finally, the third major area of improvement is the packaging and the reverse logistics associated. Whether it is contained in a can or in a glass bottle, the return ratio after consumption is still no high enough and most importantly, the recycling loop is way too big. The amount of energy that goes in the manufacturing of a beer container is important, and it's therefore crucial to make sure this energy is valued as much as possible by reducing the size of the post-disposal loop. The Ellen Macarthur foundation (2019) classifies reusability in four categories according to the ownership of the packaging and the geographical requirements for the reuse. Beer most likely falls in the category called "return on the go" meaning the packaging cannot be reused as it is and that the customer needs to drop it off at a dedicated drop off point. The main potential challenges they have identified concerning this are

- The right deposit and reward scheme that shouldn't scare customers with a too important price tag, while the incentives to return the packaging should be high enough.
- Availability and ease of return points.
- Room for storage of returned packaging.
- Local reverse logistics facilities.
- System to keep track of deposits and handle payouts.

The importance of beer for the economy is no longer to prove, and with the other principal actors of the beverage industry, it's the whole reverse logistics that still needs improvements.

To conclude on this topic, it's true that the sector is amongst the most innovative ones and can be taken as an example, but there is still room for improvement. The transition to circular economy is happening, and with it comes new opportunities to further improve the sector.

Despite the brewing sector being among the most innovative ones, there is still room for improvement and circular economy is part of the solutions.

4.3 Hypothesis 3

The next hypothesis establishes the huge gap between industrial and craft brewers that can't compete in terms of circularity because of the size and financial differences.

The answer to the first hypothesis already demonstrates that financial issues are slowing craft breweries down to implement more circularity inside their brewery. The first gap takes therefore place here, with the seamless unlimited financial power industrial brewers seem to have. This money allows for major investment rapidly monetized because of the immense quantities they're dealing with.

Beer is no exception to the theory of economies of scale and the gigantic quantity of beer they're producing requires them to brew continuously and therefore recover heat between every batch, for example. The craft brewers expressed their optimization strategies that consist of concentrating batches successively, and in the case of industrial brewers it simply never stops being in activity. The very large quantities also justify for example the investment in a CO2 recovery equipment that then becomes profitable and accounts for more overall circularity.

Aside from the latest machinery and equipment they possess, their financial power allows them to employ full-time experts dedicated to tackling sustainability topics. Pointed out by the BBP as one pain point slowing them down towards achieving more circularity, industrial brewers are able to dedicate full teams to R&D and other sustainability issues like reporting. This is how AB InBev developed their Simmer & Strip technology (AB InBev, 2018), and Carlsberg reinvented primary and secondary packaging. (Carlsberg group, 2019) Packaging is precisely where breweries can still achieve a lot, embedding circular economy practises like Eco conception including the use of recycled and bio-based materials, among others.

However, regional subsidies represent a very unique opportunity to finance circular economy undertakings, whether it's plain cash or via the financing of expertise, the available solutions are numerous. In the Walloon region, the SOWALFIN programme called 'Easy Green' finances SME and micro-enterprise projects up to one million euros, so does the 'Next' programme from the SRIW for bigger enterprises. The SOWALFIN also offers a financing up to 75% of a CE expert, which can eventually lead to a financial help. SRIW's subsidiary, SOWECSOM, helps and finances the transition to servicization and the economy of functionality that we mentioned earlier in the document. (SOWALFIN, 2020) (SRIW, 2020) In order to see clearer and have a better view of what financing help to reach out to, there is a helpdesk to call for every region.

To summarize, there is indeed a gap that resembles more to an abyss, in terms of circularity competition. But the craft and industrial brewers aren't competing on the same market with the same constraints, and in the long run the latter contribute to the innovation of the sector that craft brewers will benefit once the technology has gone mainstream.

The gap between industrial and craft brewers shouldn't be considered negatively but should be seen as sign of an innovative sector from which everybody will benefit.

4.4 Hypothesis 4

Brewers want to actually embrace the circular economy concept, but they don't have any external help to support them toward a transition of their business to a more circular approach of their activities, despite being willing to receive one.

