

Drinking locally

The implications, from a sustainability perspective, of emerging
Belgian microbreweries

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Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, September 2015

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Published in 2015 by IIIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiiee@iiiiee.lu.se.

ISSN 1401-9191

Acknowledgements

Many are to thank for me being able to get where I am today.

First of all, I would like to thank my supervisor Åke Thidell, who pushed me not to give up and to go for that last mile.

Dear fellow batchmates, how crazy you must all be to have dealt with me for two years, what a truly unique experience I shared with you and for that I thank you all!

I would like to thank the Belgian Brewers for contacting all the breweries. I would also like to extend my thanks to all the breweries that were part of the research and thank them for opening the door of their breweries to me. Without them this thesis would not have been possible.

Choosing to delve into the world of cleaner production in Belgian breweries would never have been an option, if it were not for the SED exercise conducted in Portugal. So thank you relatively old people for working with me on that eye opening project.

Kindness is the adjective I would use to describe Birgitta. Birgitta's help and assistance during those two years is immeasurable. You calmly dealt with Belgian social insurance papers and were always there for us, the students. Tack såjättemycket!

This thesis would not have been so clear without the help of Titia Tops and my mother, thank you so much for the time you devoted to this work.

I would like to thank my parents and sister for welcoming me back home and supporting me, in all ways possible, not only during these last intense three months, but also during my whole life. Thank you Mamie for your support and sharing those stories of your youth and the role of beer at that time. Thank you Pépé and Mémé for always believing in me. Finally I dedicate this thesis to the memory of Pépé.

Audrey, merci.

Carpe Diem

Abstract

In similarity to other European countries and the USA, Belgium, has been facing an emergence of microbreweries in the last decade. However, given the environmental footprint and, particularly, the water footprint of beer as well as the fact that microbreweries can sometimes lag behind in energy efficiency or water usage, it is worth considering the sustainability implications of this trend. The sample of visited breweries reflects the variety, in beer volumes and geographic dispersion, of the Belgian beer sector. The data analysis is framed by a three-pillared approach to sustainability and guided by the concept of Natural Resource Accounting and Maintenance Social Sustainability, respectively, to answer the questions pertaining to the environmental performance and the local culture dimensions of microbreweries.

It was observed, by comparing small- and large-scale breweries that there are differences in water consumption. Usually, higher beer volumes suggest lower water consumption levels per litre of beer produced. This can be attributed to differences in cleaning procedures, water treatment and recycling. Breweries also have varying reusing practices. The research concludes that it is important, from an early stage for breweries to embrace a holistic approach towards water consumption and waste generation in their facility. This, in turn, can contribute to breweries' resilience and the sustainability of brewing activities, especially in light of the growing numbers of microbreweries whose aim is to satisfy the demand for a local product.

Keywords: Sustainable Beer Brewing, Cleaner Production, Pollution Prevention, Resource Efficiency, Water Efficiency, Microbreweries.

Executive Summary

In 2013, the world produced close to two billion hectolitres of beer, of which more than 50% originated from China, the USA, Brazil, Germany and Russia. Computing the virtual water content of a litre of beer, namely the water required to grow the primary ingredients and water needed to process the beer, it can be concluded that beer production necessitated 59.6 trillion litres of water in 2013. For every 298 litres of water necessary to manufacture one litre of beer, 85% is rainwater, 9% is freshwater pollution needed to dilute pollutants to maintain water quality and the remaining 6% is the surface or groundwater needed. The major share of the latter 6% is associated with the brewing process, as between 4 to 10 litres of water are generally required to make one litre of beer.

Efficiency improvements achieved at a brewery can be perceived to only slightly affect the total water balance. However, water used in breweries usually originates from groundwater or surface water and its opportunity cost is higher, given its scarcity, than other fractions. As a result efficiency gains in breweries can have deep implications for the sustainability of scarce water resources. Even more striking is that inefficiencies inside breweries do not only reveal resource inefficiencies, but also economic losses. The true value of water encompasses not only the purchasing cost of water, but also the cost of treating water prior to usage, and the cost of treating wastewater before its release into a water body. A similar logic can be followed to account for the economic losses incurred by a brewery with regard to its waste.

After several decades of brewery consolidation in Europe, which led to a sharp decline in the total number of breweries, many countries are now undergoing a revival of their beer sector. After both the UK and USA saw an explosion in local beer brewing, the Belgian market has followed suit. Today, Belgium counts around 160 breweries, six of which own more than 50% of the market share, and whose production is greater than a million hectolitres annually. Yet, with 150 breweries producing around 40% of Belgian beers, Belgium is experiencing an impressive rebirth of its breweries. However, owing to a series of factors, microbreweries can sometimes lag behind in energy efficiency or water usage, mostly because they do not enjoy economies of scale. Consequently, it is worth considering what the implications are, from a sustainability perspective, of this emergence of microbreweries.

In this context, the research seeks to investigate the sustainability of the Belgian microbrewing sector by revealing the true cost of water and waste used for brewing and discovering the contribution of local culture to sustainability when establishing microbreweries in Belgium. This enables the research to disseminate the knowledge already available in Belgium among breweries.

In order to fulfil those aims, the author visited eleven breweries, whose production fluctuates between 80 and 850 000 hL of beer annually. The breweries are spread throughout Belgium's three regions. Both qualitative and quantitative data were collected to assess the environmental performance of the breweries visited. The eleven breweries were accompanied by two additional brewery visits and one expert interview to better understand the role of local culture in relation to sustainability. A three-pillared approach to sustainability was adopted as framework of study. The concepts of Natural Resource Accounting (NRA) and Maintenance Social Sustainability (MSS) were, respectively, adopted in guiding to answer the questions pertaining to the environmental performance and the local culture dimensions.

Based on defined aims, the following four research questions were investigated:

What is the true cost of water and waste in Belgian breweries?

It was found that for breweries using municipal water, the cost of water could vary depending on the region and localities, as the municipality's water price is obliged to reflect the true cost of water purification and wastewater treatment. In many microbreweries, water does not undergo treatment prior to its usage. In those cases, it was concluded that the Total Corporate Environmental Cost (TCEC) of water, which includes the cost of purchasing water as well as the cost of treating the water before use as well as the cost of wastewater treatment, ranged from 3.35 to 4.65 EUR per m³. When breweries treat incoming water with chlorine dioxide to a level of 15mg/L, the water's TCEC amounts to 5.33 EUR per m³.

Waste was divided into two components, organic and inorganic waste. Organic waste's TCEC was not calculated, since the waste is the result of a beer recipe's raw material and is inherently difficult to decrease without affecting a beer's taste. On the other hand, inorganic waste is the product of inefficiencies in the packaging area. It reflects an economic loss ranging from 0.134 to 0.136 EUR per 0.33 L bottle, including the cost of the bottle, cap and waste disposal. For breweries able to sell their glass and metal waste, the TCEC was estimated to range from 0.046 to 0.056 EUR per 0.33 L bottle. In the case of breweries using screen-printed bottles, the TCEC is equal to 0.331 EUR per 0.33 L bottle. Unfortunately, it was not possible to determine nor estimate the TCEC of other types of inorganic waste generated in breweries, such as plastic, cans or cardboard.

What are the common cleaner production and pollution prevention techniques and practices in place in the Belgian brewing sector?

It was found that water consumption in the Belgian brewing sector ranges from 3.94 to 15 litres of water per litre of beer (L_w/L_B) produced, mirroring the variation in cleaning procedures and other water consuming techniques. Being extremely water intensive, improvements in cleaning procedures can bring about significant water efficiency gains. Yet, at present, those gains should not come at the cost of quality or at the risk of spoiling beer batches. Consequently, adjustments in cleaning procedures should be made carefully. Two patterns were identified, one common among breweries producing less than 500 hL per annum and another present in large-scale breweries. Microbreweries often clean their equipment with a three-step cleaning procedure where, after a first rinse, a detergent is used for the caustic cleaning and sterilisation is done by water vapour. Where microbreweries usually implement one cleaning technique, larger scale breweries developed several procedures. However, it is generally geared around the following five steps:

1. Pre-rinse with water at ambient temperature;
2. Detergent circulation at either hot temperature or ambient temperature;
3. Intermediate rinse at ambient temperature;
4. Disinfection circulation for disinfection and neutralisation of potential alkaline residues; and
5. Final rinse with sterilised water.

Other breweries usually implemented cleaning procedures inspired by both cleaning patterns, with minor adjustments dependent on their size and technology.

It is very common for the organic waste created during brewing to be recycled or reused by farmers, either as fodder for various kind of animals or to be spread onto fields. The latter being especially true for spent hops. GMP¹ certified breweries have, in addition to benefiting

¹ GMP stands for Good Manufacturing Practices and, in this case, is a certification ensuring that safety, quality and compliance standards for the use of organic waste from a brewery for the farming sector (SGS, 2015).

from free disposal cost, the opportunity to sell their organic waste around 0.045 EUR per ton of dry matter for spent grains as well as hops and 0.4 EUR per ton of dry matter for spent yeast. Regarding inorganic waste, it is mandatory for any Belgian brewery to sort their waste stream into cardboard, plastic, metal, glass and residual waste. Contrary to the organic waste, inorganic waste has an annual disposal cost vacillating between 490.2 and 1 661.4 EUR for microbreweries, including all fractions of waste. At the other end of the spectrum, large-scale breweries, partly owing to the large volumes of waste generated, are able to receive 0.21 EUR per kilo of inorganic waste. Yet, it does not disincentivise large-scale breweries from reducing inorganic waste generation, as the waste still embodies an economic loss as well as resource inefficiencies.

One major improvement and investment carried out by breweries of all sizes is Cleaning-In-Place (CIP) tanks. The most basic CIP technology continuously reuses the cleaning solution during the cleaning procedure, allowing for more than 60% water reduction compared to a total loss cleaning system. Advanced CIP technology, in addition to the continuous reusing of the water, enables the recuperation of the intermediate and final rinsing waters to be recycled in subsequent cleaning as intermediate and pre-rinse water. This latter CIP can cut water consumption by up to 80% compared to a total loss cleaning system.

An area of the brewing process that was identified by some breweries as harbouring great potential for recycling and reusing of water was packaging. Water used to rinse new or single-use bottles can be reused for another application as the water contains little to no impurities, because bottles have already previously been washed and sanitised. Contrary to one-way bottles, reusable bottles are to undergo a thorough cleaning procedure including a series of hot and caustic baths, before entering the bottling line. This can be a source of high chemical load for the wastewater treatment facility and generates a large quantity of wet labels containing glue, which are sorted separately from other waste streams, increasing breweries' disposal costs. To remedy these issues, breweries recycle their water and cleaning solution in a counter-current fashion. Optimised bottle-washing machines consume between 0.22 to 0.25 litres of water per 0.33 L bottle. It was observed that one microbrewery, owned a relatively small size bottle-washing machine consuming 0.66 litres per 0.33 L bottle. However, as the brewery opted for screen-printed bottles, it is avoiding having to deal with large quantities of wet label or label pulp.

The most efficient way to reduce water consumption is simply not to use it, therefore by optimising cleaning procedures and avoiding unnecessary washing, breweries can reduce up to 25% of water. Breweries are also able to cut down on water utilisation in the packaging area by optimising the bottle-filling procedure. Starting the filling of clearer and weaker beers before moving on to darker and stronger beers enables the brewery to only lightly rinse the bottle-filling machine between different styles of beer. In order to reduce water use, some breweries ran only a simplified cleaning procedure on a day-to-day basis and less frequently a complete cleaning procedure for the bottle-filling machine.

Almost all breweries cooled down their wort – wort is beer, when the yeast has not been added yet and that it only is a sweetened liquid – after the wort-boiling stage with either used water or with water designated for use at a relatively high temperature, which, in addition to reducing water consumption, also prevents energy from being wasted. Finally, as floors require less systematic and methodical cleaning, breweries sometimes reuse water and cleaning solutions from a cleaning procedure to wash and sanitise floors.

Analysing the difference between the water use and wastewater generation ratio provided information on water lost or trapped during the brewing. The difference between the two

ratios ranged from 1.4 to $1.95L_w/L_B$. However, it was deducted that around $1 L_w/L_B$ ended up in the final product, of which a small portion evaporated. In addition, between 0.14 and $0.39L_w/L_B$ is trapped in the wet organic waste engendered by the brewing process. The remaining segment of the difference between the two ratios depended on the machinery installed at the facility, which can encompass input water for elements such as steam boilers, cooling circuit or other closed loop systems, which inevitably experience some water losses. It can be concluded that for microbreweries approximately $1.95 L_w/L_B$ is lost or trapped during the brewing process.

What is the role of culture with regard to sustainability in the microbrewery sector?

MSS encompasses the heritage of a region, province or locality in the form of the norms, values and shared beliefs of its inhabitants. The cultural heritage took the form of the old traditions and craftsmanship of brewing beer permeating the whole Belgian beer sector. The neolocalism component was further sub-divided into a link to the community and the creation of a sense of place. However, it was concluded that the neolocalism component perceived in today's breweries builds on the accumulated Belgian cultural heritage or cultural capital. This cultural capital manifests itself in the variety of beer brewed, the brewing location or the name of the beer. Moreover, MSS can be perceived to be strong and even gaining importance in Belgium with the emergence of microbreweries, often seeking to identify themselves as part of the cultural heritage.

Lastly, the research attempted to investigate whether the local environment influenced a beer's taste, or in other words the existence of a terroir of a beer. It was only in the case of spontaneous fermentation beers that the hypothesis was found to be correct, as the yeast inoculation is dependent on the yeast present in the air during the brewing process. Although this leads to the conclusion that the terroir of beer only exists for spontaneous fermentation beers, the interviews brought forth a novel definition of terroir, where diversity, density and craftsmanship bring to life a terroir. This last definition sees competition and rivalry as driving forces for the recognition of a certain craft. Moreover, terroir here is not restricted to the beer craft but embodies all crafts pertaining to a certain province or locality. A few breweries exemplified the fact that beer craft could be a vehicle of communication for other types of crafts. This was expressed through the incorporation of crafts into one another, such as beer pairing or beer using locally produced goods (e.g. beer with speculoos) and sharing of communal space, where one craft brings attention to another one. The label 'Streek Product – Regio en Traditie' (e.g. Regional/local Product – Region and Tradition), personifies this new idea of terroir. It was concluded that the emergence of microbreweries passing on and representing the values, beliefs, traditions and craft of a province or locality could contribute to sustaining the cultural capital of that region.

How could small Belgian breweries further optimise their water consumption and waste generation patterns?

Adopting a new mind-set with regard to water, waste and wastewater management by accounting for the TCEC of the natural resource has the potential to reveal the true cost behind resource inefficiencies. In reality, it appears that breweries start significantly tackling inefficiencies beyond the 4 000 hL per year threshold. However, the emergence of microbreweries that are not aiming at producing large volumes of beer could, theoretically, negatively impact the environmental footprint of the brewing sector. Consequently, it is important for breweries to embrace from an early stage onwards a holistic approach towards the water consumed and waste generated in their facilities to ensure the brewery's resilience and the sustainability of brewing activities.

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Abbreviations

BBW	Belgian Beers of Wallonia
BOD	Biological Oxygen Demand
BSS	Bridge Social Sustainability
COD	Chemical Oxygen Demand
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EMA	Environmental Management Accounting
HACCP	Hazard Analysis and Critical Control Points
hL	Hectolitre
KPI	Key Performance Indicator
L _w /L _B	Litres of water per litre of beer produced
LCA	Life Cycle Analysis
MSS	Maintenance Social Sustainability
m ³	Cubic meter
NRA	Natural Resource Accounting
SS	Suspended Solids
TCEC	Total Corporate Environmental Cost

1 Introduction

1.1 Background

In 2013, worldwide, close to two billion hectolitres² (hL) of beer were produced (Statistica, 2013; Kirin Beer University, 2014). The world's beer market is heavily dominated by China, producing more than 30% of the world's production, followed by the USA, Brazil, Germany and Russia (Kirin Beer University, 2014). Those top five producing countries combined, supply more than half of the beer demand worldwide. However, what is little known about beer making is its environmental footprint and, more specifically, its water footprint. The water footprint of beer is the sum of all water necessary to produce one litre of beer (Mekonnen & Hoekstra, 2011), including the water needed to grow its main primary ingredients, which are hops and malted grains, generally wheat and barley (Mulder & Dubief, 1861; Briggs, Brookes, Stevens, & Boulton, 2004).

According to Mekonnen and Hoekstra (2011), beer requires a total water input of 298 litres to produce one litre of beer. From this can be deducted that in 2013, 59.6 trillion litres of water were necessary for the production of the world's total beer production [derived from Mekonnen and Hoekstra (2011)]. Of this, 85% is constituted of rainwater, while 9% is freshwater pollution needed to dilute pollutants to maintain water quality and the remaining 6% is surface or groundwater. The major share of the latter 6% is associated with the brewing process, since between 4 to 10 litres of water is required to manufacture one litre of beer (Brewers of Europe, 2012; Olajire, 2012).

The marginal importance, in volumes, of water used by breweries, gives the impression that efficiency improvements do not significantly influence the total water balance of beer. However, as water used in breweries usually originates from groundwater or surface water and is more scarce than other fractions, it possesses a higher opportunity cost (Chapagain & Hoekstra, 2011). As a result, from a cost perspective, efficiency gains in breweries have deep implications for the sustainability of scarce water resources around the world.

In addition, water, like any other primary ingredient, has a cost for breweries. The cost for breweries not only includes the cost of purchasing water, but also the cost of treating the water before use as well as the cost of wastewater treatment before releasing it into a water body. This holistic cost is what Jasch (2009) refers to as the True Corporate Environmental Cost (TCEC). Therefore, inefficiencies inside breweries do not only reveal resource inefficiencies but also unveil the economic losses of the true value of water. A similar logic can be followed to account for the economic losses incurred by a brewery with regard to its waste.

Modern and efficient breweries consume between 4 to 7 litres of water per litre of beer produced (L_w/L_b) (IFC, 2007). AB InBev, the world leader in beer production, whose brewing facilities are spread all over the world – examples include Skol in Brazil, Jupiler in Belgium and Budweiser in the USA – prides itself on the fact that it achieves a worldwide water ratio of 3.2 L_w/L_b (AB InBev, 2015). However, after several decades of brewery consolidation in Europe leading to a sharp decline in the total number of breweries, many countries are now experiencing a revival of their beer sector (Swinnen, 2011). Belgium, which has always been known and famous for its beer craft, has seen its beer sector reborn (Dauliac & Jackson, 2008). A movement spurred by the booming beer market of the USA and UK (Swinnen, 2011). Today, six breweries, whose production is greater than a million hL annually, own more

²One hectolitre equals a hundred litres and is a typical unit in the brewing industry.

than 50% of Belgium's beer market. Still, smaller-scale breweries and microbreweries have not been left behind, as around 150 breweries produce about 40% of Belgium's total production.

Yet, though only little is known about microbreweries the evidence points to the fact that they are not as resource efficient as their larger counterparts (Brones, 2015). Another factor widening the efficiency gap between breweries is the fact that larger breweries, especially, focus on efficiency improvements, and have stakeholders all over the world, forcing them to introduce sustainability goals into their decision making (Tokos, Pintarič, & Krajnc, 2011). Consequently, it is worth wondering what the implications are, from a sustainability perspective, of the emergence of microbreweries.

1.2 Aims and Research Questions

Given what little knowledge is available with regard to microbreweries' environmental performance, the thesis has two principal aims. The first aim is to investigate sustainability in the microbrewing sector in Belgium. To achieve that aim, the research seeks to reveal the true cost of water and waste used for brewing. In order to determine these costs one needs to understand the factors influencing them. This is carried out by reviewing the water, waste and wastewater management of Belgian breweries. By reviewing the management practices of the entire beer sector, in terms of volumes of beer produced, enables to map the current state of common practices and techniques. Simultaneously, the thesis explores the contribution of local culture to sustainability when establishing microbreweries in Belgium. The latter aims to understand both the positive and negative repercussions of the microbrewing trend from a sustainability point of view.

The research also intends to disseminate knowledge already available in Belgium among breweries. Building on the first principal aim, the thesis's purpose is also to draw conclusions and suggest practices applicable to microbreweries.

The principal aims of the thesis can be summarised in the following research question:

What are the implications, from a sustainability perspective, of emerging Belgian microbreweries?

In order to answer this overarching research question, the thesis aspires to answer four sub-questions:

1. What is the true cost of water and waste in Belgian breweries?
2. What are the common cleaner production and pollution prevention techniques and practices in place in the Belgian brewing sector?
3. What is the role of culture with regard to sustainability in the microbrewery sector?
4. How could small Belgian breweries further optimise their water consumption and waste generation patterns?

1.3 Limitations and Scope

Although the study reviews the environmental performance of breweries, the focus does not lie on the performance of certain styles of beer. This also implies that the environmental impact of growing hop, barley, wheat or other ingredients necessary for brewing beer is excluded from the research. In addition, though one brewery visit was conducted in Sweden, the sample solely consists of Belgian breweries. Lastly, the thesis concentrates on bottled beer and does not go into the details of beer sold in casks, barrels or kegs.

It is important to note that two breweries were previously contract breweries, meaning that their beers were brewed by another brewery, following their recipes. Nonetheless, during the data collection, those microbreweries were in the final construction stages of their own facilities. They were added to the sample because of their particularities. One brewery developed an interesting synergy with supermarkets to reduce food waste, while the other installed itself in an old brewery and uses screen-printed bottles. Moreover both breweries, have installed Cleaning-In-Place (CIP) tanks, a feature that was previously not common among microbreweries and that has important implications for water consumption. Since the volumes of beer produced are brewed at another facility and subsequently water consumption data was not available, it was, conservatively, assumed that they had a water consumption ratio equal to the highest water ratio.

In addition, during data collection, some breweries were unable to specify the volumes of wastewater released annually. As a result, following what was found in the literature, a conservative estimate was made that the difference between water consumption and wastewater generation was equal to $1.8L_w/L_B$. In other cases where data was unavailable, conclusions were constructed only on information provided by the breweries, which decreases the accuracy of the conclusions drawn from them.

The US' Brewers Association (2015) has defined breweries – microbreweries, regional breweries, large breweries – according to a series of conditions that have to be met, but they add unnecessary complexity and are not relevant to the case of Belgium. Therefore, in this thesis, breweries are solely divided into two categories, small-scale breweries or microbreweries, producing less than 17 600 hL annually and large-scale breweries producing more than that limit. The threshold of 17 600 hL per year was chosen, as it is a defining criteria of microbreweries, according to the US's Brewers Association's definition. It is acknowledged that there might be limitations to such a dual division of the beer sector. However, the division is supported by the observation that above the 17 600 hL threshold, breweries tend to have a very similar pattern with regard to water, waste and wastewater management.

It is to be noted that brewery visits and interviews took place in both French and Flemish, with the exception of the visit that occurred in Sweden, which was conducted in English. Hence, any misinterpretation of the collected information remains the responsibility of the author. Moreover, sometimes, complementary information was provided through email exchanges with breweries visited.

Finally, the thesis does not aim at pointing out best and worst practices. It solely tries to assist breweries in understanding the challenges linked to water, waste and wastewater managements, while providing tools to improve their environmental performance. As little literature on environmental performance is targeted at microbreweries, this research seeks to contribute in filling in that knowledge gap.

1.4 Audience

The primary audience of this paper is the Belgian brewers' association (e.g. Belgian Brewers) in order to provide them with a clearer understanding of the current state of resource management in the Belgian brewing sector. To achieve the aim of disseminating knowledge already available in Belgium among the various breweries, the role of the brewers' association is of great importance. Undeniably, brewers are expected to advance their ability to identify inefficiencies as well.

The inclusion of a Swedish brewery in the sample demonstrates that there are many common features between the Belgian and Swedish beer sector. Moreover, owing to the history and importance of Belgium in the beer industry, the conclusions drawn could be of interest for breweries outside of Belgium.

It appears that the environmental performance of microbreweries has not yet been given precise attention in academic literature. To date, there has been only one paper solely devoted to microbreweries. Williams and Mekonnen(2014) delved into the Life Cycle Analysis (LCA) of a microbrewery. Owing to the broader scope of that research, however, few findings were of relevance for the thesis at hand. In addition, in the document produced by the European Integrated Pollution Prevention and Control Bureau (EIPPCB)(2006) a short case study tackles the issue of process optimisation in a small brewery. However, due to its very limited scope, it provides little complementary information.

1.5 Ethical considerations

Beer is an alcoholic beverage and should be consumed wisely.

As requested by some breweries, the breweries' names are not disclosed. The visited breweries are named from A to K, in the order in which they were conducted. The two additional breweries interviewed as part of the investigation into the contribution of local culture to sustainability, are named L and M, also in the order in which they were conducted. The male expert employed at the APAQ-W, an association in charge of promoting quality agriculture in Wallonia, interviewed for the Belgian Beers of Wallonia identification tool is referred to as the expert interviewee.

1.6 Outline

This thesis is made up out of eight chapters. The first chapter is the introduction describing the background information necessary to understand the issue. The chapter also explains the aim and lists the research questions that the study answers. Further, it states the limitations and scope, the target audience, and provides an outline of the thesis. The second chapter presents the methodology and the framework of the study, the literature review and data collection. Afterwards, it explains how the data was analysed. The third chapter seeks to familiarise the reader with the brewing process, while the fourth chapter provides background information about the beer market's evolution. The literature review is extensively dealt with in the fifth chapter and follows the structure delineated by the framework of study. The sixth chapter presents the data gathered from the various brewery visits and interviews in a similar fashion to the previous chapter. Framed by the four research questions, the seventh chapter discusses and analyses the findings. Finally, the eighth chapter summarises the main findings and delivers suggestions for further research.