First of all, the answers are all going in the same direction regarding their willingness of the brewers to go towards more circularity in the future. Being the innovators that they are, it's not surprising to see that they already launched circular implementations in order to be a part of the early adopters and not lag behind when it's too late. These circular initiatives and strategies are often initiated on their own with the help of internet or just common sense.

Half of the breweries interviewed seem to be aware of existing support tools in order to help them in this process. However, when we look more carefully at their answers, we realize that

what they're referring to as supports, are either very general guidelines such as CSR practices or governmental helps that are, administratively speaking, very demanding. On top of that, when they were asked if they would have liked or still now would like to benefit from a kind of supporting tool, they agree once more that it would be very beneficial and more than likely, widely used by Belgian brewers.

The general agreement is obviously positive both for the brewing sector and for the purpose of this thesis because it comforts the demand for what was set out as final output of this paper. Nevertheless, when it comes to the content and what the support tool should look like or even who should be responsible of providing it, the opinions seem to be diverging. When a brewer thinks a checklist to follow is what should be provided, one totally disagrees and believes a gathering of best practices is the path to follow. In order to answer this question properly, the sample we used should be widened to have a representative number of participants.

Even if the answers don't allow to orientate the form and content of the aforementioned tool, at least it fills its original purpose which was to make sure there is a demand for what we're aiming to create and that the approach and structure followed for this paper is seemingly the right one.

Brewers want to embrace circular economy and have already started doing so, but they would like a reference support to help them implementing circular practices.

V. Part IV

This final section of the thesis is the summary of all the information collected and analysed so far, gathered in a very compressed and refined output. There are mainly two reasons behind this decision and the first one is my will to make this work count and turn it into a useful document that hopefully will be shared and used by others. This is why the diagram presented exists in English and in French. (See Appendix 5) The other reason is to offer a clear take away message to the readers and to structure one last time the content developed throughout the paper.

5.1 Solid waste

From a circularity point of view, it's obviously the most challenging and concerning aspect, and is therefore considered as the number one priority here.



The application of the “4 f” framework: A better revaluation of BSG is among the top priorities to shorten the circularity loop that is today mostly widened by feeding the animal and ultimately humans. The order of priority for BSG revaluation is therefore Food (human), Feed (animals), Fiber and Fuel. The fact that food is at the top leads up straight to the next point.

1.FOOD
2.FEED
3.FIBER
4.FUEL

Requirements to prioritize food: Most of the human consumption related BSG revaluation is achieved by transforming humid BSG into dry BSG leading to plenty of possibilities that arise when it's grinded into flour. This process ultimately requires a dryer and a grinder.

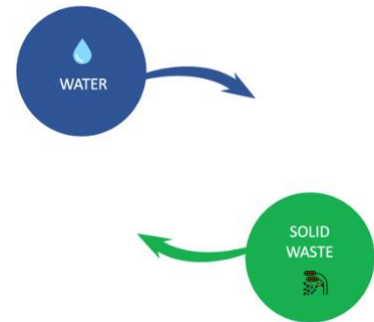
Improvement area: Packaging is the most impactful category with barley agriculture and is also the most prone to circularity and subject to improvements. Apart from kegs that require a sufficient infrastructure to be used, it makes no doubt that using returnable glass bottles is the most circular practice there is. Due to the fact that it requires no transformation to be reused, unlike cans or one-way bottles.

One-way vs reusable: Using returnable glass bottles or kegs when exporting makes no sense up to a point, and it's important not to put circularity ahead of everything else. In order to help

choosing between the two types of packaging, a solution has been developed and consists of establishing a maximum value of CO₂ emissions per quantity of beer.

5.2 Water

The biggest focus for most brewers over the last years has been the subject to many improvements, and rightfully so. Here is what's to be remembered.



Order of priorities: The order to follow for water use optimisation is to adjust the water flow first. Then to modify existing equipment or to install water-saving devices. In third, to change to more water-efficient equipment. Followed by the reuse and recycling of the water. Finally, shift to a low-water or waterless process.

Closed-loop water system: The recovery of rainfall as well as processed water coming from the bottle washer is usually reused for cleaning the floor or the first rinse of tanks. This contributes to the creation of a cleaning closed-loop water system that is what brewers should aim for in the long term. The next step should be to reinsert on-site treated water back in the cleaning loop and to create a closed-loop cleaning system, but releasing clean water outside is also giving back, and represent another way to close a larger loop.