2 Method

The thesis primarily seeks to investigate sustainability in the microbrewing sector in Belgium. Overall, the method adopted is based on a combination of a thorough academic literature review, observations from brewery visits and interviews with brewmasters. To acquire an initial understanding of the current state of the brewing industry in Belgium both qualitative and quantitative materials were required. Although, as Venkatesh, Brown and Bala (2013) recommended, a method mixing qualitative and quantitative methodology is not always advised, in some cases, such as for complementarity purposes, mixed methods are adequate. Here, qualitative data complements quantitative data to gain better insight in the various aspects of sustainability in the brewing industry. The guidelines that are to be followed for a mixed method are (Venkatesh, Brown & Bala, 2013):

1. The study must be empirical;
2. Quantitative and qualitative methods must be employed; and
3. Quantitative and qualitative data must be presented.

When exploring the role of sustainability's maintenance social aspect, the research mainly relies on qualitative data and methods (e.g. interviews with brewmasters). Whilst when examining the current state of the brewing sector in Belgium, mostly quantitative data is gathered, some qualitative data was also collected to provide additional information describing and explaining the quantitative data (e.g. information on practices aimed at rendering water use more efficient in breweries). Since the data was collected through interviews and surveys, the study is empirical.

2.1 Background Information

To answer the four research questions, the thesis is based on academic literature, brewing manuals, history books tackling brewing and a literature review of cases studies, best available techniques of the food and drink industry as well as the potential synergies that could be developed in breweries regardless of their size. The thesis' introductory segment divides itself up into three main parts: the brewing process, the economics of brewing, and the literature review. This last part is subdivided into a Natural Resource Accounting (NRA) and a Maintenance Social Sustainability (MSS) section.

The author has sought to deepen his knowledge of brewing, which enables a better grasp of the usefulness of each brewing technique, the inflow and outflow as well as the quality requirement linked to it. The research was completed using the following keywords in English and French on Google Scholar and LUBsearch: 'beer', 'brewing', 'brewing process', 'brewing technique', 'history of brewing'. Results highlighted few seminal books in the brewing industry, which form the basis of the understanding of the brewing process, with the oldest book being a French treatise on beer brewing dating back to 1861.

The chapter on the economics of brewing intends to explain how brewing evolved in scale over the last century. In addition, the chapter portrays the current state of the beer market in Belgium and worldwide, based on the work of Swinnen (2011), and reports from the ECB (European Convention of Brewers) and other large brewery associations.

Finally, in the literature review's first sub-section, Google Scholar, LUBsearch, Science Direct and Engineering Village were used to gather more in-depth knowledge on resource management in the brewing industry by using the following keywords, this time in French, English and Dutch: 'water', 'wastewater', 'waste', 'brewery', 'beer', 'environmental footprint', 'water footprint' and 'LCA'. This resulted in a collection of many scientific peer-reviewed

articles either tackling water, wastewater and waste management specifically for breweries or articlestackling the food and beverage industry in general. The aim of the gathered documents varied widely. Some focusing on potential efficiency gains in one step of the brewing process (Talbot & Talbot, 2011; Fillaudeau & Blanpain-Avet, 1999; Simate et al., 2011), others looking at it more holistically (Cordella, Tugnoli, Spadoni, Santarelli, & Zangrando, 2007; Fakoya & van der Poll, 2013; Melon, Wergifosse, Renzoni, & Léonard, 2012; Peel, 1999; United Nations Environment Programme, 1996; Koroneos et al., 2005) or investigating alternative techniques (Geiselman, 2005; Bamforth, 2006). Another group of papers developed the concept of Material Cost Accounting for the brewing sector to help identify opportunities for increased efficiency in beer operations (Ayes, 2010; Jasch, 2009; Wan, Ng, Ng, & Tan, 2015). Google searches also helped find UNEP's best available techniques and common practices in the food and drink sector (European Commission, 2006).

A second sub-section of the literature review investigates the social and cultural aspects of sustainability. Definitions of social and cultural sustainability are, depending on the authors, sometimes rallied under the concept of social sustainability (Vallance, Perkins, & Dixon, 2011) and at other times seen as two distinctive, yet interdependent, concepts (Chiu, 2004; Hawkes, 2001; Soini & Birkeland, 2014). This research mainly used social and cultural sustainability as search words. In the context of the brewing sector, the concept of MSS was further divided into cultural heritage and neolocalism. The cultural heritage dimension, was aimed at unveiling the shared beliefs, values and norms rooted in the community and passed onto each generation by education and social interactions (Chiu, 2004; Hawkes, 2001; Soini & Birkeland, 2014). The literature review studied the concept of MSS and its growing importance in the brewing sector by examining the role of neolocalism and the localisation of breweries in relation to sustainability (Blitz, 2014; Flack, 1997; Patterson & Hoalst-Pullen, 2014; Schnell & Reese, 2003; Zegler, 2012). The research was accomplished by researching Google Scholar and LUBsearch with solely English keywords: 'neolocalism', 'localization', 'local beer'.

Finally, in the section over environmental sustainability, the requirements and legislation imposed on breweries by Belgian as well as European authorities was also investigated. The homepage of the European Union³ as well as several regional environmental protection agencies of Belgium were browsed for directives, decrees and laws on water, waste and wastewater. As a result, the following directives were found to play a major role in influencing operation in the brewing sector: Drinking Water Directive, Waste Framework Directive, Waste and Packaging Waste Directive, Food Hygiene Directive and Water Framework Directive. As directives, they guide the sector and ought to be translated into national regulations most of which, in Belgium, appear in decrees⁴. Furthermore, thanks to van Oeveren (2009), the mapping of legislations affecting brewers was simplified, as the presentation highlights that on top of the above mentioned legislations chemical usage is regulated by the REACH (Regulation, Evaluation, Authorization and Restriction of Chemicals) directive.

³ <http://eur-lex.europa.eu/homepage.html?locale=en>

⁴ 27 mai 2004 - Décret relatif au Livre II du Code de l'Environnement constituant le Code de l'Eau; 24 Mei 2002 - Decreet betreffende water bestemd voor menselijke aanwending; Arrêté royal relatif à l'hygiène des denrées alimentaires; 25 mars 1999 - Arrêté royal portant fixation de normes de produits pour les emballages.

2.2 Method for Empirical Data Collection

2.2.1 Brewery Visits

Brewery visits helped gather qualitative as well as quantitative information on water, wastewater and waste management. After an initial contact with the Belgian Brewers, they kindly offered to contact all the breweries that form part of their network to help gather material. Following the answers from various breweries, a selection was made so as to have a significant sample of breweries in Belgium. Out of the approximately 160 Belgian breweries, eleven were part of the brewery visits ranging from almost very small-scale breweries to large-scale breweries part of AB InBev. The sample is representative of the Belgian brewing landscape as the number of visited breweries represents almost 10% of the brewery population, are geographically spread over Belgium's three regions and include various brewery sizes.

These visits were conducted following the checklist contained in Table 2-1. The format of the checklist was inspired by a checklist arranged by the USEPA (United States Environmental Protection Agency) on water and wastewater as well as *Cleaner Production in Breweries: a Workbook for Trainee*, the template and a case study provided by Jasch (2009). The checklist material brings together knowledge from above mentioned literature while also relying on the literature review that was gathered on the themes of water, wastewater and waste management in the food and drink industry and in breweries (European Commission, 2006).

Table 2-1. Natural Resource Accounting checklist for brewery visits.

Topic	Units
Beer production	hL
Water consumption	m ³
Water consumption per step (Mashing, Wort processing, Fermentation, Maturation, and Packaging)	m ³ (If available)
Size of batches	hL
Treatment of water before usage	Description
Costs of water treatment before usage	€/m ³
General cleaning procedure	Description
Cleaning procedure per step (Mashing, Wort processing, Fermentation, Maturation, and Packaging)	Description (If available)
Wastewater characteristics (BOD, COD, SS, phosphorus, nitrogen, pH, temperature)	Mg/L, Mg/L, Mg/L, Mg/L, -, °C (If available)
Treatment of wastewater	Description
Costs of wastewater treatment	€/m ³ (If available)
Waste recycling	Description
Waste sorting	Description
Costs of waste sorting	€/kg/fraction

Source: Author's own illustration.

The checklist was first tested during a visit to a Swedish brewery, Brewery A, thereby enabling the author to fine-tune aspects of the checklist that were unclear or irrelevant⁵. The reason

⁵ Following the Jasch's material flow accounting excel sheet for breweries (2009), it was expected that breweries could provide detailed water consumption data for each brewing process. However, when faced with the reality of the field, the infeasibility of gathering that type of data became obvious.

behind conducting the test visit in a Swedish brewery is three-fold: first, studying at the IIIIEE at Lund University, Sweden, convenience played an important role. The second reason is that conducting it outside of Belgium allows for impartiality and objectiveness. The third reason is that although the visit was a test run, it allowed a comparison to be made and thus appreciate the generalizability of the conclusions drawn.

Table 2-2 summarises the sources from which qualitative and quantitative data were gathered as well as the dates when the brewery visits and interviews took place.

Table 2-2. Summary of breweries visited, breweries part of the interviews and expert interview.

Date (D.M.Y)	Brewery	Beer production [hL] (2014)	Visited (Y/N)	Interviewed (Y/N)
05.06.2015	Brewery A	500.00	Y	Y
18.06.2015	Brewery B	4 000.00	Y	Y
23.06.2015	Brewery C	9 765.00	Y	Y
26.03.2015	Brewery D*	2 000.00	Y	Y
30.06.2015	Brewery E	87 544.54	Y	Y
02.07.2015	Brewery F	850 000.00	Y	Y
06.07.2015	Brewery G	80.00	Y	Y
07.07.2015	Brewery H*	233.33	Y	Y
09.07.2015	Brewery I	131 406.00	Y	Y
13.07.2015	Brewery J	2 200.00	Y	Y
14.08.2015	Brewery K	1 000.00	Y	Y
27.06.2015	Brewery L	N/A	N	Y
04.07.2015	Brewery M	3 000.00	N	Y
14.07.2015	APAQ-W employee	N/A	N/A	Expert Interview

Source: Author's own illustration.

*Breweries already producing beer under contract but in the process of constructing their own brewery, therefore, these beer production numbers are those manufactured at outside brewing facilities.

To ensure data accuracy, a final version of the work was sent by mail to the breweries on the 14th of September 2014. This allowed for breweries to confirm the exactitude of the data gathered as well as comment on the analysis. Although the level of response was rather low, only two minor imprecisions were brought forth⁶.

2.2.2 Interviews

Qualitative data gathered via interviews with brewmasters or tradespeople enables to explore the contribution of local culture to sustainability in the brewing sector. The methodology applied was what Flick (2009) defines as semi-structured interview. The interview were structured around following topics:

- History of the brewery;
- Drivers towards starting to brew;
- Involvement in the local community (e.g. festivities, local races);

⁶One revealed the ownership of a buffer tank and the other revealed that brewery B cooled down its hot wort as all the other breweries by using brewing water.

- Interaction with the local community;
- Existence of a terroir of beer.

Breweries that formed part of the brewery visits are included in the qualitative data gathering of this second section, see Table 2-2. However, some additional breweries were included for the purpose of this section as they highlighted a variation in brewing purposes (e.g. a brewery brewing for the sole purpose of supplying its restaurants) and brewing styles (e.g. spontaneous fermentation).

Finally, an expert interview was conducted with an employee at the APAQ-W, an association in charge of promoting quality agriculture in Wallonia, who, in February, decided to launch an identification tool: Belgian Beers of Wallonia. Although covering similar topics to that of the semi-structured interview conducted with breweries, this interview followed the guidelines of an expert interview (Flick, 2009). Therefore, the questions were sent to the expert interviewee prior to the phone call, the question set, translated from French is to be found in Appendix I.

2.3 Framework of Study

To answer the overarching research question looking at the sustainability implications of microbrewing, a three-pillared approach to sustainability is adopted. This approach was preferred for its flexibility in suiting the brewery industry as well as other needs (Slaper & Hall, 2011). In addition, the triple bottom line approach allows for breweries to evaluate the long-term sustainability of their decisions. As illustrated in Figure 2-1, the three pillars consist of an economic, environmental, and social dimension.

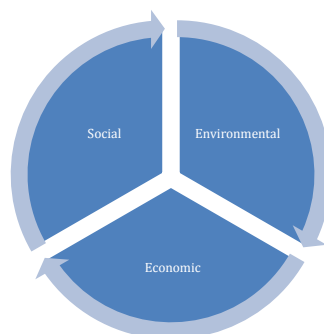


Figure 2-1. Three-pillared approach to Sustainability.

Source: Author's own illustration adapted from Slaper & Hall (2011).

To investigate this three-pillared approach to sustainability, the research is made up of two components, a technical one encompassing mainly economic and environmental aspects and a second component including social aspects. These components are two pieces of the same puzzle. The first more technical component helps to understand the economic driver that can be fostered and improved by reducing water consumption and waste generation. The second component assists in understanding the philosophy, ambitions and goals aimed at by breweries. These goals are inevitably intertwined with the economic and environmental drivers as the findings and analysis demonstrate.

2.3.1 Natural Resource Accounting

An aim of the thesis is to explore the true cost of the natural resources used in brewing, namely, water, malt, hops and yeast. A common methodology to assess the environmental performance in the brewing sector is adopting a Life Cycle Approach (Koroneos et al., 2005;

Cordella et al., 2007; Melon et al., 2012; Williams & Mekonen, 2014). However, since the approach embraces a holistic perspective and solely takes into account the environmental impact of beer from cradle to grave, it neglects the economic facet’s importance. Therefore, in an attempt to reveal the true cost of the resources used for brewing, the thesis is framed by the concept of Environmental Management Accounting (EMA). EMA tries to connect environmental information to economic variables in order to improve the internal decision-making process to take into account the full picture (Jasch, 2009). Given that the focus of the thesis lies on the natural resources used in breweries, EMA in this context refers to Natural Resource Accounting (NRA), a branch of EMA. This approach requires more monitoring of the various flows of the industry, which is illustrated by Table 2-3.

Table 2-3. Input-Output flow of breweries excluding emissions to air, noise and energy.

Input	Output
<i>Raw Material</i>	<i>Product</i>
Malted Barley	Bottled Beers
Yeast	Canned Beers
Hops	
Brewing Water	
<i>Packaging</i>	<i>By-products</i>
Bottles	Spent Grains
Cans	Spent Hops
Caps/Corks	Liquid Yeast
Labels	
<i>Operational Materials</i>	<i>Waste</i>
Cleaning Products	Glass
Disinfecting Materials	Metal
Neutralisers	Plastic
Cooling Materials	Cardboard
Salts	Mixed Waste
Filters	Sludge
Other	
<i>Water</i>	<i>Wastewater</i>
Municipal Water	
Ground Water	
Spring Water	
Rain/Surface Water	

Source: Author’s own illustration adapted from Jasch (2009).

2.3.2 Social Sustainability

Although the environmental dimension is a condition without which the other aspects would not exist, social sustainability is necessary to reconcile the three dimensions (Vallance et al., 2011). According to Vallance, Perkins and Dixon (2011), social sustainability can be organised into three categories namely Development, Bridge and Maintenance Social Sustainability, as shown in Figure 2-2.

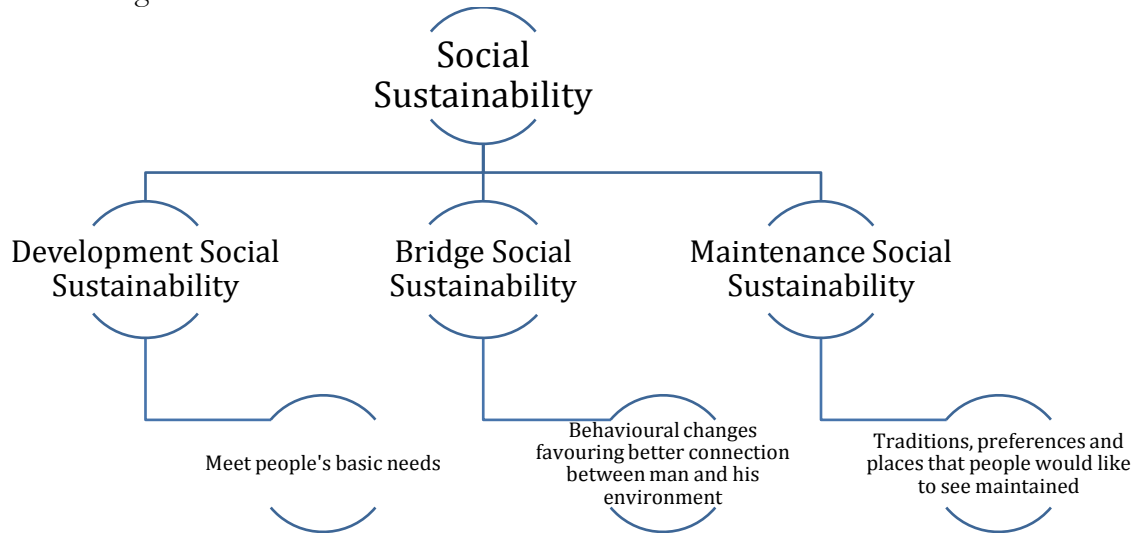


Figure 2-2. Social Sustainability.

Source: Author's own illustration adapted from Vallance et al. (2011).

In this case, social sustainability only encompasses MSS; Development Social Sustainability is left out, as it is a more holistic concept not applicable to the case at hand. Bridge Social Sustainability (BSS) is not part of social sustainability, as the thesis's scope is limited to the boundaries of a brewery and that BSS pertains more to the beer consumer. Some authors perceive MSS as a fourth pillar to sustainability, namely cultural sustainability (Soini & Birkeland, 2014). This cultural dimension, whether seen as a separate pillar of sustainability or not, can be understood as pathways to sustainability when they are compatible with the values, traditions, and history of the locality or region (UNEP, 2002). However, it can be a hindrance when new sustainability initiatives contradict cultural preferences or clash with traditions (UNEP, 2002; Vallance, Perkins, & Dixon, 2011). Consequently, culture is part of the instrument enabling other dimensions to achieve sustainability (Soini & Birkeland, 2014).

MSS encompasses the heritage of a region, province or locality in form of the norms, values and shared beliefs of its inhabitants (Vlek & Steg, 2007). In addition, the culture of beer has, in the last decades, risen from the ashes (Swinnen, 2011). Therefore, to account for this rebirth of microbreweries, an additional factor specific to beer sharpens the concept of culture. Flack identified this as neolocalism: "this self-conscious reassertion of the distinctively local" (1997, p. 38). Nevertheless, because the term local is too often conflated with sustainable (Duell, 2013), the thesis investigates the role of culture with regard to sustainability in the microbrewing sector. The chosen framework of the study is portrayed in Figure 2-3, the unique design of the framework is a consequence of its novelty, as neolocalism has not yet been studied as part of a three pillared approach to sustainability. Patterson & Hoalst-Pullen (2014) only designed a set of questions for breweries related to social and cultural sustainability, but never developed a concrete framework of study.



Figure2-3. Maintenance Social Sustainability Framework.

Source: Author's own illustration inspired by Vlek & Steg (2007) and Vallance et al. (2011).

2.4 Data Analysis

In the findings chapter, the data, both qualitative and quantitative, collected during the visits and interview, are presented. Following the framework, the results are divided into two components, the NRA and theMSS. The format in which those data is shown depends on the type of data gathered; quantitative data are displayed in graphs and charts. The qualitative data related to the NRA are used as explanations of the quantitative data. Appendix III contains the original data gathered from the visits that are processed through Microsoft Excel and presented following the literature review's structure. In the case of the MSS component, the quantitative data collected in the form of notes during the exchange with brewmasters are paraphrased in the findings chapter and structured according to the literature.

3 The Brewing process

Before delving into the thesis' core research, it is useful to retrace the origins of beer as well as to explain the brewing process. Elucidating beer brewing enables the reader to, later on, better understand why some steps can be considered as hotspots in terms of water consumption, waste production or wastewater generation.

3.1 History of Brewing

The origins of fermentation are the source of great debates; Joffe (1998), Braidwood (1953), and Katz and Voigt (1986) defend the hypothesis that it was the discovery of fermentation that brought nomads to settle down. Whereas Hornsey (2003) argues that the ability to produce alcoholic beverages sprung from a sedentary lifestyle. Regardless of the debate on the origins of fermentation, brewing is believed to have been discovered around 8 000 years ago (Hornsey, 2003; Bamforth, 2009). Latterly, with the rise of urbanisation and the resulting increase in population density, the issue of contaminated water arose (VisitFlanders, 2014). This triggered the search for alternative, non-contaminated beverages. Beer proved itself to be the most suitable as it was easily accessible, relatively inexpensive to produce and being boiled it presents little risk of contamination.

3.2 The Brewing Process

As dictated in the Belgian royal decree of the 31st of March 1993, beer is: “[a] drink, obtained after alcoholic fermentation of a wort prepared principally from sugary and starchy raw materials of which at least 60% is malted barley or wheat, from hops, optionally in processed form, and brewing water”⁷. This definition of beer lists the main ingredients necessary for brewing: water, malt, and hops. Yeast is not listed as a main ingredient as some brewers ferment the wort by spontaneous fermentation. Regardless of whether yeast is added by the brewer, the brewing process is a slightly complex process starting with the malting of the grains, usually barley⁸, and ending with packaging of the beer, as illustrated in Figure 3-1.

3.2.1 Malting

Barley is the most utilised type of grain in brewing, this results from some of its properties which renders it particularly adequate for beer making: easy to malt, high starch to protein ratio⁹, low moisture content and simpler to grow than other types of grain (Buglass, 2011a). Since barley in itself is hard and not easily friable, brewers prefer using malted barley (Mulder & Dubief, 1861; Briggs et al., 2004). Malting is a special degree of modification to the grain¹⁰ that softens it and renders the inner part of the barley more soluble (Buglass, 2011a).

⁷31 mars 1993. - Arrêté royal concernant la bière. Art. 2 §1.

⁸ Millet, rye, wheat, sorghum and oats can also be malted (Briggs, Brookes, Stevens, & Boulton, 2004).

⁹ Sugars are important in the brewing process as they trigger natural enzymatic reaction for the breakdown of starch into fermentable sugars.

¹⁰ Different degrees of modification yield distinctive malts that are then used for particular types of beer, a least modified malt is preferred for traditional Pilsner style beers, whereas rather more highly modified malts are used for pale ales (Buglass, 2011a)

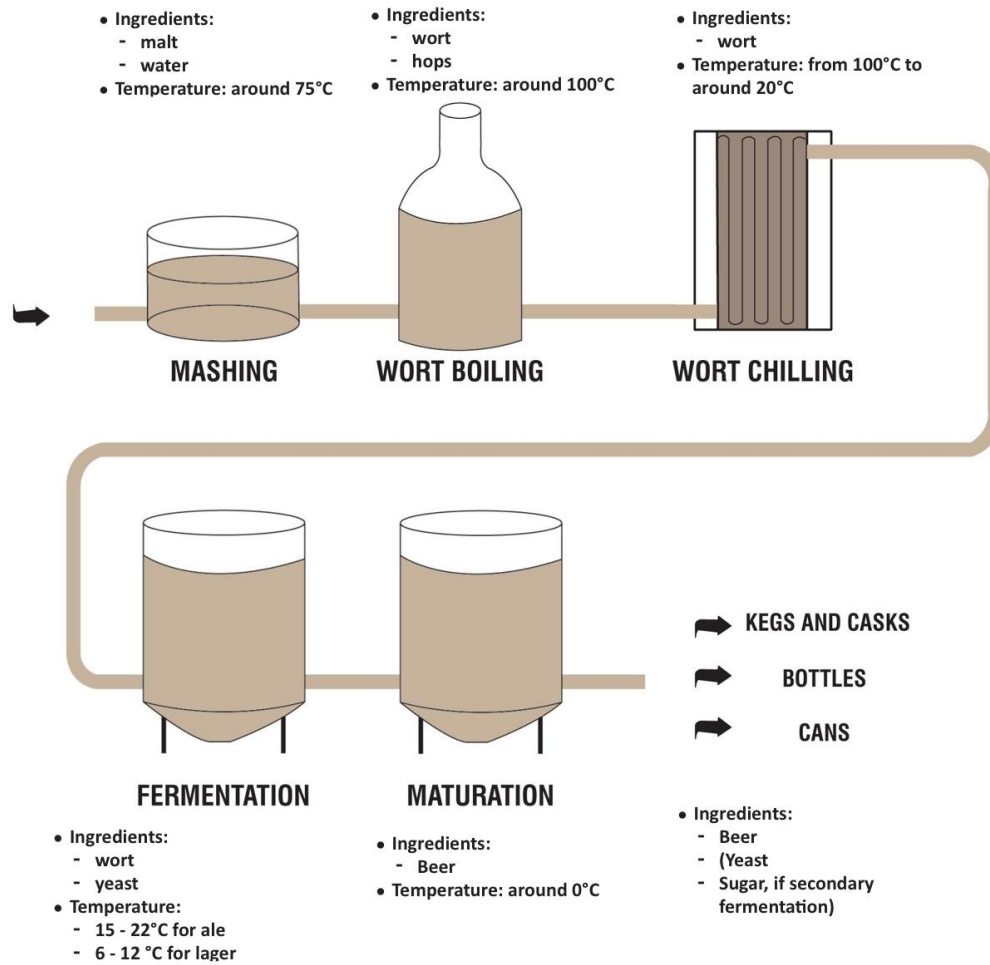


Figure 3-1. Brewing process.

Source: Author's own illustration inspired by Hardwick (1994) and *The Brewers of Europe* (2002).

3.2.2 Milling and Mashing

Now that the barley has been malted, the malt can be milled and mashed to trigger the fermentation process.

Milling

The objective of milling is to break open the malt in order to maximise the extract yield during the mashing phase (Briggs et al., 2004). According to Buglass (2011a), small breweries prefer coarse milling as it leaves the malt's hull undamaged allowing it to act as a filter bed in a later step of the beer production, namely mashing.

Mashing

At this stage, the second main ingredient is introduced in the process: water. The principle behind mashing is mixing malt with hot water, between 63 to 75°C depending on the type of mashing¹¹, for a given period of time in a mash tun or vessel to obtain wort, a liquid rich in materials dissolved from malt (Briggs et al., 2004). The mashing step can be done in wood, steel (Mulder & Dubief, 1861) or aluminium vats, but metallic surfaces should be favoured as they facilitate cleaning procedures (Buglass, 2011a).

¹¹Infusion mashing, Decoction mashing, Double infusion, or Temperature programmed infusion.

3.2.3 Lautering

Lautering is the term used in brewing when solids and other residues are removed from the wort. The enriched liquid flowing out of the mashing step is filtered either through a false bottom filter bed or with the hull of the malt acting as a filter bed (Buglass, 2011a). Modern lauter tuns include rakes to agitate the mash, pumps to improve run-off efficiency or are designed to minimise oxygen intake, which can affect beer quality (Boulton & Quain, 2008).

To improve extract recovery rates, breweries use sparging. After the wort has been filtered and recuperated, the retained grains are rinsed with 74 to 78°C water (Buglass, 2011a). This yields a second and even third wort that carry away remaining extracts of the malt (Briggs et al., 2004). All worts are then recovered in a collection vessel before being processed.

Spent grains recuperated from lautering have high Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Suspended Solids (SS) content, making them a valuable by-product that can be used as fodder.

3.2.4 Wort Processing

Wort Boiling

During wort boiling, a third ingredient is added: hops or hop preparations (Pavslar & Buiatti, 2009). As the name of the method reveals, the wort is brought to a boil to fulfil several objectives: sterilising and concentrating the wort, stopping further transformation of the wort, removing unwanted volatile compounds and precipitating materials such as spent hops, which are removed in the clarification phase (Briggs et al., 2004; Pavslar & Buiatti, 2009; Buglass, 2011). It is interesting to note that this 1-1.5 hour long process consumes half the energy required in the brewing process (Briggs et al., 2004; Buglass, 2011a).

Wort Clarification

Wort boiling helps separate the 'hot break', which consists of spent hops and other residues circulating in the vessel, from the wort. In the clarification phase, wort is again filtered through either a perforated false bottom or through the spent hops acting as a filter bed (Buglass, 2011a). Similarly to the lautering step, the spent hops is sparged with hot water to maximise the recovery of remaining hops extracts. Alternatively, whirlpool tanks are now widely being adopted in breweries to purify wort (Briggs et al., 2004; Buglass, 2011a). A centrifugal force is induced to the circulating wort, forcing the residues and deposits to settle in the centre of whirlpool tanks.

Analogically to the spent grains, spent hops is characterised by high BOD levels and has a high SS content that could cause rises in effluent charges if that waste was to be drained (Briggs et al., 2004). Consequently, the spent hops is usually used as fertiliser (Buglass, 2011a).

Wort Cooling

The purpose of cooling down the hopped wort is to obtain a temperature suitable for yeast inoculation or pitching in brewery terms (Briggs et al., 2004). It was already known in the 19th century that wort had to be cooled down quickly to prevent microbial contamination (Mulder & Dubief, 1861; Briggs et al., 2004). The wort temperature after cooling depends on the type of beer, ales require 15 to 22°C, whereas lagers demand 6 to 12°C (Briggs et al., 2004). Habitually, breweries use vertical coolers, in which the wort is introduced at a temperature close to 93°C. This method cools down wort in a counter-flow manner with the help of heat exchanger plates.

In this process, the ‘cold break’, small particles precipitating, separates from the wort (Briggs et al., 2004). There is a debate on whether or not this ‘cold break’ should be removed, Buglass (2011a) defends the position that small amounts are beneficial to fermentation whereas others argue that it can negatively influence fermentation (Briggs et al., 2004). Brewers removing ‘cold breaks’ usually filter the cooled wort with diatomaceous earth or perlite. They use centrifugation, sedimentation or flotation. Flotation is a preferred method as it can be combined with yeast aeration and pitching.

Wort Aeration

The last step before the yeast can be pitched is the oxygenation or aeration of the wort, necessary for yeast growth (Briggs et al., 2004). When the wort has not yet been separated from the cold break, aeration has the double function both to achieve the desired level of dissolved oxygen in the wort and, as some of the oxygen rises to the surface, they collect some particle of the ‘cold break’ forming a foam layer, this is called flotation. Some beers, such as Lambic, Gueuze and certain African beers, use open air-cooling to provoke spontaneous fermentation, meaning that while the wort cools down the yeast naturally present in the air inoculates the wort.

3.2.5 Fermentation

Yeast is a microorganism that breaks down the sugar in the wort and mainly produces ethanol and carbon dioxide (Briggs et al., 2004). Consequently, the conversion rate is directly proportional to the quantity of pitched yeast and temperature of the wort (Bamforth, 2003). The pitched yeast can either be derived from previous fermentation or bought from a yeast producer (Buglass, 2011a).

During fermentation, brewers have to control several parameters that influence the quality of the final product, namely the type, quality and quantity of yeast pitched, the composition of the wort and its pH as well as the temperature and pressure of the fermenting wort (Briggs, Hough, Stevens, & Young, 1982).

3.2.6 Beer Processing

Yeast removal

After the wort has been pitched with yeast and undergone a primary fermentation, the resulting product is called ‘green’ beer (Briggs et al., 2004). Before the green beer starts secondary fermentation, the maturation phase, a large portion of yeast is removed whilst the beer is being transferred from the fermenting vessel. Ale yeast can either be removed by skimming the surface film or by taking advantage of fermentation tanks’ conical design, which lets the yeast settle down and facilitates yeast separation (Buglass, 2011a). The collected yeast can be stored in a refrigerated room before being pitched into subsequent beer batches.

Maturation

The green beer then needs to be stored for several weeks with decreasing temperature until it reaches 0°C. This process serves a number of purposes: flavour maturation, carbonation, standardisation and clarification (C. W. Bamforth, 2003; Briggs et al., 2004; Buglass, 2011a).

3.2.7 Finishing and Packaging

Finishing

Before the beer can be packaged, it needs to undergo a final clarification and filtration stage to remove any remaining yeast and other impurities. Again, the design of the maturation tanks can play a key role in simplifying the yeast removal phase (Briggs et al., 2004). Clarification can

either be completed by letting the yeast surplus settle at the bottom of the maturation tanks or by centrifugation (Briggs et al., 2004). Whereas the former technique traps a certain quantity of beer, the latter technique presents the disadvantage of consuming a lot of electricity and increasing the beer's temperature by a few degrees.

Filtration is a final step in clarification, removing remaining yeast cells and particles, it is a polishing step (Briggs et al., 2004; Buglass, 2011a). Sheet filter is the technique achieving the most cost effective beer clarification. It either uses diatomaceous earth or perlite, a volcanic material that is gaining a renewed interest as environmental and health concerns are being raised regarding the waste management issues related to diatomaceous earth¹² (Briggs et al., 2004, Olajire, 2012).

Packaging

Before being filled with beer, bottles and cans are washed and rinsed with sterilized water then supersaturated with either carbon dioxide or nitrogen (Buglass, 2011a). When filled, bottles and cans' carbon dioxide content is adjusted to exclude oxygen as much as possible.

For a longer shelf life, if full sterilisation has not been carried out previously, pasteurisation is required (Buglass, 2011a). Bulk beer in kegs is flash pasteurized, whereas bottles and cans are tunnel pasteurized (Briggs et al., 2004). Flash pasteurisation uses a plate heat exchanger to bring beer to pasteurisation temperature before cooling it down with a counter flow of cold beer (Briggs et al., 2004; Buglass, 2011a). Tunnel pasteurisation sprays hot water on bottles to keep them at an approximate temperature of about 60°C during 20 minutes before slowly cooling down the bottles. Although a very safe sterilisation method, it is respectively twice and five times as expensive as sterile filtration and flash pasteurisation.

¹² "From environmental point of view, the diatomaceous earth is recovered from open-pit mines and constitutes a natural and finite resource. After use, recovery, recycling and disposal of [diatomaceous earth] (after filtration) are a major difficulty due to their polluting effect. From the health perspective, the used diatomaceous earth is classified as "hazardous waste" before and after filtration. From an economic standpoint, the diatomaceous earth consumption and sludge disposal generate the main cost of the filtration process." (Olajire, 2012, p. 6)

4 The Economics of Brewing

In the nineteenth century a series of discoveries drastically changed the brewing industry. The most important are probably the discovery of lagering¹³, pasteurisation and the steam engine, which, on top of assisting in operating machinery, helped decrease transportation costs (Swinnen, 2011). Nonetheless, just like any other industry, the brewing one was deeply affected by the World Wars. Food shortages and mobilisation translated into expensive primary ingredients, such as grains, and a growing scarcity of manpower (Swinnen, 2011; Patterson & Hoalst-Pullen, 2014). Even after 1945, food scarcity persisted; consequently many breweries were forced to close down.

The twentieth century is therefore seen as a turning point in the brewing sector as it triggered consolidation in Belgium, as illustrated in Figure 4-1 (Swinnen, 2011). Consolidation meant that breweries would either combine efforts to increase their competitiveness or be acquired by rivals (Patterson & Hoalst-Pullen, 2014). It was necessary since large investment was required to revive and mechanise the industry (Swinnen, 2011; The Economist, 2011). Some breweries, such as Martin's, expanded their offer and started producing mineral water and lemonade, which contributed to achieving economies of scale and reducing costs (Swinnen, 2011; Martin's, 2015). Yet, in less than one century the Belgian brewing industry lost 96% of its breweries either to consolidation or due to economic downturn (Swinnen, 2011). Other countries such as the UK and the USA experienced a similar decrease in the number of breweries.

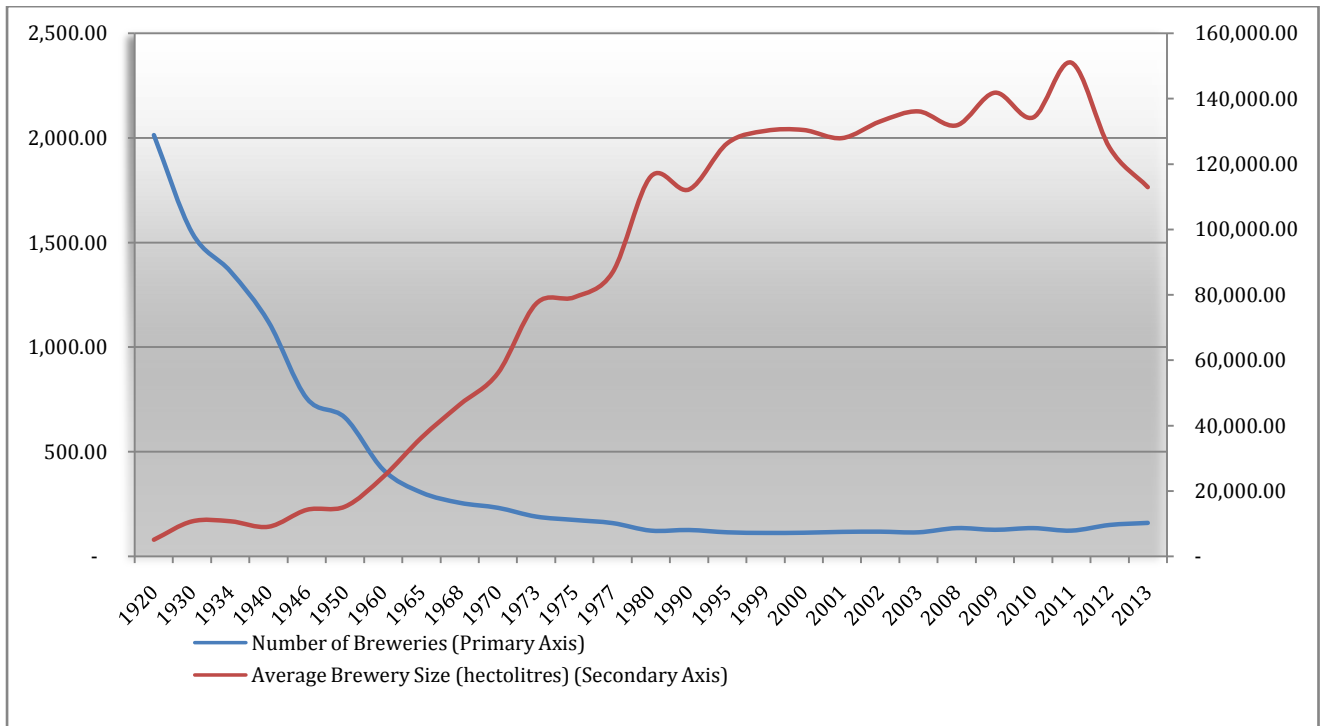


Figure 4-1. The number of breweries and the average size of breweries in Belgium (1920 – 2013).

Source: Author's own illustration adapted from Swinnen (2011), Vanneste (n.d.) *Brewers of Europe* (2014) and Thijs (2015).

¹³Lagering is a brewing technique whereby, through cold storage, beers are bottom-fermented. Today more than 90% of beer produced are lagers (Pavslar & Buiatti, 2009).

Since 1980, a counter-movement to this standardisation trend has formed; special beers are experiencing a renewed interest (Swinnen, 2011; Patterson & Hoalst-Pullen, 2014). The USA is the country where very small breweries, called microbreweries, have flourished the most. Although many have grown a lot since then, the label microbrewery sticks because of the type of beer produced. In the USA, they now represent 5 to 7% of the market. In Belgium, where some beers were traditionally brewed in monasteries and abbeys, the revival is even more remarkable as breweries producing less than 200 000 hectolitres per year now represent more than 40% of the total Belgian beer production [derived from (Swinnen, 2011)].

If, at the beginning of the twentieth century, 90% of Belgian beer production was destined for the domestic market, nowadays more than half of the total beer production is exported (Swinnen, 2011; Brewers of Europe, 2014). This radical change can be explained by two factors. The first important factor is globalisation, which has transformed the world market by increasing consumers' beverage choice, among which wine, cider, and other types of drinks are to be found. Globalisation has also enabled Belgian beers to reach new markets, driving big breweries to increase their capacity. Consequently, those breweries as they mechanise their operations and standardise their beers leave market opportunities for special beers. The second factor is income: after the two world wars, incomes have increased allowing consumers to purchase both more as well as new and different products. This is why consumption, on a per capita basis, in beer-producing countries such as Belgium has been decreasing (The Economist, 2011). Yet, nowadays, combined Belgian breweries produce more than 1 500 different brands of beer and have revenues amounting up to 2.2 billion EUR (VisitFlanders, 2014). In addition, the Belgian brewing sector employs 4 469 workers directly and 45 000 indirectly.

As large breweries seek to take advantage of every opportunity, many have developed or purchased microbreweries. On top of reaching new niche markets, those beers can benefit from the "mother" breweries' distribution system. Alken-Maes brewery is one such example: it mass brews approximately 600 000 hL of six different types of craft beer annually, Grimbergen, Ciney, Hapkin, Judas, Scotch Watneys and Red Barrel (Pascal, 2004). AB Inbev, the world's largest brewery also capitalised on these market opportunities as it owns Leffe, an abbey beer, perceived as a regional special beer, now holding a 10% market share of France's beer sales and is exported to more than 70 countries (AB InBev, 2013; Le Boulenger, 2014).

This rebirth or rise of microbreweries over the last 25 to 30 years, is an issue that has caught the attention of many connoisseurs and has even given rise to a new term: neolocalism (Flack, 1997; Patterson & Hoalst-Pullen, 2014). Flack in his paper "*Ale-ing*" for a Sense of Place gives the first definition of the term: "self-conscious reassertion of the distinctively local" (1997, p. 38). According to the author, the success of microbreweries cannot be analysed without acknowledging the neolocal component.

However, given that brewing is a water intensive and waste generating process (Olajire, 2012; Patterson & Hoalst-Pullen, 2014), this emergence of microbreweries raises important issues regarding sustainability.

5 Literature Review

The literature review intends to clarify the study's framework, which entails clarifying the term sustainability and developing the NRA and MSS frameworks in the context of beer brewing. The literature review also briefly elucidates the best cleaner production and pollution prevention practices and techniques adopted by the brewing sector. Finally, waste, water and wastewater management subsections are supplemented by European and Belgian legal requirements.

5.1 Sustainability

Sustainability has a plethora of definitions and is often used interchangeably with the term sustainable development, as defined in the Brundtland Report. Here, the definition of Kohn and Gowdy (2001) is adopted, where sustainability is defined as a life principle about self-reliance and adjustments to internal as well as external factors. In this case, these factors or dimensions are three-fold: economic, environmental and social. They represent the three-pillared approach to sustainability guiding the research, illustrated in Figure 2-1.

5.2 Natural Resource Accounting

5.2.1 Economic sustainability

Economic sustainability outlines how economic strategies in the brewing industry should evolve to increasingly account for the scarcity of natural resources (UNEP, 2002). As Jasch (2009) puts it:

“Conventional management accounting systems attribute many of [the] environmental costs to general overhead accounts, with the consequence that product and production managers have no incentive to reduce environmental costs and are often unaware of the extent of environmental and material flow related costs.” (Jasch, 2009, p. 3)

One type of environmental management system that has gained attention is green accounting or EMA (Brorson & Larsson, 2006). EMA's aim is to reveal the true cost of waste (Jasch, 2009). This management system seeks to correct assets according to their environmental costs, assist in avoiding economic burden and detect environmental costs that could be capitalised on (Brorson & Larsson, 2006; Jasch, 2009). In other words, EMA helps link material and energy flow with financial information (Jasch, 2009). EMA can be a complex and tedious task, especially if all aspects are included. Therefore, in this thesis, EMA is limited to one branch, namely NRA and only includes waste, water and wastewater flows in breweries. The reason for choosing those three features is related to the fact that the brewing industry still faces significant environmental challenges in the management of waste, water, and wastewater (Olajire, 2012).

One of the minor aims of the thesis is to reveal the true costs of water and waste. Wherever possible the Total Corporate Environmental Cost (TCEC), as shown in the equation below, is calculated (Jasch, 2009). TCEC is one of the Key Performance Indicators (KPI) that is used to compare large-scale and microbreweries in Belgium. Environmental Protection Expenditure are the costs linked to technologies or systems in place that either treat emissions before they are released into the environment, e.g. cleaner production, or contribute to the prevention of pollution. Material Flow Cost encompasses the purchase cost of the material, the cost of handling it as well as its disposal.

$$\begin{aligned} \textit{Total Corporate Environmental Cost} \\ = \textit{Environmental Protection Expenditure} + \textit{Material Flow Costs} \end{aligned}$$

This type of cost accounting system has already been studied for different breweries by Jasch, (2009), Fakoya and van der Poll (2013) and Fakoya (2014). The authors all come to the same conclusion that EMA could, in an industry with such considerable waste, provide new opportunities to increase profitability and reduce wastage.

5.2.2 Environmental sustainability

The previous section showed that in order to make the case for waste reduction and input optimisation, a new kind of accounting was needed, one that would connect environmental costs to financial information. Such accounting has the potential of underscoring existing inefficiencies along the brewing process, inefficiencies upon which management teams will want to act. As the thesis' scope is limited to water, waste and wastewater, the following literature develops a general overview of the pollution prevention and cleaner production techniques already in place in breweries in those fields.

Hygiene and good housekeeping are of the utmost importance in all production of goods, but, when it comes to human consumption, stringent hygiene standards have to be respected. Therefore, it comes as no surprise that huge amounts of water are consumed per annum in order to wash and sanitise the various pieces of equipment required to brew beer. According to Brewers of Europe (2012), breweries all across Europe use 2.5 to 6.4 L_W/L_B produced. For Olajire (2012) efficient breweries have a water consumption ratio between 4 and 7 L_W/L_B , whereas breweries' water ratio in general varies between 4 and 10 L_W/L_B . Goldammer(2008) also points out that such a ratio is even higher for small breweries. In 1998 the World Bank reported a range for the German industry ranging from 4.9 to 12.6 L_W/L_B . In addition, breweries also generate large amounts of organic waste as a result of the mashing, wort processing and fermentation steps. Figure 5-1 provides a visual summary of the main waste and water flows occurring along the brewing process.

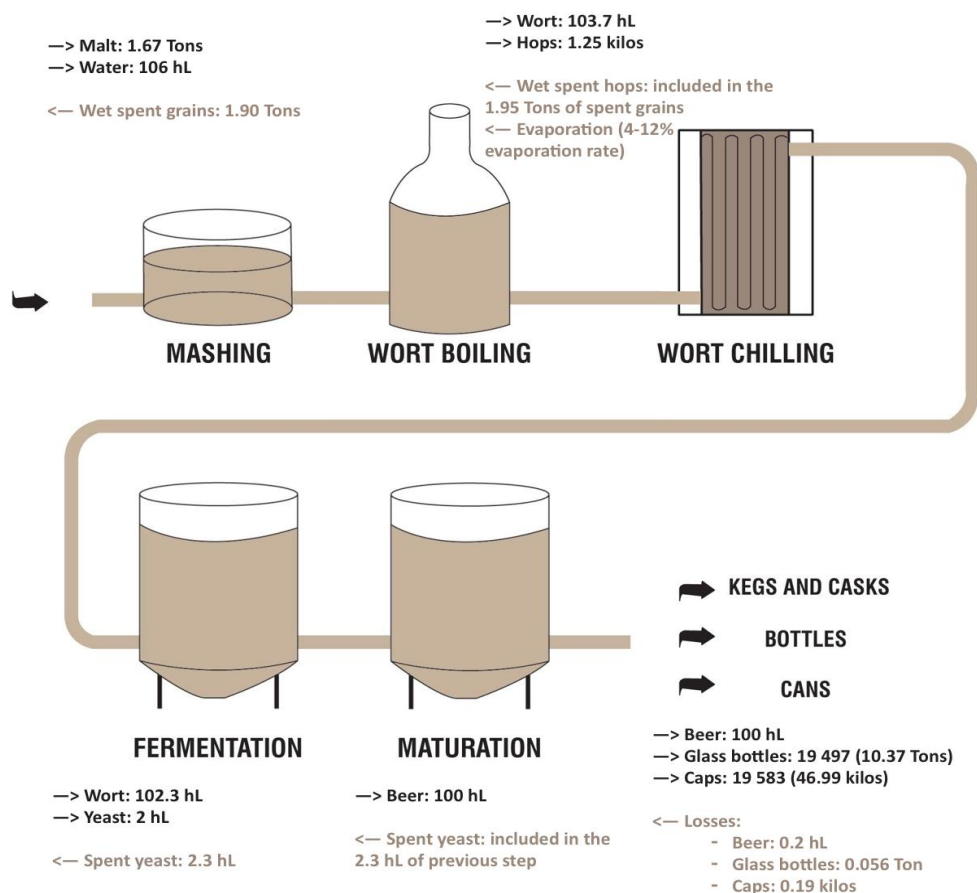


Figure5-1. The brewing process and the main inputs and waste produced and normalised for the production of 100 hL litres of beer, step by step, excluding cleaning water and products (Black arrows and texts indicate inputs; beige arrows and texts indicate waste generated).

Source: Author's own illustration inspired by Koroneos, Roumbas, Gabari, Papagiannidou, & Moussiopoulos (2005) and Olajire (2012).

Water Management

Water is a key natural resource in the production of beer for several reasons. First of all, beer is made out of more than 95% of water (Olajire, 2012; Patterson & Hoalst-Pullen, 2014; Skovira, 2015). It therefore comes as no surprise that the quality of the water and its mineral content play an important role when brewing (Patterson & Hoalst-Pullen, 2014). Eßlinger and Narziß (2009) even go as far as stating that water is the element explaining “why different beer types developed in different regions” (Eßlinger & Narziß, 2009, p. 184). Secondly, large amounts of water are used for cleaning and washing as well as for cooling and heating, which is reflected in the relatively high water ratio of breweries (Briggs et al., 2004). According to the World Bank (1998), a brewery's water use, ranging from 4.9 to 12.9 L_W/L_B , can be divided following the brewing process:

1. Brewing: 2.7 – 6.8 L_W/L_B ;
2. Packaging: 1 – 2.3 L_W/L_B ; and
3. Auxiliary (e.g. sanitary, steam boiler, air compressor): 1.2 – 3.8 L_W/L_B .