Joining forces with technology: Automation when used appropriately can reduce the water consumption drastically. The instant leak detection, the use of the exact and minimal quantities required, as well as unrivalled time and energy efficiency, are amongst the reasons to consider an automatic CIP or any other automation device.

5.3 Energy

The flow generated and the actual technologies allow to channel the energy and recirculate it back into the system, creating a loop.



Closed-loop energy system: Aiming at a closed-loop system for energy is the circular energy objective for brewers. It's already in their DNA to recover heat between two successive batches, but steam condensing whether it's from the fermenting process or any other process is actually worth investing into.

Joining forces with technology: The numerous temperature requirements of the brewing process require obviously numerous changes and heat transfers that can be optimized with an automatic process using just the right amount of necessary energy.

Sourcing green energy: Optimizing energy comes with more internal circularity but also economic savings. Sourcing from non-fossil-fuel energy provides a holistic circularity and represents the ultimate local energy loop. To help with the financial aspect associated with a higher price tag than conventional boilers, refer to the financial leads below.

Offsetting GHG: The energy required to support the brewing activity emits GHG and completely closing the loop, at a very global level, would require offsetting those emissions by planting trees. Many NGO's and other organizations are already offering this service to companies looking to be carbon neutral, and doing so, closing the loop for their CO2 emissions.

5.4 To be explored

Some implementations take more time to set up because of the numerous actors involved or for other reasons, and some implementations are just beginning to appear and are therefore interesting leads to explore.



Local barley sourcing: The total distance travelled by all the ingredients of a beer can be quite surprising and a lot of that has to do with barley that requires space to be cultivated, and often comes from Eastern Europe despite being malted in Belgium. Developing a short circuit involving local actors can benefit the community and the environment. Developing new types of grain like perennial Kernza also is an interesting lead that is currently taking more importance in the USA but also starting to settle in Belgium, at Agro-Bio Tech of Gembloux for example.

Eco conception packaging: Craft breweries don't necessarily have the time to start investigating new ways to develop eco-conceived packaging involving bio-based or recycled materials, as well as modular design that facilitates the reuse or recycling like industrial brewers. However, it has been shown that the use of a screen-printing technique can wash away without polluting the water. Furthermore, eco-design also includes standardization practises that would, in the beer-bottle case, allow for more circularity among breweries, collect points and bottle washers. However, for some breweries it represents a differentiation feature that is part of their branding.

Yeast revaluation: Often left in wastewater or mixed with BSG, yeast can be revaluated with a higher added value. The yeasty spread called “Marmite” (“vegemite” in Australia) appears to be very successful in these countries and it could also be the case here if a company wanted to investigate this practice. Dietary complement is increasingly becoming popular in a population paying more attention to mental and physical wellbeing, and yeast is the perfect source of complement, but the lead is still unexplored yet. Finally, yeast is also an excellent alternative to pollen for feeding bees in case any beekeeper is around for industrial ecology.

Industrial ecology: Craft brewers have no use for recovered CO₂, but the growing of plants and the production of carbonated beverages do need carbon dioxide for their activities. The revaluation of BSG into human food consumption requires most of the time transformations like drying and grinding, but brewers don’t have the means nor the will to undertake this kind of activity. This therefore opens up opportunities for upcoming businesses. Furthermore, industrial ecology also includes equipment pooling and in the case of craft breweries, this is also true. The aforementioned dryer and grinder could be mobile and shared, as well as the bottle washing machine and even the brewing infrastructure itself, to increase the beer production rate and the overall efficiency of the brewery at the same time.

Investment: Financial issues have been pointed out as a major pain point slowing circular transition down. But solutions have been identified such as the functionality economy and public subsidies. The investments to improve environmental performances are getting easier to get supported by the government and circular economy is now being recognized as improving environmental performance. The functionality economy, on the other hand, is a new type of practice that is seen more frequently nowadays and can be used to buy green heat instead of oil-fired boilers, as well as on-site wastewater treatment in modular container generating electricity at the same time. The Belgian cooperative Coopeos offers the heating financial system while in the USA, a startup developed the wastewater treatment with a similar financing service.