To better understand the struggles behind minimising water consumption in breweries, the ratio is written out as an equation where water is divided according to the different grades of water required in breweries, namely brewwater and process water. This classification is based on the categories defined by Briggs (2004) and Klemes, Smith and Kim (2008).

$$\text{Water Use} = \frac{\text{litres of water consumed}}{\text{litres of beer produced}} = 0.95 + \frac{\text{process water} + \text{water losses}}{\text{litres of beer produced}}$$

Consequently, it would be impossible for any brewery to achieve a water usage ratio below 0.95 litres, as the brewwater is, in the end, the beer's water content, which is inherently a constant value¹⁴. Reaching such a low ratio would mean that there are no leakages, that all losses to evaporation are recycled and finally that all the wastewater flowing out of the various tanks after cleaning is entirely recycled and reused (Klijnhout & Eerde, 1986; Force, 2013). Supporting the idea that achieving such low water efficiency is difficult, the Environmental Technology Best Practice Programme (1998) and Force (2013) state that most breweries discharge between 70 and 90% of their input water as effluents.

Process water consists of cleaning and sanitising water that needs to meet certain quality criteria so as to optimise the cleaning agents' effectiveness, which impurities in water could undermine (Briggs et al., 2004). To meet the standards set by breweries, water can be treated by using filtering systems, water softeners, reverse osmosis or other water purifying techniques (Bamforth, 2006). Process water is also used for cooling purposes during the fermentation and ageing stages and for heating purposes during the mashing and boiling

¹⁴To simplify calculations, the assumption is made that the input brewing water is equal to the water content of a beer. In practice, input brewing water is higher than the water contained in the final product, this is mainly due to evaporation occurring in the mashing and wort boiling phase and water present in by-products, spent grains, hops and liquid yeast (Brewers of Europe, 2002). However, condensates can be reused or recycled in the drinks industry as the European Commission with its BAT documents on integrated pollution prevention demonstrates (2006). In addition, water contained in wet by-products can be recuperated by centrifugation. Consequently, this false assumption does not refute the fact that 0.95 is a limit below which it would be physically impossible for any brewery to go.

phases or even for vapour utilisation in some breweries and for steam boilers (Tokos, Pintarič, & Krajnc, 2011).

After its first usage, water can still often be reused for a later cleaning procedure; a straightforward practice to effectively reduce water consumption and a practice that CIP tanks can facilitate. Other practices include recycling water for another use with lower quality requirement (e.g. floors and counter-current rinsing) and optimisation of cleaning processes (The Brewers of Europe, 2012). To both minimise water and energy losses, breweries generally try to design their cooling and heating systems so as to have a closed loop, where little to no water is lost and thus only requiring minor water input. The wide variety of process water used, underlines the widespread range of water quality requirement in breweries, as water used for steam boilers has different quality requirements than that utilised during the last step of a sanitising procedure (Briggs et al., 2004).

The water use ratio also illustrates the gain that occurs when breweries scale up their production (Palmer & Kaminski, 2013). In most cases, the relation between beer production and water used for cleaning is non-linear, meaning that as beer production increases, water use rises but very often to a lesser extent. This follows largely from two interdependent variables: the cleaning procedure and the tanks. A tank's size and surface are the endogenous variables affecting the exogenous variable, namely the cleaning procedure (Bamforth, 2006). Similarly, larger beer production volumes suggests higher revenues and thus potentially more investment capacity to increase water efficiency inside the brewery (Briggs et al., 2004). Increased actions to reduce the water use ratio can also be taken in recovering water trapped in by-products or lost in some part of the process, such as in the form of evaporation during the wort boiling stage (EIPPCB, 2006). The organic waste's water content can be retrieved through centrifugation and evaporation loss reused or recycled through condensate recovery.

Furthermore, from a legal standpoint, all waters used within a brewery in Belgium, have to follow the quality requirement dictated by the Belgian royal decree of the 14th of January 2002¹⁵. The water has to meet the minimum requirement on microbiological and chemical parameters set by points I and II of the royal decree's annex. In another Belgian royal decree that was modified on the 13th of July 2014¹⁶, food business operators are required to prevent contamination, to appropriately disinfect all pieces of equipment, to ensure staff awareness about health issues, etc. Although other decrees regulate some smaller aspects of the brewing industry, the previous two decrees are the most constraining and important.

Table 5-1 briefly illustrates various practices commonly implemented in breweries to reduce water consumption. Obviously, the following recommendations are general suggestions and their implementation will be dependent on the brewery's capacity and investment potential. Depending on the beer's type and market regulation, some breweries might be forced to pasteurise their beers, which would *hitherto* increase water consumption significantly (EIPPCB, 2006).

Table 5-1. Common practices to reduce water consumption in breweries.

Process Stage	Practice Description	Costs	Benefits	References
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¹⁵ 14 janvier 2002 - Arrêté royal relatif à la qualité des eaux destinées à la consommation humaine qui sont conditionnées ou qui sont utilisées dans les établissements alimentaires pour la fabrication et/ou la mise dans le commerce de denrées alimentaires.

¹⁶ 13 juillet 2014. — Arrêté royal relatif à l'hygiène des denrées alimentaires

Wort Boiling	Condensate recovery supplying hot brewing water for the next batch or for cleaning operations	High upfront cost with a payback period of a few years	Water savings Energy Savings	(EIPPCB, 2006)
Wort Cooling	Counter-current heat exchanger	Less than 1 500 € with a payback period of less than a year	Water savings Wastewater reduction Energy savings	(EIPPCB, 2006)
Fermentation	Closed-circuit cooling	Less than 1 500 € Payback period of a few months	Water and wastewater savings Improved cooling	(EIPPCB, 2006)
	Fermentation tanks with cooling jackets (instead of panel coolers)	Dependent on tank capacity	Easier cleaning	(EIPPCB, 2006)
Beer Processing	Cross-flow filtration instead of diatomaceous earth	High upfront cost with a payback period of a few years	Water savings Reduce wastewater load Reduce waste disposal costs	(EIPPCB, 2006; Fillaudeau, Blanpain-Avet, & Daufin, 2006)
Packaging	Reduce nozzle size of bottle-rinser from 8 m ³ /h to 3 m ³ /h	Price of nozzles	AB Inbev Leuven saved 47 000m ³ by reducing nozzles' size	(The Brewers of Europe, 2012)
	Overflows from the pasteurisers are collected in tanks	The capital costs were 162 000 € with a payback of around 15 months	Savings in water and wastewater of 80 % and of 23 % in chemicals were achieved	(EIPPCB, 2006)
	Bottle cleaning machine: neutralisation of the first hot bath after caustic bath with CO ₂		Achieve a water consumption per bottle of 200ml. Chemical savings and improved efficiency Reduce wastewater load and scale formation	(EIPPCB, 2006)
	Bottle cleaning machine: Reuse of final rinsing water for the first rinsing steps.		Water savings	(EIPPCB, 2006; The Brewers of Europe, 2012)
	Reduced nozzle size (from 2.5 cm to 1.25 cm diameter) and high pressure hoses	Low: Training and costs of the nozzles	Optimise water consumption Savings up to 30-40% and up to 60% for high pressure hoses	(EIPPCB, 2006)
Good Housekeeping	Tank design: adapt surface and shape for specific brewing steps.	Dependent on tank capacity	Renders cleaning easier, and helps separate yeast from wort.	(Buglass, 2011)
	Collecting rain water	Storage tank	4,3% of the total water used in the brewery was diverted	(The Brewers of Europe, 2012)

			to rain water	
	Training of the staff	Time and training	Good implementation of all saving measures	(Puplampu & Siebel, 2005; EIPPCB, 2006)
	CIP		Increased cleanliness High level of automation Water savings: 37% (Coors Brewers) Chemical savings	(ETBPP, 1998; EIPPCB, 2006; and Klemes et al. 2008)
Cleaning	Optimising CIP programmes to each brewing process	Training and manpower	Up to 30% water reduction	(EIPPCB, 2006)

Source: Author's own illustration, adapted from ETBP (1998), EIPPCB (2006), Klemes et al. (2008), Derden (2008), Buglass (2011a), and The Brewers of Europe (2012).

Williams and Mekonen(2014) are the only authors to have examined the environmental performance of microbreweries. For the brewing process, quantities used did not differ significantly from Figure 5-1. The authors found that to produce one litre of beer, the English microbreweries used 0.15 kilos of malted barley(=1.5 Tons per 100 hL beer production), 0,002 kilos of hops (=20 kilos per 100 hL beer production), and although not explicit in Williams and Mekonen's calculations, the quantity of brewing water is very similar. However, interestingly, the English microbrewery, with its 3.4 L_w/L_B, can be perceived as a very efficient brewery, even when compared to large-scale breweries. Unfortunately, the authors do not describe practices in place and techniques used in the microbrewery.

The EIPPCB(2006) briefly tackled the issue of process optimisation in a small brewery. It recognised that water consumption, beer losses and wastewater load are above the industry average. In the case study, the brewery that decided to act upon its inefficiencies was able to reduce its water consumption by as much as 40% by installing water meters, optimising cleaning procedures, replacing defective and leaking pieces of equipment and installing high efficiency nozzles for cask cleaning. The investment that had to be made had a payback period of three months and helped save an annual 73 000 m³ of water.

Reducing water consumption for cleaning purposes can be achieved by process optimisation, reusing and recycling water. Developing adequate cleaning procedures for the brewing process' major stages is also of great importance to decrease water and chemical consumption inside a brewery. Jeffery and Sutton (2008) presented potential reduction in water and detergent usage that could be achieved through the use of different CIP systems, Table 5-2 illustrates the main findings. According to the WRAP's research on CIP in the UK's drink sector (WRAP, n.d.), the total cost of a cleaning procedure in Coors Brewing Limited, including chemicals, electricity and water, was decreased from 53 to 30 EUR¹⁷ per tank cleaning procedure by more precisely dosing and controlling the procedure. However, the research does not provide information relative to the CIP's capacity nor to the beer tank's size.

¹⁷Given an exchange rate of: 1 GBP = 1.37 EUR, <http://www.xe.com/en/> on the 22nd of August 2015.

Table 5-2. The effect of different cleaning configurations on water and chemical use for a 30 hL vessel.

Cleaning System	Description	Water Usage [L]	Detergent Usage [L]
Boil out system	Flooding the vessel to clean it	6 500	45
Total loss system	Cleaning the vessel with the help of a spray ball	3 000	30
Single use CIP	Cleaning the vessel with the help of a spray ball and recirculation of the cleaning solution during the procedure	1 200	3
Partial reuse CIP	Cleaning the vessel with the help of a spray ball and recirculation of the cleaning solution during the procedure. Has a recovery tank to reuse the detergent solution for subsequent cleaning.	1 100	2
Full reuse CIP	Cleaning the vessel with the help of a spray ball and recirculation of the cleaning solution during the procedure. Has a detergent recovery tank and a rinse recovery tank, which uses the final rinse as a pre-rinse in next cleaning procedures.	600	2

Source: Author's own illustration adapted from (Jeffery & Sutton, 2008).

There are three parameters influencing any cleaning procedure. The first one is the equipment parameters that highlight the importance of opting for a design and materials that can facilitate the sanitation phase (Bamforth, 2006). Secondly, residues that are to be washed off and the water's quality determine the system parameters. Operational parameters are the third and final factor influencing a cleaning procedure and determine the cleaning result. The cleaning result of a cleaning procedure can always be described by the following equation (Bamforth, 2006):

$$C_r = C + M + T + Z$$

Where:

- C_r is the cleaning results, which is to be constant;
- C is the chemical properties of the cleaning solution;
- M is the mechanical properties of the cleaning solution;
- T is the temperature of the cleaning solution; and
- Z is the contact time of the cleaning solution with the equipment.

The variables, C , M , T and Z , can fluctuate during the cleaning process so as to attain the best cleaning result.

Although cleaning procedures should be adapted to equipment needing to be sanitised, Table 5-3 provides a common framework that breweries can fine tune according to their necessities. For example, fermentation tanks need to be cleaned thoroughly between beer batches, whereas a bottling line should only be cleaned thoroughly at least once every seven days (Briggs, 2004).

Table 5-3. Common cleaning procedure framework.

Phase	Description	Temperature	Contact time	Chemical agent
1. Pre-rinse	Removal of loose residues, at low temperatures to avoid cooking protein and starches on a tank's wall but high pressure (use of spray balls)	Below 35°C	Time required to flush all the residues	Water
2. Detergent circulation	Detergents dissolved in water to chemically wash off remaining deposits	~75-90°C	Establish standard time, varying with beer type (15-20 minutes)	Water and caustic soda (1-5%) or caustic potash (1-2%)
3. Intermediate rinse	Removal of all trace of detergent	Below 35°C	Time required to flush all traces of detergent	Water
4. Disinfection	Option 1: Thermal sanitation does not require a final rinsing step but does require wet steam in opposition to superheated.	130-140°C	15-20 minutes	Water vapour
	Option 2: Chemical Sanitation: chlorine dioxide	Ambient to 40°C	Until pH or electrical conductivity is at process water levels	Water, chlorine dioxide
	Option 3: Chemical Sanitation: peroxide compounds	Effective a low temperature	Until pH or electrical conductivity is at process water levels	Peracetic acid (100-200mg/L) or hydrogen peroxide, and water
5. Final rinse	Water rinsing to completely remove any sanitizers		Until pH or electrical conductivity is at process water levels	Water

Source: Author's own illustration adapted from Briggs (2004), Bamforth (2006), Tamime (2008) and Goldammer(2008).

Waste Management

The three major types of organic waste that flow out of a brewing process are spent grains (e.g. malted barley or wheat), spent hops and yeast. In cases where there is a wastewater treatment plant at the facility, a fourth waste stream might be added, namely sludge. The International Financial Corporation (IFC, 2007) estimated that for German breweries producing more than a million hL per annum, by-products generation on a kilo per hL of beer produced basis is as follows:

- Spent grains: 16 – 19 kg/hL; and
- Yeast: 1.7 – 2.9 kg/hL.

Whereas in the past it was not uncommon to wash spent grains and hops down sewers (Briggs, 2004), most brewers nowadays partner up with farmers, who use it as a fodder supplement for their animals (Oreopoulou & Russ, 2007). However, because of the high water content of this type of waste, around 80%, organic waste is not biologically stable and must therefore be used within two to three days. Yet, as the waste is of value to other industries, there is a certain willingness to pay evaluated to be in the range of 1 EUR to 6 EUR per ton of spent grains (Fillaudeau et al., 2006; Brewers Association, n.d.).

Regarding the yeast, breweries cultivating their own yeast reuse part of their yeast, but still have to discard large parts of it, just like breweries not re-pitching yeast (Buglass, 2011a). As yeast has high COD and SS content, it makes it a potentially significant contributor to wastewater load treatment when washed down a sewer (EIPPCB, 2006). A widespread secondary use for the surplus yeast is animal feed. Brewer's yeast is also believed to have health benefits and is used by the pharmaceutical industry (WebMD, 2009).

As any industry producing waste, breweries are bound to respect the food hygiene directive¹⁸, forming the basis of the European Food Safety Authority and dictating that food business operators shall apply the HACCP(Hazard Analysis and Critical Control Points) system. The directive's annex II also requires that food business operators properly store waste in containers to avoid any contamination of any product for human consumption. Regarding inorganic waste, mainly produced in the packaging area, the European Parliament and Council Directive of 1994 is particularly relevant as it aims at “[harmonising] national measures... to prevent or reduce the impact of packaging and packaging waste”¹⁹. The directive translated into national law²⁰ aims at facilitating the identification of the different types of waste to dispose of or recycle them according to the waste hierarchy.

Packaging costs can amount to up to 50% of a beer, as the Brewers Association (n.d.) points out, which, in itself, already makes a strong case for minimising losses of caps, bottles, cans and labels. Moreover, if the waste handling and disposal costs are added to the purchase cost, it becomes increasingly interesting, from an economic and resource efficiency point of view, to optimise the bottling line. Fillaudeau et al. (2006) for instance, estimated that disposal costs for waste labels can range from 0 EUR to 92 EUR per ton of wasted labels. Although, in some cases, such as for metal and glass scraps, the waste can be sold for recycling, as the selling price is inferior to the purchasing price, it should not decrease the brewers' effort to augment efficiency in the packaging area (Brewers Association, n.d.).

Wastewater Management

Similarly to the water efficiency ratio used to calculate the water consumption of a brewery on a beer production basis, an effluent generation ratio exists. According to the EIPPCB(2006), most modern breweries have an effluent generation ratio in the range of 3 to $9L_w/L_B$.

$$\begin{aligned} \text{Effluent Generation} &= \frac{\text{litres of wastewater discharged}}{\text{litres of beer produced}} \\ &= \text{Water Use} - 0.95 - \frac{\text{Water losses}}{\text{litres of beer produced}} \end{aligned}$$

Rewriting the formula and making it dependent on the water consumption makes it clear that all optimisations and reduction on the water use side have a direct impact on the effluents that have to be dealt with, be it at the facility's or municipality's wastewater treatment plant. Consequently, the difference between the two ratios will inevitably always be superior to $0.95 L_w/L_B$, while the upper limit lies, according to EIPPCB (2006) at around $1.8 L_w/L_B$. Water losses can come in the form of steam discharge, wet by-products and beer losses, the latter is estimated to range from 1 to 5% of the total beer production (IFC, 2007).

A brewery's wastewater is characterised mainly by its Biological Oxygen Demand (BOD) COD, SS, nitrogen and phosphorus level as well as its pH and temperature. Most of the BOD and COD content of a brewery's effluent have the fermentation and filtering stage as their origin (EIPPCB, 2006). The concentration of organic materials can consist of items included in the following non-exhaustive list: grains, yeast, weak wort, returned beer, push water. The SS levels in the wastewater originate from the brewing process' spent grain, hops and surplus yeast, labels from the bottle cleaning equipment and, if used, diatomaceous earth from the filtration phase. Cleaning agents contribute to both nitrogen and phosphorus levels contained

¹⁸Council Directive 93/43/EEC of 14 June 1993 on the hygiene of foodstuffs

¹⁹European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste. Art. 1 §1.

²⁰ 25 mars 1999 - Arrêté royal portant fixation de normes de produits pour les emballages.

in effluents and determine the pH. In addition, malt and additives also contribute to high nitrogen levels. The beer production industry is usually characterised by a very low level of heavy metals (EIPPCB, 2006; Olajire, 2012). Table 5-4 summarises the characteristics of brewery effluent that have been discussed in this paragraph.

Table 5-4. *A brewery's wastewater characteristics.*

Parameter	Unit	Range	Source
BOD	Mg/l	1 000 - 3 600	Organic materials
COD	Mg/l	1 800 – 6 000	Organic materials
SS	Mg/l	200 – 1 000	Label pulp, by-products, filtration
Total Nitrogen	Mg/l	12 – 100	Cleaning agents, malt, additives
Total Phosphorus	Mg/l	10 – 100	Cleaning agents
pH	-	3 - 13	Cleaning agents
Temperature	°C	18 – 40	

Source: Author's own illustration adapted from EIPPCB (2006), Brito et al. (2007), Simate et al. (2011) and Olajire (2012).

When these values are compared to the legal requirements set by the Urban Wastewater Directive of 1991 and translated into national law in the 'Code de l'Eau'²¹, see Table 5-5, it becomes obvious that treatment of the effluents is necessary. Whether a brewery opts for treating the water at its own facility or to discharge it in the sewer, the concentration level of the various parameters determines the cost of wastewater treatment. Should breweries decide to let municipalities take care of the effluent, then the taxation is based on the formula that is a function of the pollution load, namely the SS, COD and BOD levels, as well as the temperature and toxicity of the effluents. Appendix II provides more detailed information on how the pollution tax is levied.

Table 5-5. *Requirements for discharges from wastewater treatment plants.*

Parameter	Unit	Maximum concentration	Percentage reduction in relation to influent
BOD	Mg/l	25	70 - 90
COD	Mg/l	125	75
SS	Mg/l	35	90
Total Nitrogen	Mg/l	10	70 - 80
Total Phosphorus	Mg/l	2	80
pH	-	6 to 9	-
Temperature	°C	Dependent on the receiving body	-

Source: Author's own illustration adapted from Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment and 'Code de l'Eau'.

There are several drivers behind breweries installing wastewater treatment plants, the most important of which is costs. As volumes increase, the organic load of the effluents will inevitably be higher, which translates into higher costs. Consequently, the costs charged by the municipality's wastewater treatment plant increase, and it becomes increasingly interesting to

²¹27 mai 2004 - Décret relatif au Livre II du Code de l'Environnement constituant le Code de l'Eau

treat the effluent on site. As explained before, breweries' effluents are influenced by the brewing steps resulting in large fluctuations in the effluents' characteristics (Brito et al., 2007). Table 5-6 lists commonly used wastewater treatment methods used in the brewing sector (EIPPCB, 2006). Although primary treatments can all, potentially, be sequentially implemented in wastewater treatment plants to improve the process' overall efficiency, secondary treatment techniques are generally mutually exclusive.

Table 5-6. Summary of wastewater treatment methods in the brewing sector.

	Treatment	Treatment Description	Environmental Benefits	Disadvantages
Primary Treatments	Screening	Device with openings preventing large solids from entering the effluent	Decreases the organic load, reduces the SS levels and reduces the risk of odour emissions	
	Flow and Load Equalisation	Buffer tanks	Optimises the efficiency of the next treatment techniques and levels off the pH and temperature of the effluents	
	Neutralisation	To control the pH level further, the acidity or alkalinity of the effluents is neutralised	Optimises the efficiency of the next treatment techniques and reduces corrosion	If chemicals are used to neutralise it can increase the produced solid waste
	Sedimentation	Separation from water by letting particles settle or float	Reduces SS levels	Occupies large surface area if it does not use lamella separators
Secondary Treatments	Aerobic treatment	Remove biodegradable organics and SS by stabilising the waste aerobically, thanks to the addition of air or oxygen	Reduces BOD levels by up to 90%, phosphorus level by 10 to 25%	High energy cost and sludge generation, odour generation. Requires an even load.
	Anaerobic treatment	Organic matter is broken down in the absence of oxygen producing methane	Can deal with high BOD loads, reduces COD level by 75 to 90%, produces less sludge than aerobic treatment, produces methane	Slower than aerobic treatment and needs to be followed by an aerobic process before being released
	Sequential Batch Reactors	A variant of the aerobic process with two reaction tanks	Reduction of BOD, COD, nitrogen and phosphorus levels, it is a simple and more robust aerobic digester compared to conventional ones	See aerobic treatment
	Trickling filters	Water is filtered by letting it run through a bed of rocks or different types of plastics	Reduction of BOD, COD, nitrogen and phosphorus levels and potentially also hazardous substances	Odour nuisance
	Aerobic Lagoons	Large shallow basins where the effluents are aerobically digested by algae and bacteria	Reduces BOD and nitrogen levels	Potential odour nuisance, soil deterioration and groundwater contamination

Source: Author's own illustration adapted from EIPPCB (2006).

5.3 Maintenance Social Sustainability

The term sustainability was previously defined, but to understand MSS, it is important to also explain culture. Culture is a broad term, which grants it its complexity. According to Hawkes (2001), culture permeates to two interrelated concepts:

- “- the social production and transmission of identities, meanings, knowledge, beliefs, values, aspirations, memories, purposes, attitudes and understanding; [and]
- the ‘way of life’ of a particular set of humans: customs, faiths and conventions; codes of manners, dress, cuisine, language, arts, science, technology, religion and rituals; norms and regulations of behaviour, traditions and institutions.” (Hawkes, 2001, p. 3)

This division into two intertwined branches of culture reflects the two aspects illustrated by the framework of Figure 2-3: the cultural heritage and the neolocalism facets. The first branch refers to the cultural heritage of a Belgian province²², its values, memories and beliefs. The second branch *de facto* pertains to neolocalism, more particularly the role of beer in the life of the people living around the brewery and the province's inhabitants. MSS is about traditions, practices and places, which echoes Hawkes' meaning of culture. This type of sustainability can be perceived as the “safeguarding and accumulation of cultural capital” (Soini & Birkeland, 2014, p. 219). Culture both contributes to maintaining communities and their heritage as well as providing a resource for regional development (Soini & Birkeland, 2014), an idea which is correctly worded in Farsani, Coelho and Costa's definition: “the concept for the recovery and protection of cultural identities” (2012, p. 30). Their definition most accurately describes the link between culture and the environment, while differentiating it from the BSS, as the focus is no longer on the individual but rather the society wherein he or she lives.

Cultural Heritage

Cultural heritage embodies two different types of heritage, namely a tangible and an intangible one (Soini & Birkeland, 2014). The tangible heritage refers to areas, buildings and monuments that have made and are part of history, whereas intangible elements include things such as the traditions linked to specific events or tangible cultural capital. As culture arises from social interactions and its resulting customs and traditions, it is self-evident that social sustainability and the cultural dimension are inseparable (Chiu, 2004).

With the passing on of gathered knowledge from one generation to another, mankind was able to adapt to his environment, whether it was in Africa or in the most northern countries of Europe (Chiu, 2004). This also explains the deep-rooted link existing between culture and the environment, how the maintenance of one affects the other and why encouraging greater environmental responsibility requires the recognition of local cultures (Chiu, 2004; Soini & Birkeland, 2014). Consequently, it comes as no surprise that given the sense of belonging and identity provided by culture (Hawkes, 2001), the cultural heritage facet and neolocalism have become interwoven.

Neolocalism

To understand the revival of local breweries and beers, neolocalism is studied through two proxies, namely terroir and the idea that breweries create a sense of place or, in other words, a local identity, as illustrated in Figure 5-2. A terroir is defined by Patterson and Hoalst-Pullen as

²² Belgium is divided into 10 provinces whose size ranges from 1 000 km² to about 4 500 km², in other words ranging from one to three times the size of London.

“the influence that the environment has on taste” (2014, p.16). The authors define the sense of place as an attempt to recreate a link to the local community.