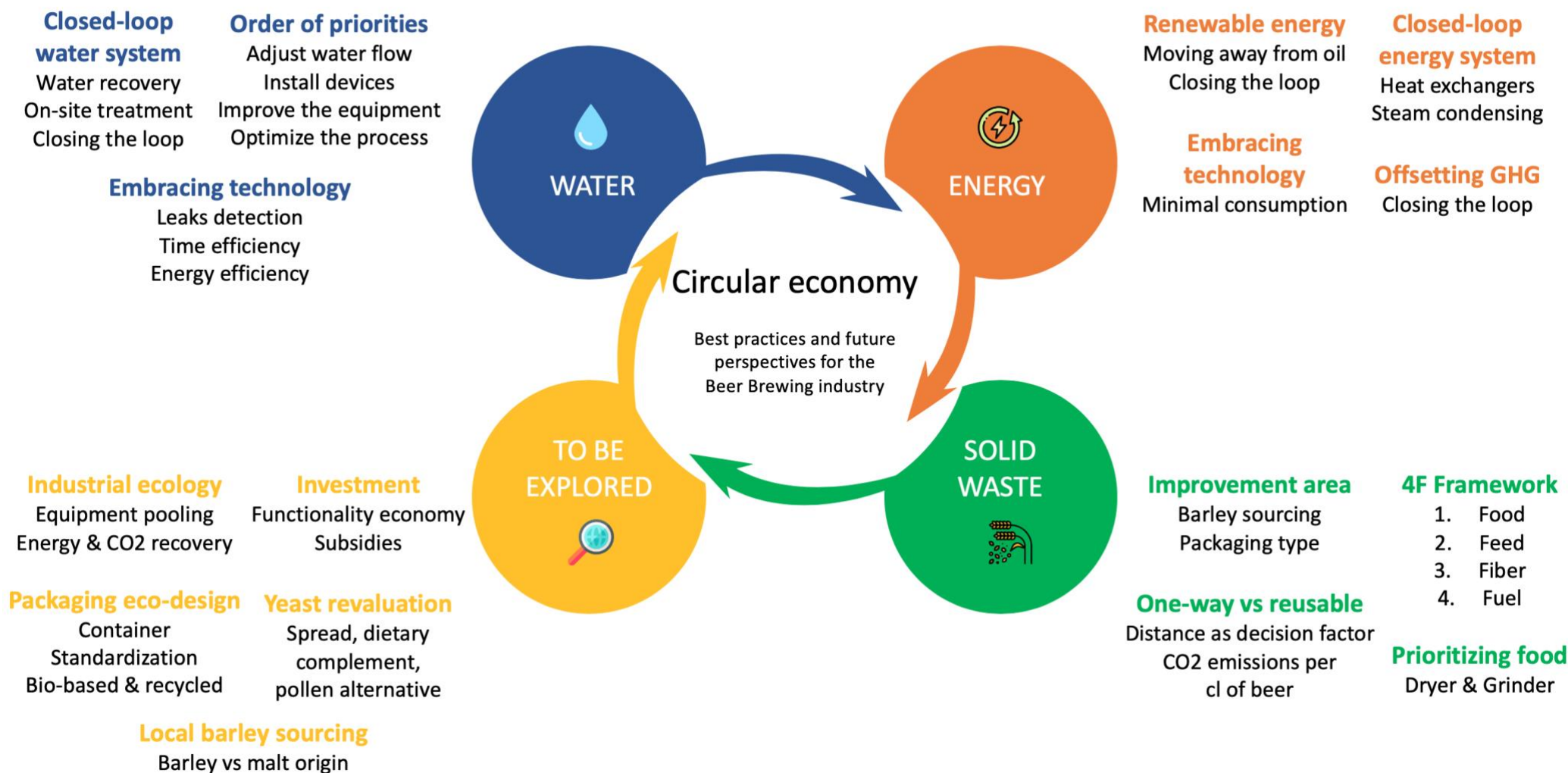


Figure 12: Circular economy - Best practices and future perspectives for the beer brewing industry