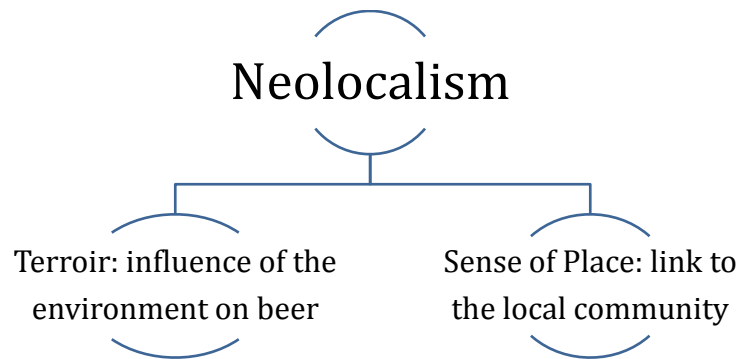


Figure 5-2. Neolocalism Framework.

Source: Author's own illustration inspired by Flack (1997) and Patterson & Hoalst-Pullen (2014).

As was highlighted in a previous section, the success of microbreweries cannot be analysed without acknowledging the neolocal component (Flack, 1997). According to Flack (1997), local microbreweries are increasingly playing an identity. Yet, in the eyes of some, this neolocalism is often assumed to produce economic and ecological benefits (Duell, 2013), a wrong assumption to make as producing something locally is no insurance that ecological impacts are diminished or taken into account (Born & Purcell, 2006). Consequently, the aim of this second component of the three-pillared approach to sustainability is simply to examine the contribution of local culture to sustainability when establishing microbreweries in Belgium.

The instigators of this incredible growth in the brewery sector are to be found on the other side of the Atlantic. The USA and UK have long defended small-scale²³ and traditional methods (Buglass, 2011b). The USA went from having 82 breweries in 1982 to having more breweries than Germany within a mere decade. By 2002, the country had more than 1 500 breweries producing beer locally (Schnell & Reese, 2003). The UK too has, since 2012 surpassed the 1 500 breweries threshold (Blitz, 2014). This movement has, in turn, influenced and infused a wind of change in the old continent's beer industry, which had been slowly decaying.

Around a century ago, Belgium had more than two thousand breweries. There are many reasons why this number was so high, first of all the industrial revolution had not significantly affected the industry yet, beer could not be conserved for long periods of time and, most importantly, beer had a different purpose (Germain, 1992; Swinnen, 2011). In those days, most of the beers had a much lower alcohol content, around 1%, and was drunk by the whole family, because of the bad water quality (Germain, 1992; Visit Flanders, 2014). Elderly people still recall that one would have to go to the local brewery or bar to fill a few pitchers of beer to drink later at home. However, at the same time, this neolocalism plays into the cultural heritage of the province, as it is perceived as a reassertion of the distinctively local (Flack, 1997).

A factor playing into the success of small-scale and microbreweries and even enhancing it, is the growing interest in zythology (Leboulenger, 2015). Zythology is to beer what oenology is to wine. As amateurs develop their palate, they raise their standards and start craving new and

²³In the UK, breweries brewing less than 5 000 hectolitres a year benefit from tax breaks (Blitz, 2014).

more innovative beer, a demand, which microbreweries tend to meet. However, large-scale breweries do not want to be left out of this trend, hence the fast development of beer offered by breweries such as Hoegaarden, Leffe, Chouffe, Duvel, etc. Duvel annually releases a limited edition of Duvel Tripel Hop, Leffe produces beers with varying types of hops (Leffe Royale Cascade IPA, Leffe Royale Witbread Golding, Leffe Royale Mapuche²⁴) and those special beer batches and editions are clearly aimed at amateurs seeking new flavours and complexity in their beers (Leboulenger, 2015). Again, as the evolution of beer in many ways resembles that of wine, beer lovers are starting to collect beers and to build beer cellars.

As with other fermented beverages such as wine, beer also has its own appellations. The Beer Judge Certification Program recognises 80 different kinds of beers, and only very few of them are restricted to a geographical area, namely, the spontaneously fermenting beer (e.g. lambic) (Patterson & Hoalst-Pullen, 2014). This is probably why the term terroir of beer has not really gained as much attention over the years.

Nowadays, however, consumers not only want good beer but opt for local beer as well (Flack, 1997). Recreating a sense of place can also occur through the revival of an ancient beer or the restoration of decaying breweries by new brewmasters (e.g. OudBeersel). As shown in Figure 5-2, the beer or brewery seeks to link its product to the local community by appealing to its tangible or intangible capital. Feeding this craving are breweries, using regional or local produce, such as speculoos for the cookie beer, chestnut and nougat for beers of Corsica and Brittany (Sannier, 2015). Other Belgian examples are cherry from Schaerbeek for 'Oude Kriek' van OudBeersel and 3 Fonteinen²⁵.

²⁴<http://www.leffe.com/fr/bieres>

²⁵<http://www.3fonteinen.be/proef/oude-schaarbeekse-kriek.html>; <http://www.oudbeersel.com/nieuws-uit-de-brouwerij/oud-beersel-plukt-zelf-schaarbeekse-krieken/>

6 Findings

The findings chapter presents the research's results, the NRA and MSS section mark the two overarching axis around which results are presented.

6.1 Natural Resource Accounting

Following the principle behind EMA to connect environmental costs and financial information, the following section is solely divided into the three variables developed in environmental sustainability: water, waste and wastewater Management. The quantitative data gathered and processed in the following section, in the form of figures, graphs and tables, is presented in Appendix III.

6.1.1 Water Management

Among the sample of breweries visited, water management differed according to many interdependent variables, ranging from the type of beer brewed to the volumes of beer produced. As a result of the brewery visits, it was concluded that for all breweries, cleaning was the single most important factor affecting water use. Being a product intended for human consumption, there are strict rules, set by AFSCA, the Belgian federal food chain security agency, which must be respected. However, as cleaning procedures, techniques and pieces of equipment can vary from one brewery to another, it follows that water consumption for washing and sanitising fluctuated accordingly.

Water Consumption

Figure 6-1, portraying the findings of the brewery visits, clearly demonstrates that rather than observing a linear correlation between water use and beer production, the graphic presents a non-linear trend curve. The trend curve, based on the data of the eleven breweries, predicts a statistical model or pattern with a steep curve up to 4 000 hL of beer production before starting to stabilise. However, it should be noted that the model is not precise, as the accuracy level is only of 40.3%.

Brewery F, which has the lowest water use ratio and is the biggest producer of the sample, has a water efficiency ratio of $3.94 L_w/L_B$ that can be broken down into three main components:

1. The whole brewing process: $2.52L_w/L_B$;
2. Conditioning, which includes the packaging of non-returnable bottles, returnable bottles, barrels and other: $0.99L_w/L_B$; and
3. Utilities, which includes facility maintenance and other support functions: $0.43L_w/L_B$.

While Figure 6-1 gives a full picture of the whole sample to detect trends, it does not allow for an accurate understanding of the microbrewing sector. To remedy this, Figure 6-2 focuses on the 80 to 9 765 hL block enabling a better comparison between the eight breweries producing less than 10 000 hL on a yearly basis.

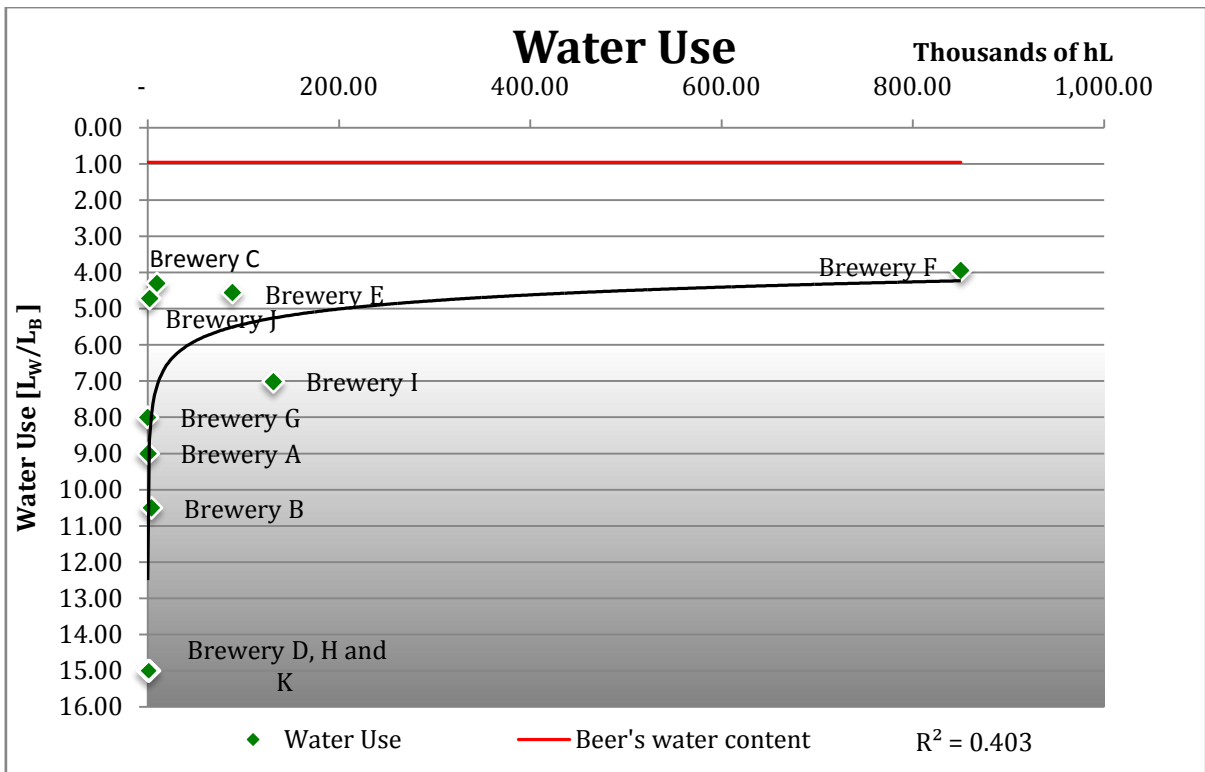


Figure 6-1. Water use in breweries producing between 80 to 850 000 hL (2014).*

Source: Author's own illustration.

* Given that breweries D and H are not yet brewing in their own facility, a conservative estimate was made to assign them the water ratio of the brewery with the sample's highest ratio, namely brewery K's ratio of 15.

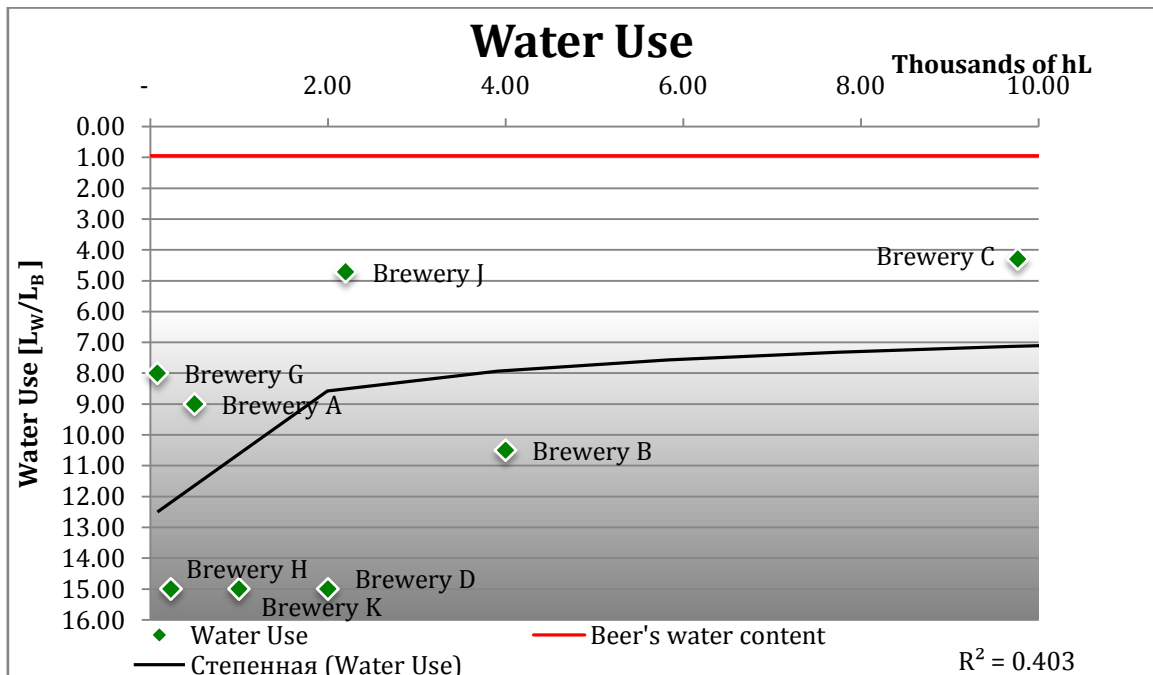


Figure 6-2. Water use in breweries producing between 80 to 9 765 hL (2014).

Source: Author's own illustration.

Water can originate from diverse sources; it can be pumped from a well on the property of the brewery, from a lake or dam on the estate or collected from rainwater, but most commonly the municipality provides it. In this sample, municipalities supply nine out of the eleven breweries and charge price (EUR) on a per cubic meter (m³) basis as summarised in Table 6-1. Breweries F and I are the only two breweries in this sample, pumping all of their water from groundwater, after appropriate treatment in their facilities. Brewery K only uses groundwater for the brewing process, water for cleaning purposes comes from the municipality. Breweries A, B, C and K were the only breweries willing and able to provide accurate information on the cost of their input water. The other breweries' water extraction costs were deducted based on the information available on documents drafted by the operators in charge of the distribution and sewerage (Hydrobru), the Walloon Water Management Company (SPGE) and the Flemish Environmental Agency (VM) (Hydrobru, 2014; SPGE, n.d.; VM, 2014). From the results presented in Table 6-1, it becomes apparent that costs can vary widely across Belgium. This is a consequence of municipalities' obligation to charge water at its true cost, (SPGE, n.d.). The true cost includes the costs endured by the municipality to treat the water for human consumption and distribute it to the consumers, which will be dependent on the size of the municipality, the quality of the water before treatment, the infrastructure needed to distribute water and other factors.

Table 6-1. Cost of water extraction (EUR) per m³ for the breweries (2014).

Brewery	Cost of water extraction or pumping [€/m ³]
A	1.20
B	1.58
C	2.62
D	2.29
E	1.45
F	N/A
G	2.89
H	2.89
I	N/A
J	2.62
K	2.00
Median	2.00

Source: Author's own illustration.

* As brewery A is a Swedish brewery the rate of exchange of 0.12 was applied to the 10 SEK charged by the Swedish municipality where the brewery resides.

Water Treatment

As has already been stated before, water plays a key role in the production of beer, and its quality is of paramount importance for the end product's taste. Yet, breweries do not all set similar quality requirements on water. For instance, brewery F, brewing close to a million hL a year, purposely uses water that is relatively hard, around 16°fH²⁶, as it is part of its beer's

²⁶French degrees is the unit used to express the degrees of hardness, thus the total content of calcium and magnesium of natural water (Eßlinger & Narziß, 2009).

signature taste. Table 6-2 uncovers the different water treatment methods observed in the ten breweries. A final row listing each brewery’s beer production was added to the Table, since observing if and how water treatment evolves as brewing volumes increase could provide an interesting insight.

Table 6-2. Different types of water treatment prior to use in breweries (2014).

Brewery Treatment	A	B	C	D	E	F	G	H	I	J	K
Water treatment procedures	0	1	1	1	3	4	0	1	2	0	0
Removal of iron and manganese									X		
Softening the water				X	X	X		X	X		
Sand filter						X					
Active carbon filter			X	X	X	X		X			
Ultrafiltration									X		
Reverse Osmosis					X	X					
Chlorine dioxide		X			X	X			X		
UV light			X	X							
Beer production [hL]	500	4 000	9 765	2 000	88 618	850 000	80	233	131 406	2 200	1 000

Source: Author’s own illustration.

Breweries A, G and J use water provided by the municipality and have all decided not to treat their water prior to use as the quality is sufficient according to their standards. Brewery G had the opportunity of using a well on its property as its water source but decided against it, as the costs were too prohibitive. Brewery K neither treats the water supplied by the municipality nor the water extracted from the well.

There are two rather clear water treatment patterns: the first is adopted by breweries producing more than 17 600 hL. Breweries E, F and I all have more than one water treatment procedure, soften their water, use a filtration process with very small pores, ultrafiltration or reverse osmosis and use chlorine dioxide. The second pattern in the sample is common among microbreweries: active carbon filters and UV lights to treat incoming water.

When a brewery only uses one water treatment procedure, the water’s quality has to meet the requirement set for the brewery’s highest quality application. For breweries, the highest grade of water is the one needed for the tanks’ final rinse. Although when small volumes of water are used, implementing several water treatment procedures could prove to be a tedious and costly task. When more than 40 000 m³ of water are to be treated per annum, employing several water treatment procedures becomes an obvious option to reduce costs.

Table 6-3 describes each water treatment procedure of breweries E, F and I in greater detail. Breweries investigated can have up to four different types of water:

1. Brewing water, which is used as an input in the mashing step and thus contained in the final product.
2. Rinsing or softened water is a type of water required for cleaning procedures.

3. Completely softened water is solely needed for the final rinsing stage of a cleaning procedure and requires a more thorough treatment to avoid impurities negatively affecting the efficiency of disinfectants.
4. Water for steam boilers is required to reach a very high purity level to increase the performance and the longevity of the boiler, which contributes to avoiding unnecessary costs.

Table 6-3. Different water treatment procedures for breweries E, F and I (2014).

Brewery	E			F				I		
	Water Treatment	Brewing	Rinsing	Steam boiler	Brewing	Rinsing	Completely softened	Steam boiler	Brewing	Softened
1. Removal of iron and manganese									X	X
2. Softening	X	X	X	X (16°fH)	X (7°fH)	X (0-1°fH)	X (0-1°fH)		X	X
3. Sand filter				X	X	X	X			
4. Active carbon filter	X	X		X	X	X	X	X	X	
5. Ultrafiltration										X
6. Chlorine dioxide		X (0.25ppm)		X (0.2ppm)	X (0.4ppm)	X (0.2ppm)	X (0.2ppm)			X
7. Reverse Osmosis	X		X				X			

Source: Author's own illustration.

The water treatment procedures follow the exact order in which the treatments are listed with the exception of brewery E's brewing water. Brewery E uses reverse osmosis to filter and remove impurities from the water. However, after reverse osmosis treatment, the water is too pure to be used as brewing water, therefore it is blended with water that has only been softened. In that case, after the blending has occurred, the brewing water goes through an active carbon filter. One drawback of ultrafiltration and reverse osmosis is the water losses inherent to this type of filtration due to the retentate. Brewery E was able to reduce those to 15%, by using a two stage reverse osmosis.

For smaller scale breweries it does not, from an economic and quality point of view, make sense to develop several water treatment methods. Subsequently, breweries often use a combination of active carbon filtration, which removes contaminants and impurities, followed by a UV light treatment sterilizing the water. Depending on the water's hardness, some breweries, like brewery D, might add a softening stage. Brewery B, which was the only brewery willing and able to fully disclose its water treatment costs, opted for chlorine dioxide, as this inexpensive treatment (around 1.98 EUR per m³) yields satisfactory results. Another reason why they selected chlorine dioxide to treat their water is that it keeps water and tanks clean for a period of up to two weeks. The brewery uses a dosage of 15 mg/L. Brewery C's cost for the treatment of incoming water, though not available, was low.

Cleaning Procedures

Cleaning procedures are necessary for three main reasons: to avoid negatively affecting the product's quality, to prevent contamination of a plant's other operations and to eliminate the

risk of microbial spoilage (Briggs, 2004). Consequently, breweries have each developed their own cleaning procedure, as shown in Table 6-4.

Similar to the treatment of water prior to its utilisation in the brewing process, there is a clear pattern among the large-scale breweries of this sample. The only exception being brewery I whose first cleaning with caustic soda is done at ambient temperature:

1. First rinse;
2. Cleaning with caustic soda, 1.5% to 4%, at a temperature between 70 and 85°C;
3. Intermediate rinse;
4. Sterilisation with peracetic acid and/or hydrogen peroxide, 0.2% to 2%, at a temperature between 70 and 80°C; and
5. Final rinse.

Furthermore, this pattern is also widely applied, though with some small modifications, to the microbreweries, such as breweries A, B, D, J and K. Breweries G and H, the smallest breweries of the sample, appear to share a common pattern: a three-step cleaning procedure where sterilisation is done by water vapour. Brewery G defended its choice of water vapour sterilisation as an attempt at curtailing the usage of cleaning products, even if it meant additional costs. Moreover, as the brewery does not brew on a daily basis, for safety reasons, tanks also undergo the cleaning procedure prior to usage. Brewery C, which changes its disinfectant every six months to avoid bacteria adapting to the chemical being used, stands out, as it uses water vapour to sterilise its equipment, despite producing 10 000 hL a year, an uncommon feature in the sample. Lastly, there are two main reasons explaining why no breweries preceded its chemical cleaning phase by a manual cleaning one in order to reduce water consumption. First of all, manpower is more expensive than water. Secondly, tanks are no longer designed with a manhole so manual cleaning is no longer a possibility.

In addition to the pattern that can be drawn from Table 6-4, large-scale breweries still distinguish themselves from smaller-scale breweries due to their development of several standard cleaning procedures. Breweries B, E, F and I all share the feature of having at least two different standard cleaning procedures, one for fermentation and ageing tanks and one for bottle-filling machines. In general, bottle-filling machines do not need the thorough cleaning procedure described in Table 6-4 as frequently as tanks. Often, a simplified version of that procedure can be run between different types of beer. In addition, breweries are careful to follow a coherent configuration when filling bottles, in other words first blond beers, then brown beers are bottled with stout or darker beers only being filled at the very end. Opting for a reverse configuration could significantly increase the risk of altering a beer's taste. A reason why smaller-scale breweries do not implement simplified procedures is that, contrary to larger scale breweries, bottling is not a daily activity. Therefore, thorough cleaning is required to ensure that no microbial contamination occurs in the period between bottling operations.

Brewery B developed four standard cleaning procedures. For fermentation and ageing tanks it follows the description in Table 6-4. Mashing tanks are cleaned using only the three first steps, namely a first rinse, a caustic solution and then a hot water rinse. Pipes used for wort and beer transferring are washed with the fermentation tanks, but after that they are steamed and treated with CO₂ to expel any remaining oxygen. Finally, the bottle-filling machine is washed and sanitised with the following procedure: first rinse, caustic soda solution, rinsing with water and finally hot water to disinfect. In addition, brewery B, the only brewery able and willing to provide insight into its operating costs, disclosed that the whole cleaning procedure costs around 20 EUR per 50 hL batch in cleaning products.

Table 6-4. Different types of chemical agents use for cleaning procedure in breweries (2014).*

Brewery Treatment	A	B	C	D	E	F	G	H	I	J	K
Cleaning procedures	1	4	1	1	3	5	1	1	5	1	3
1. First rinse	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
2. Cleaning	KOH (0.02%) 70°C	NaOH (4%) 70-80°C	Disinfectant solution 20-30 minutes	NaOH + NaCl 40°C	NaOH (1.5%) 80°C	NaOH (4%) 85°C	NaClO Hot	NaOH Hot	NaOH (2%) Ambient	NaOH + NaCl 40°C	NaOH + NaCl (2%) 40°C
3. Rinsing	Water	Hot water	Water	Water	Water	Water			Water	Water	Water
4. Acid cleaning		Sulphur (4%) 70-80°C								H ₃ PO ₄ , KOH**	
5. Rinsing		Water Ambient								Water	
6. Sterilising	H ₂ O ₂	C ₂ H ₄ O ₃ (0.2%)	Water vapour	C ₂ H ₄ O ₃	C ₂ H ₄ O ₃ (1%) 70°C	C ₂ H ₄ O ₃ (2%) 70-80°C	Water vapour	Water vapour	C ₂ H ₄ O ₃ + H ₂ O ₂ (1%) 70-80°C	C ₂ H ₄ O ₃ Ambient	C ₂ H ₄ O ₃ (0.5%) Ambient
7. Final rinse	Water			Water	Water	Water			Water		
Beer production [hL]	500	4 000	9 765	2 000	88 618	850 000	80	233	131 406	2 200	1 000

Source: Author's own illustration.

* Many chemical agents are cited in the table under their chemical formula. Potassium hydroxide or caustic potash (KOH); Sodium hydroxide or caustic soda (NaOH); Hydrogen peroxide (H₂O₂); Peracetic acid (C₂H₄O₃); Sodium hypochlorite (NaClO); Phosphoric acid (H₃PO₄); Chlorinated alkaline (NaOH + NaCl).

**Brewery J has two cycles of acid cleaning, one with phosphoric acid and one with caustic soda, at a cold temperature, each one followed by a water rinsing step.

Brewery E, implements three standard cleaning procedures, one for its fermentation and ageing tanks, one for its bottle-filling machine and a last one for its beer filtering equipment. Brewery F has developed a standard cleaning procedure for every step of its brewing process in an attempt at optimising its cleaning process.

Finally, brewery I, in addition to the two standard cleaning procedures, made small adaptations to optimise the washing of the bottle-washing machine, the pipes and the mashing tanks. The bottle-washing machine requires further care in some critical zones and therefore an additional disinfection product is applied. When pipes are washed, the caustic takes place at a high temperature. Like brewery B, mashing tanks' cleaning procedure relies mainly on caustic cleaning. During 2014, the brewery used, 248.9 tons of cleaning and disinfection products, of which 77% were caustic soda.

To avoid contamination of tanks after washing, breweries B and K do not rinse their tanks after the disinfection step of cleaning with peracetic acid. Brewery K adapts its cleaning procedure for the mashing where the dilution of chlorinated alkaline is brought up to 2.5-3%.

From observing the previous Table, cleaning procedures might appear relatively homogeneous. Yet, in reality they can differ greatly with regard to the types of water used, the number of recycling and reusing cycles as well as in water quantity used. Being the most intensive source of water consumption, it is not surprising that breweries employ a lot of effort to try to curb their water use at this stage.

Firstly, all breweries of the sample, with the exception of breweries A, C, and G, have CIP cleaning tanks. Brewery D, which is aiming to produce 2 000 hL per year and to operate on a 10 hL batch basis, plans on using a CIP system including three 300 litres tanks to clean its equipment. Breweries such as breweries E, F and I, producing at a higher rate, are equipped with larger CIP tanks. Yet, like many aspects in the brewing industry the CIP tanks' size did not increase in a linear fashion with beer production, as for example brewery E, with its nearly 90 000 hL, only uses three 800 litres tanks. This obviously translates into a lower water use.

It would not have been possible to collect accurate data on how much water is used by breweries for the cleaning of their tanks, as the amount of reused and recycled water would have had to be exactly determined, a tedious and complicated task outside this thesis' scope. However, we were able to determine from the breweries, what their water recycling and reusing practices were. All breweries that own a CIP system were able, thanks to the equipment, to regenerate solutions. During a regular CIP procedure, brewery E would recuperate the water from the final and intermediate rinse to be used, respectively, in the next cleaning procedure for the intermediate rinse and first rinse, as the quality requirements for those rinsing phases are lower than the previous use. Breweries B and I, using the similar logic of counter-current rinsing, only recycle the intermediate rinse for a following first rinse. Brewery F, due to its larger size, adjusted and optimised each CIP system to every stage of its brewing process, which was estimated to reduce water consumption by 25%.

Water Reusing and Recycling

Besides optimising their standard cleaning procedures, breweries also seek to diminish their water use by implementing other reusing or recycling techniques. Brewery G possesses a one m³ tank, in which rainwater is collected, which in this case is not insignificant as the brewery only uses 64 m³ per year. This water can later be used to wash floors, for cooling or landscaping purposes, or even for a first rinse, as the quality standards for that water are lower than for following rinses.

One common feature shared by almost all breweries of the sample is the counter-current cooling of the wort after the wort boiling stage with water to be used as brewing water for a next beer batch. As future brewing water runs parallel, but in opposite direction, to the wort, the latter is being chilled to a fermentation temperature, between 6 and 20°C depending on the type of beer and yeast, while the former absorbs the heat. This allows a double use of water and a savings in terms of energy required for the next mashing.

On the one hand, some investments only make economic sense once certain volumes of beer are produced; recuperating condensation water from the wort-boiling step is one such example. Brewery E feeds that condensate water, after reverse osmosis treatment, to its steam boiler.

On the other hand, high beer volumes can also mean additional costs, such as the costs of washing and sanitising returnable bottles or having to pasteurise beer. Brewery F spends, on average, around 13% more water for the conditioning of returnable bottles, than for one-way bottles. This pertains to the fact that one-way bottles only need a quick rinse before usage, whereas returnable bottles have to pass through several hot and caustic baths to remove beer labels and sanitise bottles. Nevertheless, in light of the additional steps required, an added 13% water consumption for returnable bottles might seem reasonable. This requires methodical adjustment and optimisation as well as constant control of the various baths together with counter-current flowing of cleaning solutions. As a result, brewery I consumes, on average, 0.25 L per bottle (mainly 0.33 litre), while brewery F is at a consumption rate of 0.18 L per small bottle (0.25 litre) and 0.22 L per medium size bottle (0.33 litre). Brewery K works with screen-printed bottles, as does brewery H. In contrast to brewery H, however, brewery K has a small-scale bottle-washing machine which uses one m³ of water per hour on average to treat 1 500 bottles, and has a consumption rate of 0.66 L per bottle (0.33 litre). The screen-printing feature enables brewery K to eliminate the production of wet label, an important waste stream, which forms a pulp, that breweries E, F and I have to deal with. For the latter brewery this represents an annual waste of 45.42 tons.

Contrary to returnable bottles, one-way bottles do not undergo such a thorough cleaning procedure as they are already clean and have been protected during their transport. Consequently, in brewery F, these bottles are simply rinsed with water, and since that water contains little to no impurity, it is reused at different stages of the packaging area such as for pasteurisation or to give bottles a quick shower after they have been filled and capped.

Pasteurisation is another process that can increase water consumption as it adds an extra cleaning procedure and because of the water used as means of pasteurisation. It is to be noted though, that since beers of this sample's four largest breweries undergo a secondary fermentation, only flash pasteurisation is adopted.

As a brewery's floor is never in contact with wort or beer intended for human consumption, water from previous cleaning steps can be used to wash floors. This method of water recycling is widely adopted by many of the sample breweries, e.g brewery G. Brewery F reuses the water, after treatment, used to push beer from one stage to another to wash its floors. Brewery J simply lets the tank cleaning solution run on floors before rinsing them.

6.1.2 Waste Management

Brewing beer requires, in general, four ingredients, three of which will end up as organic waste, namely yeast, grains and hops. Yet, for transport and drinking purposes beer also has to be bottled or canned. And, unfortunately, it is not uncommon to have some losses occurring

in the conditioning area, which can take many forms such as broken glass or bent caps. Those losses create additional inorganic waste generated during beer production.

Organic Waste Management

Contrary to inorganic waste, which a brewery can try to avoid, organic waste is inherent to the brewing process. For each litre of beer produced, there will inevitably be some organic waste generated, a fact illustrated by Figure 6-3.

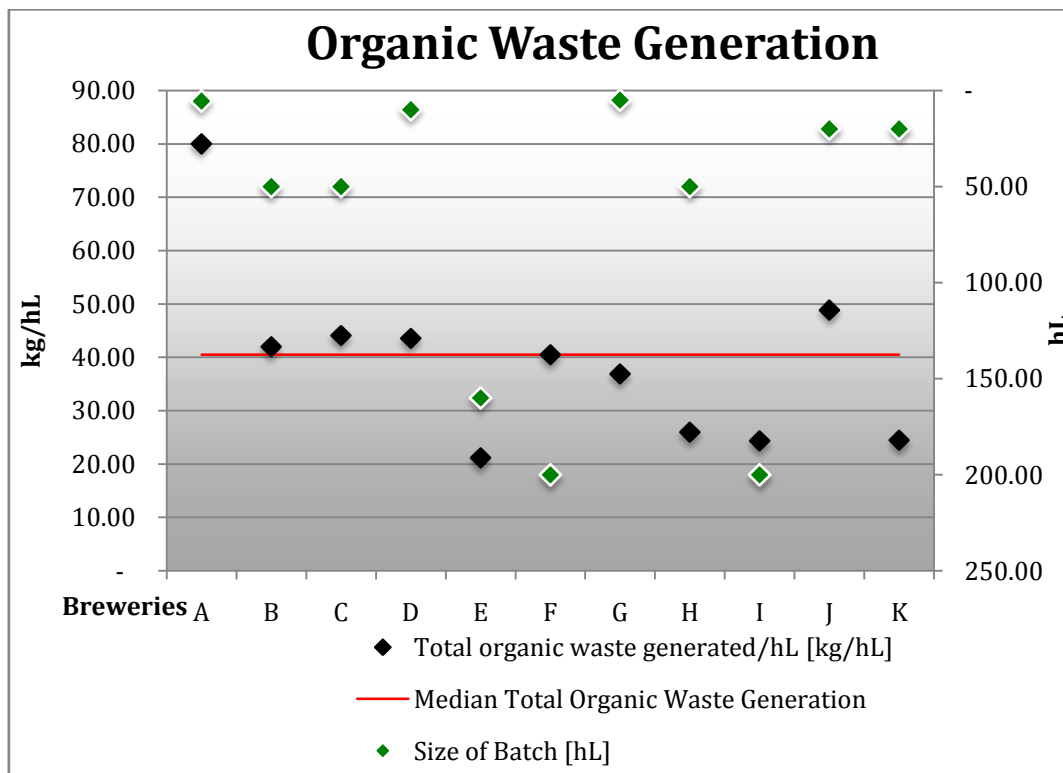


Figure 6-3. Organic Waste Generation in Breweries (2014).

Source: Author's own illustration.

By computing the total organic waste generated per hL against breweries' brewing batch size, one can identify a potential correlation. From Figure 6-3, it is difficult to observe that as breweries brew larger quantities, smaller quantities of waste are generated on a per hL basis. However, it should be noted that large organic waste generation is not a reflection of inefficiencies but rather a contemplation of brewmasters' recipes. Some types of beers require more input than others in terms of grains and hops. Some noticeable differences might be related to the type of hops used in the brewing, hops pellets being denser than flower hops, opting for whole cone flower hops requires increasing the input quantity, an active choice made by a few of the sample's breweries, such as, for example brewery G.

However, although spent grains, hops and yeast are waste to the brewing industry, they are still recoverable by other sectors, e.g. as animal feed. Breweries D and H which have not yet moved into their new facilities, have already made agreements with farmers so that their organic waste can be reused. Nowadays, there are even opportunities to sell this organic waste. This requires the breweries to be the GMP²⁷ certified. Breweries E, F and I currently capitalise

²⁷ GMP stands for Good Manufacturing Practices and, in this case, is a certification ensuring that safety, quality and compliance standards for the use of organic waste from a brewery for the farming sector (SGS, 2015).

on this opportunity, while brewery C is at the stage of being GMP certified. Although the three breweries sell their waste, sales numbers were only available for brewery F:

- Spent grains and hops is being sold at 0.045 EUR per ton of dry matter; and
- Spent yeast is being sold at 0.4 EUR per kilo of dry matter.

Yet, breweries can sometimes struggle to have farmers come and pick up their organic waste. Farmers have to pick up the organic waste the day it was generated to avoid any degradation in its quality, a trip that they are often only keen to undertake, if large volumes are involved, which is rarely the case for breweries producing less than 500 hL. For instance, when observing Table 6-5, breweries working on a 5 to 20 hL basis, only produce in the range of 0.5 to 1 ton of spent grains and hops, which has a dry matter content inferior to 20%. Furthermore, only between 20 to 75 kilos of spent yeast are generated, a type of waste with a dry content below 10% which not all farmers are willing to pick up. Therefore, many microbreweries have no other choice but to discard the spent yeast in the sewer, an option that can be problematic if the brewery treats its own wastewater since yeast has high BOD levels. Brewery G found an interesting reuse opportunity for its small quantity of spent yeast, it is apparently a great complementary fodder for pigeons, bringing many pigeon-fanciers to the brewery. Brewery A has a farmer who only collects the spent grains, and pays, 0.06 EUR per kilo, for the spent hops to be collected and used in a biogas plant.

Table 6-5. Average organic waste per fraction per brewery on a 50 hL (2014).

Brewery	Average spent grains/50hL batch [kg]	Average spent hop/50hL batch [kg]	Average surplus yeast/50hL batch [kg]	Size of Batch [hL]
A	3640.00	160.00	200.00	5.50
B	2000.00	100.00	175.00	50.00
C	2000.00	4.50	200.00	50.00
D	2000.00	28.75	150.00	10.00
E	897.00		162.00	160.00
F	2022.75	2.70		200.00
G	1650.00	45.00	150.00	5.00
H	1150.00		150.00	50.00
I	881.28	18.65	319.53	200.00
J	1875.00	18.75	549.30	20.00
K	1 000.00	125.00	100.00	20.00
Median	1 737.82	45.76	220.00	

Source: Author's own illustration.

Interestingly, brewery D is currently using food waste from supermarkets as an additional ingredient for its beer. At the end of the day, they recuperate unsold bread from six supermarkets, then grind and mill it to be used as a substitute for wheat grains for one of their beers. This is the result of its collaboration with CODUCO, an NGO that strives at reducing food waste, which, in 2014, helped avoid six tons of bread being wasted.

Inorganic Waste Management

Inorganic waste, which encompasses glass, metal, cardboard, paper, wet labels, plastic and residual waste, represents only around 3% for the sample's breweries, as shown in figure 6-4.

Yet, as the Brewers Association (n.d.) pointed out, it can amount to up to 50% of a beer's cost emphasising the need for breweries to even further minimise this waste stream.

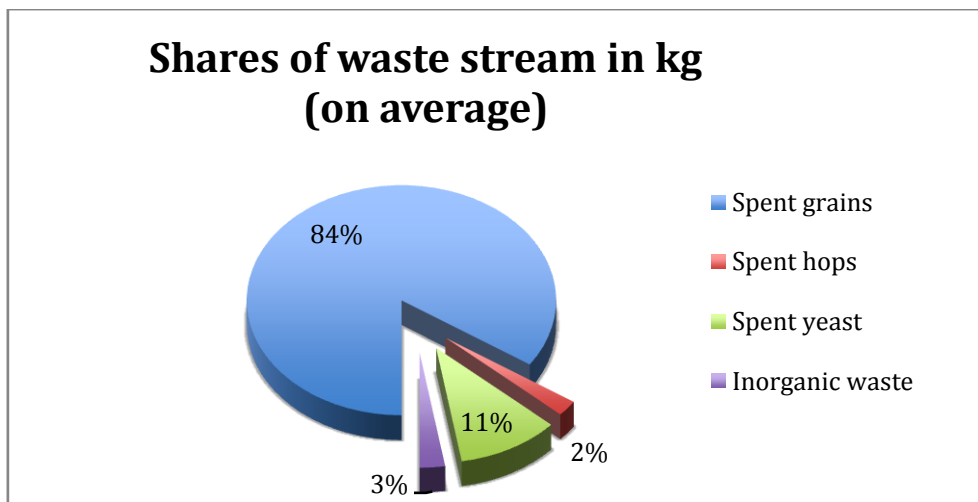


Figure 6-4. Shares of waste streams in kg (on average) (2014).

Source: Author's own illustration.

Even when large-scale breweries, such as breweries E, F and I are able to sell their inorganic waste, the selling price is far below the purchasing price. As a result, the incentive to reduce this type of waste remains. Brewery F sells its inorganic waste for an average price, all fractions combined, of 0.21 EUR per kilo. For smaller scale breweries such as brewery B, it represents a cost of around 0.11 EUR per kilo and approximately 3 600 EUR per year, including all fractions. In the case of this latter brewery, waste generated by the attending HoReCa²⁸ business is also included. Here costs are mainly driven up by the residual waste fraction, which is ten times more expensive than the other waste fractions. This difference in costs between fractions is a result of the support provided by regions and the municipality, who provide subsidies to companies sorting their waste. Although brewery C and K could not provide information on the annual quantity of inorganic waste produced, their respective costs for the disposal of inorganic waste amounted up to 1 661.4 EUR and 490.2 EUR per year, given that waste has to be sorted. Brewery J, after having struck an agreement with a German company, was able to decrease its costs of handling plastic and cardboard as those two waste streams are being taken care off at no cost.

Brewery K's choice of opting for screen printed bottles results in the elimination of wet labels from its waste stream, which are produced during the washing of returnable bottles. This waste stream can amount to 45.42 tons per annum. For brewery I, this waste needs to be treated separately because of the glue used, not considering the pollution of the wastewater flowing out of the bottle-washing machine's caustic baths.

Data for inorganic waste generation was only obtained for three breweries, and expressed on a kilo per hL basis. It should be noted that breweries B and I's inorganic waste also includes waste produced by, respectively, the HoReCa business and cheese factory attached to the estate. The results shown in Figure 6-5 depict a statistical model tending to show that as beer production increases, the inorganic waste generation decreases on a per hL basis. Here, the statistical model, though based on solely three breweries, portrays a trend curve with a 99.78% accuracy level, reflecting a model, which could predict inorganic waste generation in Belgian breweries.

²⁸It is the syllabic abbreviation of Hotel/Restaurant/Café.

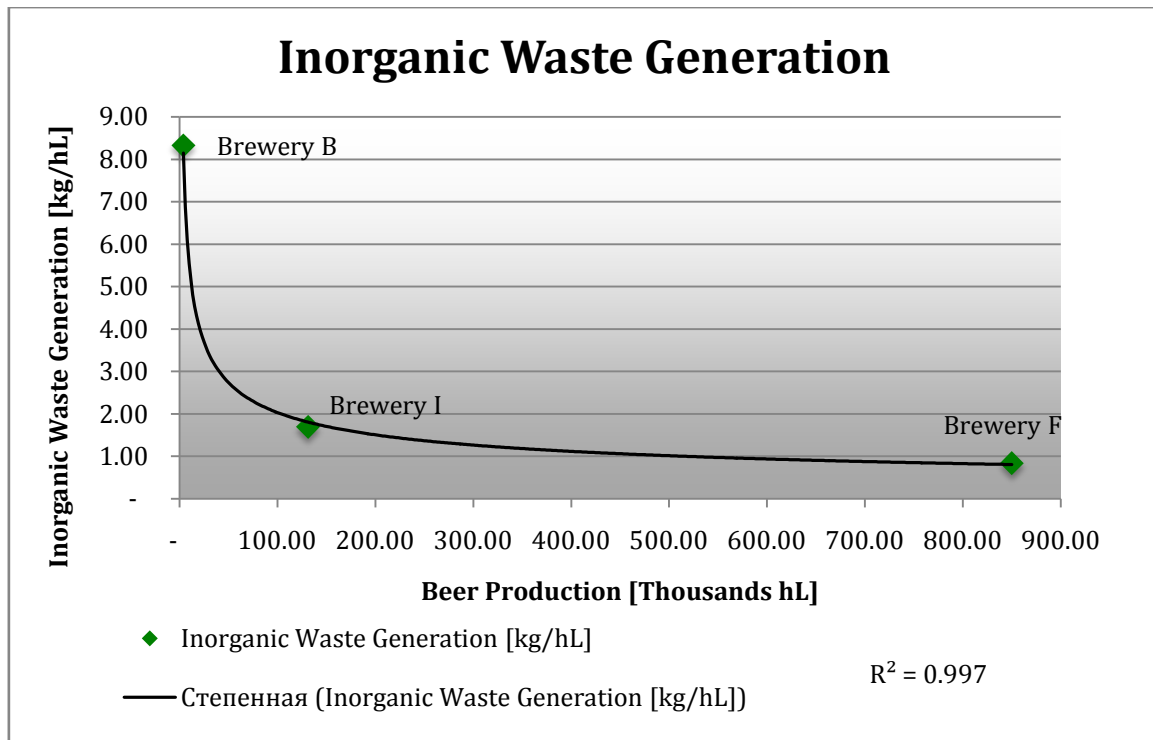


Figure 6-5. Inorganic waste generation (2014).

Source: Author's own illustration.

6.1.3 Wastewater Management

Antoine Lavoisier famously wrote: “Nothing is lost, nothing is created, everything is transformed”; and, when applied to the case of water, it demonstrates that all water consumed by the brewery eventually leaves the brewery, whether it is in the form of beer, effluents, trapped in by-products or evaporation.

Wastewater treatment

Table 6-6. Different types of water treatment prior to use in breweries (2014).

Brewery Treatment	A	B	C	D	E	F	G	H	I	J	K
Buffer tank		X	X	X		X	X		X	X	
Screening						X			X		
Neutralisation						X					
Sedimentation						X	X		X	X	
Anaerobic digestion						X					
Aerobic digestion						X	X			X	
Aeration									X		
Membrane tanks									X		
Beer production [hL]	500	4 000	9 765	2 000	88 618	850 000	80	233	131 406	2 200	1 000

Source: Author's own illustration.

To minimise the impact of breweries on the environment, there are already many directives and decrees in place regulating the acceptable levels of BOD, COD, SS, temperature and pH that can be released into any receiving body. However, the regulator chose to leave to the

brewery the choice of either treating it directly or letting the municipality handle the pollution load. Table 6-6 indicates which breweries have installed a wastewater treatment plant and which ones rely on the municipal wastewater treatment plant.

Breweries B, C and D do not have a full operating wastewater treatment plant, they only have a buffer tank to equalise the flow and load of the wastewater stream. Brewery C, because of its remoteness to a proper sewage system, installed a 22 000 hL buffer tank that needs to be emptied regularly and brought to the nearest wastewater treatment plant. As a consequence, costs are driven up as a supplement for the transport of the wastewater is charged to the brewery. There had been wastewater treatment plant but unfortunately, it was unable to cope with the flow and load of the brewery for long.

Breweries G and J are both small-scale breweries, yet they both have household wastewater treatment plants which are designed for a four and eight person load respectively. The treatment follows a usual pattern with a sedimentation step prior to the aerobic digestion and before the water is released into a nearby water body. In addition, the two breweries are the only ones where a house is attached to the brewing facility.

Brewery F's effluents first go into a buffer tank where the pH level is brought to 7 and, if needed, the water is neutralised with CO₂ gas or sulphuric gas. Afterwards, the anaerobic digester decreases by up to 90% the wastewater's volume. The methane produced during that phase of wastewater treatment is purified before being turned into biogas. The wastewater treatment plant fuels a 190 kWh electricity generating turbine. The anaerobic step decreases by a factor of 10 the COD levels that are usually around 4 000 ppm and brings them down to 400. The following aerobic digester fine-tunes COD levels by diminishing them to around 40 ppm, which is below the 125 ppm mark required by the legislation. After that the collected sludge is spread on fields. Finally, the treated water can be released into the receiving water body at a temperature between 6,5° and 9°C. The phosphate levels are, controlled with iron salts before being released into the receiving water body, should this be necessary.

Brewery I treats its wastewater with membrane filtration and sends the generated sludge, around 700 tons per year, to a biogas facility, which then turns it into electricity. This treatment is a first step in a plan to reuse the treated water for cleaning purposes. With this system in place, the brewery is able to reduce the COD content of the wastewater from around 2 500 - 3 000 ppm to below 30 ppm, within the national requirement, allowing the discharge into an adjacent water body. This solution is also being considered by brewery E, which currently relies on the municipality's sewage system to treat its wastewater.

An interesting innovation that brewery K is considering, is installing lagoons with reeds to treat their wastewater. This alternative technique, although efficient to reduce BOD and SS levels, is sensitive to high COD levels and requires a constant pH.

As breweries were not able to provide information on the estimated cost on a EUR per m³ basis for their wastewater treatment, it was assumed to be null. However, for breweries A, B, C and K releasing their effluents into the sewers, costs were provided, whilst in the case of the remaining breweries costs were deducted from the information available on documents drafted by Hydrobru, the SPGE and the VM (Hydrobru, 2014; SPGE, n.d.; VM, 2014).

Table 6-7. Cost of wastewater treatment.

Brewery	Cost of wastewater treatment [EUR]
A	1.20
B	1.77
C	1.94
D	1.66
E	2.89
H	1.86
K	2.00
Median	1.90

Source: Author's own illustration

With the information available in Table 6-7, it is now possible to estimate the total cost of water in breweries, as shown in Figure 6-6. However, it should be noted that it reflects the full cost only for breweries A, B, C, J and K, as for the other breweries, either the extraction costs are unavailable or the cost of water or wastewater treatment is unknown. The same holds true for breweries D, E, F, H and I. The exceptional value of brewery A in comparison to other breweries arises from the fact that it is located in Sweden, where prices are different. In general, the median cost of water is of 3.95 EUR per m³.

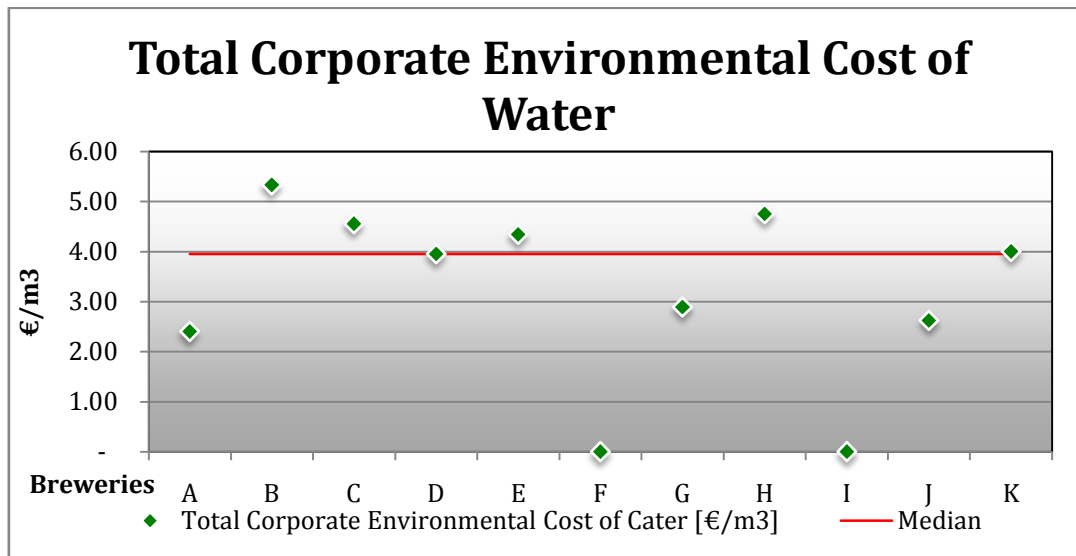


Figure 6-6. Total corporate environmental cost of water in €/m³ (2014).