VI. Conclusion

The objective of this research was to assess the presence and implementation of circular economy in the beer brewing industry on one hand. On the other hand, to identify potential future perspectives for the same sector and present these results in a condensed open-source version. In order to achieve these objectives, I opted for a qualitative analysis structured by the formulation of four hypotheses, and nourished by semi-directive interviews, as well as an online survey. The first part gathers the academic findings on all the topics covered, and so does the second part that includes the content of the interviews performed, as well as relevant public information. Once all the required information was collected, the hypotheses could be addressed and the final output started to take shape with the evidence of presenting different sections for water, solid waste, energy and explorations to be made. The final part contains the ultimate goal of this thesis which is the condensed version of circular economy for the Belgian beer brewing industry. The content fits on four pages with an additional diagram on the fifth. The scheme is even more condensed and summarizes the four retained section on a colourful one-page display.

Reflections

Looking back at my thesis, I can honestly say that I'm proud of what I managed to achieve to get to this end result. However, if time was on my side, I have to admit that I would have loved to be able to confront my final output with brewers in order to gather their feedback and readjust what would need to be readjusted, and involving them in a co-creation process at the same time. This would have undoubtedly enhanced the quality of the end result, while giving it more credibility. Nevertheless, I'm confident that the scheme offered can be used by craft brewers and also serve as a reference document to build on, to get to a tailored finished product.

Limitations

One of the main limitations is the origin of the scientific content available on the subject. Most of it is in English, and often not referring to Belgium or European countries but from the rest of the world, in the USA in particular.

The second principal limitation is the COVID-19 sanitary crisis that struck the entire world and forced the Belgian government to declare a national lockdown for the entire country. This

obviously made the interviews impossible and these therefore had to be done remotely with the help of technology. The current online meeting possibilities hopefully eased the situation, and the quality of the interviews could be sustained to an acceptable level and therefore not taint the content in any way. Furthermore, as another result of the virus, the number of interviewees was also restrained but compensated by a comprehensive literature review and exploratory research.

Finally, the third and last limitation concerns the scope of the thesis and the involvement of only one of the supply chain actors. Only the brewers were interviewed, and this transition is perfectly suited for the next category that brings up the future potential research topic.

Further Research Topics

Just like I mentioned it in the previous paragraph, the thesis only focused on the brewers and the scope of their activities, but it would be interesting to have a holistic approach of the entire supply chain. This could eventually identify the gaps in the circularity loop and analyse the potential cooperation between the actors of the beer production chain. This would hopefully lead to synergies and potential breakthrough that could enhance even more this sector.

This holistic approach can be targeted specifically at the packaging that is one of the most impactful activities related to the brewing process, and that would greatly benefit from a systemic cooperation among actors with the exploration of standard packaging and closed loop recycling among others.

Use of the thesis

The way I see this, is that I have two hopes for the purpose of this thesis. The first one is that it will hopefully be shared and used by as many brewers as possible, and especially reach those who need it the most. This is also the reason that led to the final open source output format. I already received request to share the result of my study, but I hope it can be transferred on a larger scale to those it can benefit the most.

Secondly, the paper can also serve as a support for future students intending to write their own thesis on the subject of brewing or circular economy. They will be able to use it as a reference document if they need to, or as a source of inspiration for the choice of their subject or a particular topic.

Personal Learning

This paper is definitely the most challenging work I had to provide for university both in terms of logistics and organization as well as regarding the overall completeness of the work. The long-term planning was not new to me, but clearly proved to be challenging when I look back on the whole period.

I managed to get an in-depth knowledge on the brewing process and the revaluation of the associated by-products as well. I would've loved to be able to add the physical networking side of things to this work, but it was limited to remote relationships. However, I feel like these interviews led to networking opportunities and that the bond is now created and available if I need to reach out at some point in the future.

Finally, the circular economy has fascinated me since I learned the concept and being able to witness such an advanced sector from up close is clearly inspiring. It sparkles in me the will to replicate this to other areas and adapt it to their specific needs. Added to this the fact that we're only in the early stages of circular economy, makes it even more motivating to jump into the train with the early adopters and implement this holistic approach to new fields, with the feeling in mind that this is where everybody will be headed to in the future.

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