Source: Author's own illustration.

Wastewater Generation

Figure 6-6 portrays breweries' water use and wastewater generation in comparison to their respective beer production. The left axis represents the water use and wastewater generation of the eleven breweries, whilst the right axis embodies the beer production in thousands of hL, in a decreasing fashion. It is apparent that the larger breweries tend to have a lower water use and wastewater production. Brewery C and J, however, are exceptions to the trend, with their water use below 5 L_w/L_B, though still being classified as microbreweries. Breweries D and H's ratio come from the conservative assumption made in the beginning of the findings. However, brewery K's high value could be a consequence of the bottle-washing machine.

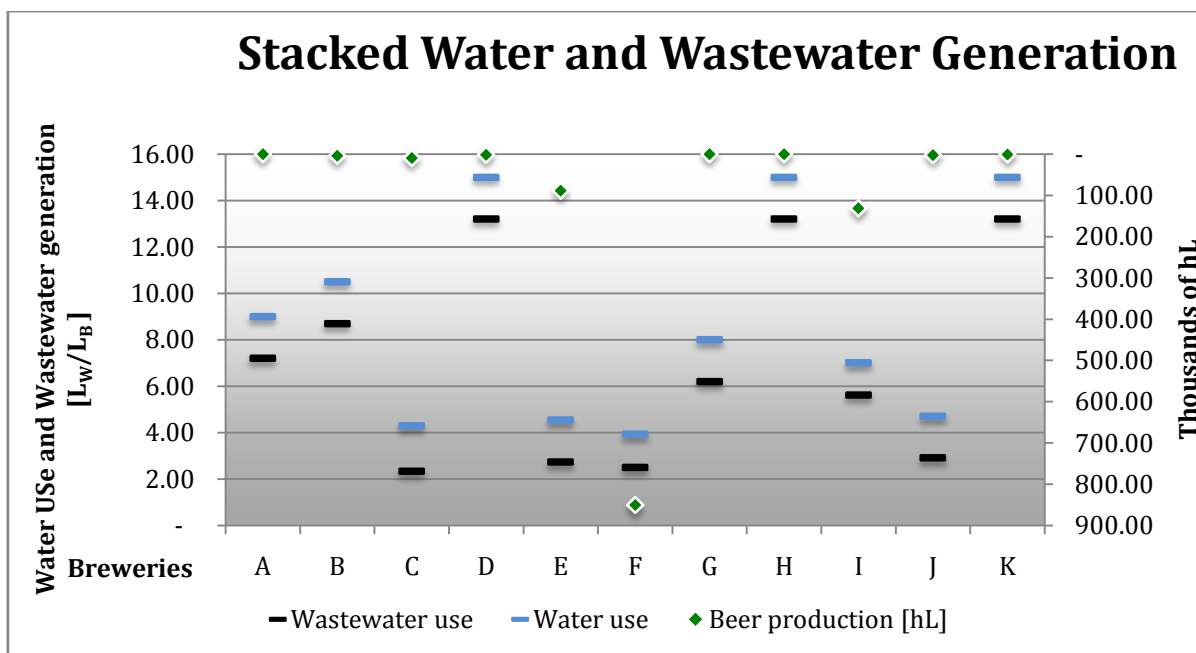


Figure 6-7. Stacked water use and wastewater generation in breweries producing between 80 to 850 000 hL (2014).*

Source: Author’s own illustration.

* Given that not all breweries were able to provide accurate numbers on the volumes of wastewater, when not available it was conservatively assumed, following the findings from the EIPPCB (2006), that there was a 1.8 L_w/L_B difference between the water use and wastewater use.

Water losses in form of leakages, trapped water or evaporation are yet another aspect of the brewing process that negatively affect a brewery’s water use. Breweries that have installed a water meter are able to track the water flow along the brewing process and thus to identify where leakages and losses occur, as well as the quantity of water that is lost. In addition, wort, which is generally constituted of more than 95% water, is often discarded with the spent grains and hops and with the yeast. All of this results in a water loss of approximately 0.8 L_w/L_B . Figure 6-7, besides providing visual information on possible correlations between beer production, water use and wastewater generation, also offers a comparison of a brewery’s efficiency in terms of water losses, the third term of the water generation ratio detailed in the literature review. Unfortunately, the exact number of wastewater released annually by breweries is only available for breweries C, E, F and I:

- Brewery C has a water loss equal to $1.95L_w/L_B$, of which almost 51% goes into beer production and 20% is trapped in spent grains, hops and yeast.
- Brewery E has a water loss equal to $1.81L_w/L_B$, of which 60% goes into beer production or is evaporated, 9% is trapped in spent grains, hops and yeast, and almost 6% is lost in evaporation from condensate, the rest is input water for the closed loop system which inevitably leads to some water loss.
- Brewery F has a water loss equal to $1.44L_w/L_B$, of which almost 70% goes into beer production and 25% is trapped in spent grains, hops and yeast.
- Brewery I has a water loss of $1.4L_w/L_B$, of which more than 71% goes into beer production and 10% is trapped in spent grains, hops and yeast.

Figure 6-8, which focuses on breweries with a higher water use ratio and lower beer production, indicates that when beer production falls below the 10 000 hL per annum mark, it is less evident to identify a pattern or correlation between beer production and water consumption.

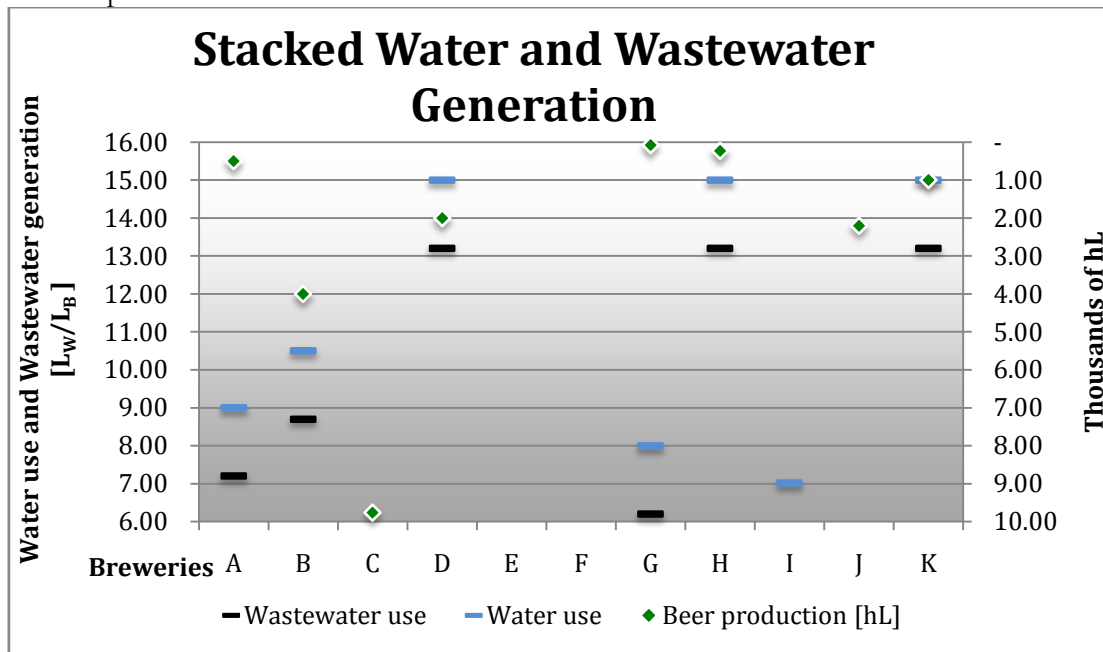


Figure 6-8. Stacked water use and wastewater generation in breweries producing between 80 to 850 000 hL (2014).*

Source: Author's own illustration.

* The left axis is limited to breweries whose water use and wastewater generation ratio is between 6 and $16L_w/L_B$, whereas the right side axis is limited to breweries producing less than 10 000 hL annually.

6.2 Maintenance Social Sustainability

As mentioned previously in the literature review, there are several components to sustainability; the section on NRA tackled the more technical and economic factors, while this section seeks to understand the contribution of local culture to sustainability when establishing microbreweries in Belgium. To achieve this aim, MSS is mainly analysed in light of the cultural heritage and neolocalism.

At the small-scale level, two mentalities were observed: in most cases the brewers launched their brewery for the love of beer and brewing, while in other cases sustainability played a major role combined with the love of brewing. In the first case, the efficiency gains were solely tackled from a cost-benefit perspective, meaning that when benefits are higher than costs for a given investment curbing water consumption, then the brewery would invest. These types of breweries follow a logic similar to that of larger scale breweries, hence resource efficiency is often a function of revenues, and thus of beer production. On the other hand, in breweries where sustainability is important, some investments, which from an economic perspective proved unprofitable, were nevertheless carried out, as it is important to reduce the brewery's environmental footprint. Brewery K perfectly embodies that philosophy, which is to take from the environment only what is needed and release back unpolluted natural resources. Breweries D and G are also good examples of breweries adopting such a philosophy; brewery G minimise its use of harmful cleaning products while brewery D, similar to brewery K invests in new technologies, such as CIP tanks and resource recovering techniques to optimise resource consumption.

6.2.1 Cultural Heritage

As Jackson stated in his book ‘La Bière’ (Dauliac & Jackson, 2008), beer is so tied to Belgian culture that it is often found on the dinner table next to a bottle of wine. Undeniably, with more than 1 500 beers, Belgium has a vast array of different styles of beer; spontaneous fermentation, fruit beers, pils, triples, blond, abbey beers, trappist beers... Many of those beers and breweries have strong links to Belgian history and culture, which is reflected in the interviews conducted with the brewmasters.

Table 6-8 provides details on the year the current brewery was launched as well as the year or century when the first beer was brewed on that location. The oldest brewery being brewery C, which can trace its heritage back to the 12th century. Beers being brewed by brewery F rely on a traditional type of beer, white beer, that was brewed by around 36 very small breweries in the middle of the 15th century. Brewery E, which is comprised of several breweries, has one of its breweries dating back to the end of the 19th century. Finally, brewery I, a Trappist brewery, is the sample’s oldest brewery continuing the values and norms of an ‘Authentic Trappist Product’ brewery. These require the brewery to be within the walls of a Cistercian abbey, beers have to be brewed under the supervision of monks and the brewery is not for profit. If proceeds are generated, they are used for the upkeep of the abbey whilst the rest goes to charity and the needy. In conclusion, a brewery can be a vehicle of culture, whereby the beer contributes to sustaining knowledge and carrying on brewing traditions, values and beliefs. This last concept is best illustrated by ‘Brasserie des Légendes’²⁹, a Belgian brewery, which has a series of beers, whose names evoke history and tales. For instance, they have a beer called Quintine, referring to a witch burned alive at the location of the brewery several centuries ago and another called Goliath referring to the fight between David and Goliath.

Table6-8. Creation date of visited and interviewed breweries in Belgium.

Brewery	Starting date	First Brewery
B	1994	
C	1993	12 th century
D	2013	
E	1892	
F	1965	1445
G	2009	
H	2013	1812
I	1856	1836
J	2002	
K	2012	
L	2013	
M	2005	1882

Source: Author’s own illustration

²⁹<http://www.brasserie-ellezelloise.be/fr/bieres>

6.2.2 Neolocalism

Sense of Place

The chapter on the economics of brewing detailed how the brewing sector suffered a significant collapse in terms of numbers. The crash stabilised at the turn of the century before slowly increasing. As can be observed in Table 6-8, within the last decade many breweries have emerged, and some, like brewery M, are resuming the activity of a decaying brewery (personal communication, brewer M). Given the strong history and notoriety of Belgian beers, cases where breweries launch their venture without trying to appeal to the sense of belonging of a local community are rare. Breweries use their beer and its name as means of identity. In continuing the beer and traditions of an old brewery, brewery M has ensured the survival of a local spontaneous fermentation beer and a brewery whose craft dates back to 1882.

More recently, brewery H, which is in the process of moving into its own brewing facility at the exact location of an old brewery, intends to provide its city with its own special beer (personal communication, brewer H). One way this is done, is with the brewery's name which refers to stilts, a traditional entertainment of its home city. Some breweries, like brewery H name their beers in reference to vernaculars, creating an even stronger link to the community by appealing to the intangible capital of its inhabitants. Sometimes, the link to the community is not a choice of the brewery but rather a consequence of the location. All of the sample microbreweries have whether inadvertently or not, been associated by the locals as their brewery, something recounted by brewer G.

Some breweries also develop a link to a community, locality or province by using a local produce or drink in the brewing process. Brewer M prides himself on using cherry and walnuts plucked in a neighbouring municipality to brew some of its beers. In other cases it is the beer that is used as an input for other local product, for instance brewery C, whose beer is used in the ripening process of cheese and whose spent grains are used to produce an alcoholic liquor (personal communication, brewer C). All these synergies between local products are factors that, in the mind of consumers, can create a link to a community and arguably contribute to the creation of terroir.

An interesting phenomenon are the brewpubs, brewery L is a brewpub, meaning that it produces beer but only for its three restaurants. From listening to brewery J's history and evolution, it was found that the brewery started as a brewpub before evolving into an actual brewery. Brewpubs produce a sense of uniqueness attached to a restaurant (personal communication, brewer L).

Finally, regardless of their size, a common feature among breweries is to sponsor local events, races and participate in local fairs (personal communication, brewers B, C, F, G, H, K). Obviously, as the brewery grows in size the events being sponsored are increasingly large, yet the involvement is still appreciated by the local community.

Terroir

When asked about the existence of a terroir of beer, answers were a relatively consistent 'no'. Contrary to wine, beer is the result of several ingredients brewed together and these ingredients, dependent on the brewmasters needs, can originate from any part of the world. Some breweries highlighted that taste disparities in a recipe arising as a result from variation in the quality of ingredients would go unnoticed among a vast majority of consumers (personal communication, brewers B and G). Backing this idea, brewer H reckons that a beer terroir could exist for beer that includes a product typical of a region just like brewer M does. A terroir of beer is also accepted for spontaneous fermentation beer, as in those cases, the beer

fermentation and process is a result of yeast present in the air at a certain location that inoculates the cooling wort (personal communication, brewery M). In a desire to protect regional product, new labels have been created such as the ‘Streek Product – Regio and Traditie’³⁰ (=Regional/local Product – Region and Tradition), which is a guarantee of authenticity, craftsmanship, and the added value of a product’s history. One of the beers from Brewery E which dates back to 1892 has been awarded that label for it still brews an ancient type of beer with spontaneous fermentation (personal communication, brewer E). Another label, which is less common as brewers often do not want to be restricted when purchasing their ingredient, is Belgian Hop³¹. This label guarantees that at least half the hops added in the brewing process originates from Belgium.

An interesting idea brought forth by brewers G and H was the idea that beer is part of a terroir that includes other crafts typical of community, locality or province. In that aspect, each craft can then be perceived as means of communication for a whole terroir. Subsequently, brewer H saw the emergence of more breweries as a driving force emulating the craft beer world.

Following the idea that Belgian breweries possess a unique heritage, many labels have been founded to protect this craft and knowledge:

- Belgian Family Brewers³² is a label grouping 22 breweries that have been in activity for at least 50 years in a row. The label promotes independent and family owned breweries to protect the identity and authenticity of Belgian Brewing methods.
- Belgium Beers of Wallonia (BBW) is an identification tool to identify beers brewed in a brewers’ own facility in the region of Wallonia.
- Authentic Trappist Product (see above).

To better understand the role of these identification tools, an expert interview was conducted with an employee at APAQ-W, a regional body promoting Walloon quality agriculture. The body launched, in February 2015, the BBW logo that is the result of both medium and small-sized Walloon brewers’ desire for recognition. Although the APAQ-W agreed to put up the platform, participants are required to actively take part in the meetings. The initiative’s main purpose is to put the sector in the spotlight. With around 27 to 30 members already registered, the BBW can already pride itself on having gathered around 45% of the breweries of Wallonia in its scheme. Reaching out and having a larger number of members will further its reputation, which in turn will benefit the breweries themselves. Brewery J is part of the new scheme.

The expert also echoed many of the conclusions reached by the breweries with regard to terroir. If it meant using ingredients supplied only in Belgium, less than three beers could meet such criteria. In his opinion, terroir could only refer to three categories of beer: beer inoculated by spontaneous fermentation, beer related to tradition (e.g. Saison beer³³) and beer using local or regional ingredients.

³⁰<http://www.streekproduct.be/steunpunt/detail.phtml?id=26>

³¹<http://www.belgischehop.be/logo-houblon-belge?lang=fr>

³²<http://www.belgianfamilybrewers.be/fr/brasseurs>

³³ Saison beers were traditionally brewed, in the Hennuyer region, to refresh workers working in the fields. The alcohol content of these beers was subsequently rather low, between 3 to 3.5%.

7 Analysis

This chapter analyses and discusses the data collected during the brewery visits as well as during the interviews. The chapter is organised according to the four research questions outlined in the introduction:

1. What is the true cost of water and waste in Belgian breweries?
2. What are the common cleaner production and pollution prevention techniques and practices in place in the Belgian brewing sector?
3. What is the role of culture with regard to sustainability in the microbrewery sector?
4. How could small Belgian breweries further optimise their water consumption and waste generation patterns?

7.1 The true Cost of Water and Waste in Belgian Breweries

There were some limitations in calculating the true cost of water or TCEC, since some breweries, regardless of their size, could not provide exact numbers on either the environmental protection expenditure, material flow cost or both. Although breweries F and I did not provide estimations on their costs for water extraction from their well, it is safe to assume that the costs are very low and even marginal. Where breweries had their own wastewater treatment plant, no water cost estimations were available, which is an unfortunate limitation, as a comparison between paying the municipal tax and owning a wastewater treatment plant could have provided insightful information. Since Belgium is obligated to charge water at its true cost, the price paid by the consumer reflects those costs exactly. Consequently, some regions are cheaper in terms of total water cost than others. For example, breweries B, C, D and K, all located in different regions of Belgium, are respectively paying 3.35, 4.56, 3.95 and 4.00 EUR per m³ to the municipality, for water extraction and water treatment costs. Brewery K does not treat its water prior to its use in the facility leaving its TCEC at 4.00 EUR per m³, whereas breweries B, C and D's costs have to be adjusted for the water treatment cost. Brewery B's water treatment cost is 1.98 EUR per m³ leading to a final cost of 5.33 EUR per m³ for a brewery producing 4 000 hL per annum. Brewery C estimates its water treatment costs to be low, whilst brewery D is not yet fully constructed.

Other industrial sectors use water purification systems similar to those present in the brewing sector. Dore, Singh, Khaleghi-Moghadam, and Achari (2013) predicted that water treatments plants using ultrafiltration and handling between 100 and 500 m³ per day, like brewery I who treats around 250 m³ per day, had marginal costs ranging from 0.06 to 0.04 EUR per m³³⁴. Costs for water treatment with reverse osmosis were only available for desalination plants and are estimated to have a marginal cost between 0.6 and 1.3 EUR³⁵ per m³ (Al-Karaghoul & Kazmerski, 2012; Sarni & Pechet, 2013).

Calculating the true cost of organic waste is more complex, since prices vary depending on the purchased quantity, the type of grains, hops and yeast bought, which are all dependent on the type of beer brewed etc. These issues make larger breweries more advantageous. As the thesis's purpose is not to delve into the details of brewing different styles of beer, it will just be stated that price of malt can vary between 576 EUR per ton for a pilsner malt to above 3 000 EUR per ton for a BIO roasted spelt malt³⁶. Yeast prices fluctuate between 2 to 10 EUR

³⁴Given an exchange rate of: 1 CAD = 0.66 EUR, <http://www.xe.com/en/> on the 22nd of August 2015.

³⁵Given an exchange rate of: 1 USD = 0.88 EUR, <http://www.xe.com/en/> on the 22nd of August 2015.

³⁶https://www.brouwland.com/content/assets/docs/Prices_FR.pdf

per kilo, whereas hops has a range of 7 to 15 EUR per kilo³⁷. In addition, calculating the true cost of organic waste for the brewing industry can almost be seen as unnecessary as the waste is, in a sense, unavoidable. Whatever the desired beer is, breweries always need malt, hops and yeast as raw ingredients, and although optimisation in batch size might slightly decrease costs and the quantity of waste produced, a certain quantity of organic waste will inevitably be generated. However, it has been observed that thanks to GMP certification, large breweries were able to sell their organic waste to farmers at a price of 0.045 EUR per ton of dry matter for spent grains and hops and 0.4 EUR per kilo of dry matter for yeast. Nonetheless, this opportunity can also be capitalised on by microbreweries, as illustrated by brewery D, who is currently in the process of becoming GMP certified.

When it comes to inorganic waste, however, any wastage in the packaging area is a loss of money that has to account for the purchasing price of the product and cost to handle the waste, in other words the TCEC of inorganic waste. In this case, waste is also an inefficient use of resources. For broken glass, it is assumed that the loss is equal to the price of the deposit, which in Belgium is generally of 0.10 EUR both for 0.25 L and 0.33 L bottles. The only exceptions are breweries H and K who use screen-printed bottles where the deposit is equal to 0.30 EUR per 0.33 L bottle. To calculate the TCEC, costs or benefits of handling the waste must be added to the purchasing price. For large-scale breweries, like brewery F, able to sell their broken glass for 0.21 EUR per kilo, given that a bottle weighs between 250 and 300 grams, the TCEC oscillates between 0.04 and 0.05 EUR per bottle. It should be noted though, that the selling price of 0.21 EUR per kilo is an average price for all waste fractions combined, a price influenced by the high selling price of metal and plastic. For smaller breweries, such as brewery B, unable to sell their broken glass, there is an extra cost to be accounted for, the cost of handling the waste, namely 0.11 EUR per kilo, resulting in a total fluctuating between 0.128 and 0.13 EUR per bottle, or 0.325 EUR per 230 grams screen-printed bottle. Similarly, the cost of handling the waste in microbreweries is an average of all waste fractions combined.

The destruction of a crown beer cap, which weighs around 0.024 kilo (Koroneos et al., 2005), represents an economic loss of 0.005 EUR³⁸ plus the cost of handling the waste of 0.0003 EUR per crown bottle cap. In the case of larger breweries, the benefits of selling the waste are equal to 0.0005 EUR per crown bottle cap. In conclusion, it can be assumed that the total corporate environmental cost of a malfunctioning crown cap is 0.006 EUR. A few Belgian breweries, such as brewery M, use corks in addition to crown caps to seal their bottles, a particularity often associated to spontaneous fermentation beers, the TCEC inevitably higher.

Then there is the issue of labels. Estimating the costs of this, however, is extremely difficult, as one would need to include the marketing costs to come up with the design of the beer, a factor that is highly variable. Brewery I for example, has a label whose design has almost never changed. The marketing costs are therefore negligible. Younger breweries however, have higher costs as they need to spend more on marketing their product and their costs have not yet amortised. We have therefore assumed the cost to be null.

Table 7-1 summarises the TCEC of water and waste in breweries. The description column lists the factor included in computing water and waste's TCEC. The organic waste and label could not be calculated as they are assumed to fluctuate too significantly from one brewery to another. Furthermore, it should be noted that water's TCEC was only calculated for

³⁷ *Ibid.*

³⁸ http://www.alibaba.com/product-detail/beer-bottle-crown-cap_60184415371.html?spm=a2700.7724857.35.1.jlLaZg

breweries, whose water is supplied by the municipality and that opt to either not treat their water prior to usage or treat their water with chlorine dioxide, at a dilution level of 15 mg/L.

Table 7-1. Total Corporate Environmental Cost for Breweries (2014).

Brewery	Unit	Description	TCEC
Water	€/m ³	<ul style="list-style-type: none"> • Water extraction • Water treatment with chloride dioxide • Municipal wastewater treatment 	5.33
	€/m ³	<ul style="list-style-type: none"> • Water extraction • No water treatment • Municipal wastewater treatment 	3.35 – 4.65
Waste	€/ton	<ul style="list-style-type: none"> • Organic waste 	N/A
	€/bottle	<ul style="list-style-type: none"> • Bottle • Crown cap • Handling the waste 	0.134 – 0.136
	€/bottle	<ul style="list-style-type: none"> • Screen-printed Bottle • Crown cap • Handling the waste 	0.331
	€/bottle	<ul style="list-style-type: none"> • Bottle • Crown cap • Selling the waste 	0.046 – 0.056

Source: Author's own illustration.

7.2 Common Cleaner Production and Pollution Prevention Techniques and Practices in place in the Belgian Brewing Sector

7.2.1 Water Management

Water Consumption

As highlighted, one of the most important KPI in the brewing industry is the water use ratio, a proxy for water efficiency in breweries. Nevertheless, there are some limitations that should be accounted for when using it to benchmark the entire brewing sector. Microbreweries do not dispose of the same equipment as large-scale breweries. For instance, though pasteurisation, filtration and returnable bottling-washing machines are a common thing in larger-scale breweries, microbreweries, often opting for craft beers, reject the use of pasteurisation and filtration while preferring to sub-contract the washing of the bottles. In conclusion, the water use ratio provides a good general overview of efficiency in a brewery, but to be able to correctly benchmark breweries, the various pieces of equipment used have to be taken into account. Therefore, this section, guided by the water consumption ratio, reviews the diverse practices and techniques of water treatment, cleaning procedures, water recycling and reusing as well as wastewater management in the eleven visited breweries.

The water use observed in the breweries' sample ranges from 3.94 to 15 L_w/L_b, as illustrated by Table 7-2. This is in line with what Olajire (2012) stated in his paper on modern breweries, which identified ratio fluctuating between 4 to 10 L_w/L_b, though the upper limit observed is higher. However, it contradicts what Williams and Mekonnen (2014) have observed during their LCA of a microbrewery that consumed 3.4 L_w/L_b. The latter ratio is rather low, as

according to Goldammer(2008) efficient breweries have ratios between 4 and 6 L_w/L_B and that small breweries can be expected to have a higher ratio. Furthermore, as the Williams and Mekonnen's focus is on the life cycle of a beer, the study does not provide many details on the brewing process for comparison, except that there is no filtration or pasteurisation involved and that the brewery solely casks its beers.

Table 7-2. Water use ratio in visited breweries (2014).

Brewery	Water Use [L_w/L_B]
A	9.00
B	10.50
C	2.29
D	15.00
E	4.55
F	3.94
G	8.00
H	15.00
I	7.02
J	4.71
K	15.00

Source: Author's own illustration.

Interestingly, the trend curve of Figure 6-1 shows similarities with the decreasing marginal return curve. Investments made by breweries to scale up their beer production process and increase resource efficiency yields more efficiency gains for smaller scale breweries, below 3 000 – 4 000 hL. At small production levels, many cost saving reductions are still to be capitalised on, whereas as the production increases the most cost efficient investments have already been made. Therefore, afterwards, adjustments tend to result in lower efficiency gains, reflected in a flattening slope.

Analysing the division of water consumption along the brewing process of brewery F and the World Bank (1998), as illustrated in Table 7-3, provides information on the most water intensive section of brewing beer. It is clear from the comparison that optimal water consumption in the packaging area should aim at a water use of 1 L_w/L_B . Regarding the water requirement of brewing, the comparison of Table 7-3 demonstrates that targeting around 2.5 – 2.7 L_w/L_B in the brewing area is a sign of efficiency. The large difference observed in the auxiliary row can reveal efficiency gains and recycling efforts that have been achieved for steam boilers, air compressors and water savings achieved for other sanitary uses since 1998.

Table 7-3. Division of water use ratio (2014).

Division of Brewery process	Water Use Brewery F [L_w/L_B]	Water Use World Bank [L_w/L_B]
Brewing	2.52	2.7
Packaging	0.99	1
Auxiliary	0.43	1.2
Total	3.94	4.9

Source: Author's own illustration and World Bank (1998).

Water treatment

The connection between water treatment prior to its usage in breweries and the water use ratio is not straightforward, as it is a matter of processing water. Nonetheless, breweries E, F and I use water treatment techniques such as reverse osmosis and ultrafiltration, which predictably affect the brewery's water use, as those filtration systems inherently involve water losses. According to brewery E, processing a significant fraction of its input water with reverse osmosis, it experiences a 15% water loss during filtration. Opting for such costly water treatment, both in economic and environmental terms, is necessary for two reasons. Firstly, those breweries use steam boilers for their heating purposes and these machineries require a high degree of water purity to avoid scale formation and other reparation costs. Secondly, since breweries E, F and I implement a final rinse after having disinfected with peracetic acid and hydrogen peroxide as a last step in their cleaning procedures, it is important that the water be free of any impurity that might nullify the whole cleaning procedure. Given that breweries B and K are not able to ensure such a high degree of water purity, they do not rinse their tanks after the disinfection step.

On the other hand, microbreweries barely treat their input water, if at all, granting them an advantage over larger scale breweries that can be experiencing some water losses due to their water treatment procedure. Depending on the quality of the input water, some microbreweries might decide to soften their water and remove impurities with active carbon filters and UV lights, like breweries C and D. Other breweries, such as brewery B, simply treat their water with small amounts of chlorine dioxide.

In microbrewing, differentiating between different water usages, such as water for brewing, cleaning and steam boilers, can imply additional costs in infrastructure higher than potential cost reduction as water is not unnecessarily treated. Nevertheless, it is apparent that at a given scale, around 85 000 hL annually, it becomes interesting for breweries to start treating their input water according to their use in the brewery to avoid treating some water more than necessary.

Cleaning Procedures

Contrary to water treatment, there is a clear link between cleaning procedure and a brewery's water consumption. The findings made it evident that, in terms of water, washing and sanitising are a major contributor to a brewery's water bill. This is supported in the literature which points out that cleaning pieces of equipment, packaging and pasteurisation are the main water consuming stages of brewing (Brewers of Europe, 2012).

The cleaning procedure followed by large breweries, E, F and I, follows the pattern described by Briggs (2004), Bamforth (2006), Tamime (2008) and Goldammer(2008), namely that a cleaning procedure is divided into five steps:

1. Pre-rinse with water at ambient temperature;
2. Detergent circulation at either hot temperature or ambient temperature;
3. Intermediate rinse at ambient temperature;
4. Disinfection circulation for disinfection and neutralisation of potential alkaline residues; and
5. Final rinse with sterilised water.

The three studies also highlighted the possibility of thermal sanitation with water vapour (C. Bamforth, 2006; Briggs et al., 2004; Goldammer, 2008) something that was observed in smaller breweries, such as breweries C, G and H, which enabled them to reduce the number of cleaning steps down to 3 or 4. Other small breweries usually adopted a simplified version of

the pattern described for large breweries by eliminating the final rinse as it requires a high degree of water purity; a costly investment.

Unfortunately, the quantities of water used per cleaning cycle in breweries were not clear. One reason for this was that many cleaning solutions are reused or recycled, making any calculation about water consumption relatively difficult. According to Jeffery & Sutton (2008), breweries can be estimated to require, respectively, 1 100 litres or 600 litres of water to wash and sanitise a 30 hL tank with a partial or full reuse CIP system. In addition, brewery F pointed out that it was able to reduce the water consumption of its cleaning procedures by 25%, simply by adjusting cleaning and disinfecting agents, rinsing and cleaning periods as well as temperatures. The EIPPCB (2006) echoing brewery F's recommendations, adds that maximising product recovery, using adapted spraying devices, controlling recycling and a washing period based on electric conductivity rather than time as well as using a turbidity detector can further optimise CIP systems and other cleaning procedures. An area where breweries already adapt their cleaning procedure is in the packaging area, as it was observed that breweries generally run a simplified cleaning procedure and less frequently used a thorough washing and sanitising cycle. Briggs (2004) also endorsed the adoption of a shorter cleaning procedure, though he recommended a thorough cleaning procedure to be conducted every seven days. A simplified version impacts water use as it is a less water intensive washing and sanitising process.

Brewery B, the only brewery able to provide data on the cost of its whole cleaning procedure, estimated that the costs of cleaning products to be approximately 20 EUR per 50 hL batch. Unfortunately, this number is impossible to compare to the 30 EUR provided by WRAP's study, as the size of its tank is not mentioned. With regard to cleaning product and procedure information, it was observed that Brewery I uses around 192.28 tons per annum of caustic soda as an alkaline cleaning product, which translates into a use of 73 kilos of sodium hydroxide per 50 hL batch. This quantity includes the entire brewing process, from mashing to bottling.

The EIPPCB (2006) provided a case study of a small brewery able to reduce its water consumption by 40%, solely by determining the water pattern in the brewery, optimising its cleaning procedure and repairing faulty equipment. However, it should be noted that given that this water consumption reduction was equal to 73 000 m³, it translates into a post optimisation water consumption of 182 500 m³, a consumption two times as high as that of brewery I. If water consumption is any proxy for beer production, then it could be estimated that that brewery would produce around 200 000 to 250 000 hL per annum, which, in the Belgian brewing sector, would classify as a large-scale brewery.

The high cost of manpower required to conduct each cleaning procedure might be one of the reasons explaining why, in the last decade many smaller scale breweries have been increasingly implementing CIP systems, although they present a high upfront cost (Briggs, 2004; Tamime, 2008). Breweries D and H, which are in the process of building their own brewing facilities, have both opted for partial reuse CIP systems and breweries B, J and K have CIP systems, though none of those five breweries produces more than 4 000 hL annually.

Water Reusing and Recycling

The collection of rainwater to be used for low-grade cleaning was only adopted by brewery G. It has a one m³ tank which helps it to save on its water bill. This investment only requiring a storage tank was an improvement already suggested by Brewers of Europe (2012) to cut down on a brewery's water bill by 4.3%. Surprisingly, only one brewery harvested rainwater to fulfil basic water consuming tasks, given that for example in Brussels, breweries can be expected to harvest between 54 and 78 litres of water per month per square meter (IBGE, 2010).

Although it would require water treatment prior to its use in the facility for cleaning or brewing purposes, this water could without any treatment replace water used for sanitary or other low-grade purposes remote from the brewing process.

Breweries often use a cross-flowing water stream to avoid heat and water losses (EIPPCB, 2006). For instance, many breweries have decided to cool down the wort by simply cross flowing the hot wort with brewing water for a subsequent mashing procedure.

A hotspot in terms of water and cleaning product consumption that is primarily faced by large-scale breweries, like breweries E, F and I, with the exception of microbrewery K, is the returnable bottle-washing machine. Although the reference document on best available techniques in the food, drink and milk industries (EIPPCB, 2006) advises for a water use of 0.2 litres per bottle, only brewery F achieves a lower water use per bottle of 0.25 L. Breweries F and I, respectively use 0.22 and 0.25 litres per 0.33 L bottle. Brewery K opted for a bottle-washing machine because of the adopted philosophy of taking care of all aspects linked to the brewing process. It achieves a ratio of 0.66 litres per 0.33 L bottle. This is associated to the capacity of the machine, which only handles 1 500 bottles per hour, whereas some modern breweries handle more than 100 000 bottles an hour (Oliver, 2011). Given the beer production of breweries F and I, it can be assumed that their machines have a capacity far superior to that of brewery K, which partly explains the wide gap in water use.

Finally, breweries also need to maintain hygiene standards in the facility as a whole, although on a less frequent basis than tanks, vessels and other machineries. However, as beer coming into contact with floors and other parts of the brewery never end up in commerce, it thus provides a perfect opportunity for reusing or recycling water from a previous cleaning stage or other water consuming tasks. Breweries have shown various recycling practices for this cleaning procedure. Brewery G uses collected rainwater to mop the floors, whilst brewery J lets cleaning solution from a tank washing procedure run on the floors. On the other hand, brewery F transferring beer through its facility with the help of push water, reuses that water after its electric conductivity has been controlled and it has undergone adequate treatment.

As previously mentioned, reusing and recycling techniques were only aimed at decreasing the process water consumption of breweries, but breweries also adopt recycling techniques to minimise water losses occurring along the brewing process. Brewery E recovers the evaporation caused by the wort boiling stage to recycle the water and heat trapped to feed hot water into its steam boiler, after it has been treated by reverse osmosis. It is estimated that between 6 to 10% of wort evaporates (EIPPCB, 2006). In the case of brewery E brewing 160 hL of beer per batch, this pertains to a potential 9.6 to 16 hL of steam discharge per batch that can be recuperated.

7.2.2 Waste management

Organic waste

Breweries, regardless of their size, have shown to be able to dispose and valorise their organic waste rather easily, as all of the sample's breweries recycle their spent grains as fodder for cattle and other farm animals. With regard to spent hops, usage varied as brewery A paid for it to be disposed of in a biogas plant. Some combined it with spent grain to be used as fodder, whilst others recycled it as a fertiliser to be spread onto fields. The ability to sell their organic waste, although at much lower price than what Fillaudeau and Blanpain-Avet (1999) and Brewers Association (n.d.) had found, is a disposal method that is currently only apparent in large-scale breweries. Brewery F sells its organic spent grains and hops at 0.045 EUR per ton of dry matter while the two studies negotiated a price ranging from 1 to 6 EUR per ton.

Finally, brewery F was also able to financially valorise its spent yeast at 0.4 EUR per ton of dry matter. Yet, the fact that brewery C is being GMP certified to sell its organic waste shows that valorising waste is an option microbreweries are starting to be able to capitalise on.

Figure 6-3 illustrating the organic waste generation in breweries highlighted that there is no clear pattern to be detected. Table 7-4 illustrates the waste generation observed in the literature and that of the sample breweries. The difference between the two types of organic waste stream might be attributed to the fact that many of the sample's breweries brew beer with an alcohol content above the 6%³⁹, which requires more grains providing the additional starch needed for the yeast to break down into fermentable sugars (Pavslar & Buiatti, 2009).

Table 7-4. Organic waste generation.

Organic Waste Stream	Average waste generation of Belgian breweries [kg/hL]	Range of waste generation in German breweries (> 1 million hL beer) [kg/hL]
Spent grains and hop	35.67	16 – 19
Yeast	4.40	1.7 – 2.9

Source: Author's own illustration and IFC (2007).

Organic waste generation is difficult to optimise, as it is the reflection of a brewmaster's recipe and not resource inefficiencies. Moreover, large discrepancies between the spent hops generations were observed. The reason for this is that spent hops is separated from the wort together with other impurities, called trub or hot break. Consequently, by using the term spent hops some brewers only communicated the spent hops quantities, while others gave the quantities of trub generated, including the spent hops fraction. As the thesis seeks to reveal the true cost of all the waste, it would have been better to use the term trub rather than spent hops to avoid confusion during the visits.

Although, synergies between breweries and other sectors leads to the reduction of waste disposal costs or, better still, generates profits, breweries can also decrease their costs by recycling waste from other commercial sectors. For instance, brewery D collects the unsold bread from supermarkets in collaboration with CODUCO to reduce food waste. This bread, after being finely milled, is exploitable for brewing purposes. The synergy enabled brewery D to reduce purchasing costs and avoid 6 tons of bread from being wasted in 2014.

Inorganic waste

Given the average price of 1.66 EUR for a beer in a supermarket (Vanel, 2015) and the TCEC of inorganic waste being 0.134 – 0.136 EUR per bottle, inorganic waste amounts to around 8% of the total cost of a beer, contrary to the 50% pointed out by Brewers Association (n.d.). However, it should be noted that here inorganic waste's TCEC solely includes the cost of beer caps, bottles and their handling costs, packaging materials, crates and other inorganic waste generated at breweries are not accounted for. In the case of brewery K, inorganic waste represents 20%, being a microbrewery brewing craft beers, the price is superior to 1.66 EUR. In contrast, large scale brewery's inorganic waste represents less than 4% of the beer's price, but often their beers are to be found at the lower end of the price range (Vanel, 2015). In conclusion, though it is difficult to assess the exact economic importance of waste in relation to the price of beer, it is safe to assume that in Belgium inorganic waste represents less than 50% of a beer's selling price.

³⁹Sample's breweries producing beer with a higher alcohol content than 6%: A, B, C, D, G, H, I, J, K.

The findings did not provide accurate data on the waste generation of all the sample's breweries except for breweries B, F and I. Figure 6-5 shows that as beer production increases, waste generation decreases drastically. Several factors could explain this phenomenon. First of all, since no waste division is operated between breweries and attending activities on their estate, microbrewery B's high waste generation could be the reflection of the impact of the HoReCa business. Secondly, the decreasing marginal inorganic waste generation could also be the reflection of increasing efficiency as beer production rises. This last explaining factor is supported by the trend curve's high level of prediction power, which signifies that efficiency gains might be incentivised by the increasingly high cost of waste generation as breweries' production is being scaled up. Finally, echoing previous factor's analysis, brewery F also sells its products in cans, which none of the two other breweries do. As cans are lighter than bottles, defective cans have a smaller impact on the total weight of inorganic waste generated, explaining brewery F's low inorganic waste generation per hL. In addition, it was found that microbreweries are expected to be charged between 490.2 and 1 661.4 EUR per annum for all the fractions of inorganic waste to be taken care of. Brewery B's annual disposal costs amount to 3 600 EUR. However, since they also include the waste stream of the HoReCa business, they are considered exceptional for a microbrewery of that size. Large-scale breweries, e.g. brewery F, are able to sell their inorganic waste for an average price of 0.21 EUR per kilo; a price mainly driven by the recycling potential of metal and plastic originating from metallic cans and plastic packaging. Findings also highlighted the possibility of synergies between two firms to cut down on costs. Brewery J disposes of its cardboard and plastic waste at no cost by partnering up with a German company.

7.2.3 Wastewater Management

Although wastewater treatment is mandatory there are, however, no obligations regarding whether it should occur at breweries' facility or be taken care of by the municipality. Therefore, it comes as no surprise that many breweries opted for it to be handled by the municipality, to avoid burdening themselves. Furthermore, the obligation of municipalities to charge the cost of wastewater treatment at its true price ensures fairness. However, as the municipal wastewater treatment is general and not sector adapted, it can lead to large breweries developing a wastewater treatment facility adapted to a brewery's effluent as an attempt to decrease costs. This is emphasised by breweries F and I, the two largest breweries: they have built their own wastewater treatment plants, while large-scale brewery E is currently planning on building one.

A common feature between the two microbreweries G and J is that their wastewater treatment facilities adjoin their house. Presumably, opting for a wastewater treatment plant was not a brewery based choice but probably a household decision, later adapted to the need of the brewery.

However, the decision to opt for a wastewater treatment plant can also be a decision guided by a philosophy. Brewery K is currently in collaboration with a university to study the cost and design of building lagoons to treat the brewery's effluents. This treatment is advocated in the literature (EIPPCB, 2006) but rarely seen in the reality, partly due to the size it occupies.

Regarding the wastewater treatment procedure, the pattern followed by all breweries followed the basic division into primary and secondary treatment, always starting with a load equalisation to enable downstream wastewater treatment to operate optimally (EIPPCB, 2006). In large breweries, primary treatment also entails a screening and sedimentation phase. Afterwards, brewery F opted for an anaerobic digestion followed by an aerobic digestion as secondary treatment, while brewery I aerates the effluents prior to treating it in membrane tanks. This latter treatment is adopted in the perspective of future reusing of the treated water

in the facility. Microbreweries' treatment methods consist of a simpler version, where primary treatments consist of a buffer tank to equalise the load and a sedimentation phase. Secondary treatments only encompass an aerobic digestion stage.

Calculating the difference between water use and wastewater generation in the four largest breweries, it appeared that the difference ranged from $1.95 L_w/L_B$ for brewery C to $1.4 L_w/L_B$ for brewery I. In general, it is apparent from the four breweries whose water use and wastewater generation ratio could be analysed that approximately 1 litre of water out of the difference between ratio goes into beer. The results from these four breweries support the general assumption that a minimum of 0.95 litres of water out of the ratio ends up in beer. With regard to water trapped in the organic waste, it was identified that with a dry matter content of 22% for spent grains and hops and 9% for liquid spent yeast, between 0.14 and $0.39 L_w/L_B$ was trapped in wet organic waste. These large variations arise from dissimilarities in the breweries' recipes.

In the case of microbreweries, as the calculation of wastewater generation was based on the literature's findings that effluents are equal to the water use ratio minus $1.8 L_w/L_B$, nothing significant could be deduced. However, based on the findings, it seems that in the case of Belgium's microbreweries a ratio difference of $1.95 L_w/L_B$ instead of $1.8 L_w/L_B$ would more accurately depict the water lost in the brewing process.

7.3 The Role of Culture with regard to Sustainability in the Small Belgian Brewing Sector

Belgian beer has been part of the culture for much of the country's history. Many of the currently operating breweries have revived decaying breweries, e.g. brewery M, or installed their facility in an ancient brewery, like breweries H, suggesting a connection to the tangible cultural capital, which brewpubs satisfy, too. Another strong example echoing people's desire to see traditional breweries attached to a certain location, was the fierce public opposition that AB InBev met when revealing its plan to delocalise the production of Hoegaarden to a more modern and efficient facility (Dauliac & Jackson, 2008). The association of beer and tangible cultural capital is also visible in the brewing process. A direct link between a community and a beer can be created by having one of the four ingredients coming from the locality or province itself, like brewery F who uses the local water as part of the signature of its beer. The use of additional ingredients to the four basic ones, such as speculoos or local fruits, also creates links between a beer and a community or province. This, in turn, creates a uniqueness to the beer and "satisf[ies] the neolocal cravings" (Flack, 1997, p. 48). Therefore, though the complementary ingredients have a special attachment to an area, they are not restricted to it. This contributes to drawing a conclusion on the existence of a terroir of beer. The findings echo what Patterson and Hoalst-Pullen (2014) have underscored, namely that, with the exception of spontaneous fermentation beers, very few beers are restricted to a geographical area.

Additionally, breweries can also create a link to their community and intangible cultural capital by adopting a certain style of beer. One of brewery E's beers is a typical ale of Flanders, while spontaneous fermentation is something quickly associated to Brussels and the Brabant province surrounding it, where brewery M has its facility. Finally Saison beers are often seen as a beer traditionally brewed in the northern parts of Wallonia. By keeping on brewing the style of beer spurred by certain regions or provinces, breweries contribute to the maintenance of the craft and traditions of that place. But the connection between beers or breweries and a community also occurs through local dialect. Brewery H is a perfect example as the brewery

refers to stilt a cultural heritage of the city where it is installing its facility, whilst the name of its beer is hops written in the city’s old dialect.

Analysing the results from the interviews with brewmasters from the thirteen breweries, it has become increasingly difficult to clearly distinguish the two factors that are part of MSS. Although it is possible to identify tangible and intangible cultural capital components to beers and breweries, a clear distinction is not possible. Cultural heritage and neolocalism are two dimensions, which are very intertwined, where the creation of a sense of place occurs by linking a beer or brewery to its community by associating it to tangible or intangible cultural capital.

Regarding the labels and identification tools developed in Belgium, two perspectives can be adopted. A first one would see them as a way of helping out consumers, in Belgium and outside the kingdom, to differentiate between a growing variety of beers. A second approach would be to associate them to a rise in protectionism and an obstacle to innovation in the Belgian beer sector, as it might dictate too strictly what a Belgian beer is. This restriction can be perceived as contrary to the Belgian traditions of a small country rich of many different styles of beer and breweries.

7.4 Suggestions for further optimisation of water consumption and minimisation of waste generation in small Belgian breweries

The answers provided in the two first research questions in the first and second section could be combined to provide recommendations for microbreweries to further improve their brewing process. By coupling the TCEC of water and waste to potential reductions in water use and waste generation one can optimise resource consumption in microbreweries.

With the use of the TCEC of water as a tool, it becomes clear that brewery D did not invest in a reverse osmosis not only because of the high upfront costs of the technology, but also because of the high water losses. Assuming that Brewery D currently uses 3 000 m³ of water to produce 2 000 hL of beer, adopting a reverse osmosis technology with a 25% or optimistically 15% loss, would be equal to an additional 750 or 450 m³ of water consumed annually. Financially, this reflects an additional annual cost of close to 3 000 or 1 800 EUR respectively. This, in turn, weakens the option of reverse osmosis water purification technology in microbreweries.

Cleaning procedures were, several times, highlighted as water hotspots because of their water intensity. Consequently, it is not surprising that there has been a growing tendency for breweries, even small ones, to switch to a CIP system with single use or partial or full recovery, which presents the advantages of substantial savings on cleaning solution. A brewery using a total loss cleaning system to wash and sanitise a 30 hL tank could decrease its consumption by 1 800 to 2 400 L per cleaning procedure. Table 7-5 provides the economic details from such an improvement in cleaning procedure, given a water’s TCEC for microbreweries ranging from 3.35 to 4.65 EUR per m³.

Table 7-5. Water and cost reduction from substituting a total loss cleaning system with different CIP systems.

Cleaning Procedure	Litres of water avoided	Cost reduction per cleaning procedure [EUR]
Single use CIP	1 800	6.03 – 8.37
Full recovery CIP	1 900	6.37 – 8.84
Full recovery CIP	2 400	8.04 – 11.16

Source: Author’s own illustration

In addition, large-scale brewery F also indicated that optimising the CIP procedure and adapting them not only to the brewing process' step but also to the beer brewed can save up to 25% of water. According to the EIPPCB (2006), such optimisation can yield up to 30% water savings.

Following the major improvement implemented by AB InBev in the bottle-rinser machine (Brewers of Europe, 2012), a reduction of 5 m³ per hour in water consumption by reducing the bottle-rinser's nozzle implies a saving of 16.75 to 23.25 EUR per hour of use. Furthermore, any recycling or reusing technique entails a cost saving fluctuating of between 3.35 to 4.65 EUR per m³ depending on the region. For instance, based on the numbers of The Brewers of Europe (2012), it can be estimated that brewery G saved 8.31 EUR thanks to the rain collection tank, given a previous total water bill evaluated at 193.27 EUR.

Finally, although no numbers were provided regarding leakages, leaks can have an estimated potential cost ranging from 7.1 EUR⁴⁰ per hour for a bottle-rinser jet left switched on to 16.4 EUR per hour for a hose left switched on (ETBPP, 1998).

Regarding waste management, it was concluded that large-scale breweries were able to sell their waste leading to a consequent price ranging from 0.046 to 0.056 EUR per 0.33 L bottle. Given that earlier on, it was assumed that bottles weighted between 0.25 and 0.3kg, and that Koroneos et al. (2005) had found that approximately 56 kilos of bottles were discarded per 100 hL of beer produced, it can be estimated that inorganic waste accounts for a loss ranging from 9.41 to 10.3EUR per 100 hL of beer produced. However for microbreweries, since they are charged for the cost of handling their waste, it is estimated that inorganic waste loss per 100 hL of beer produced amounts up to 22.85 to 30.02 EUR.

⁴⁰Given an exchange rate of: 1 GBP = 1.37 EUR, <http://www.xe.com/en/> on the 22nd of August 2015.

8 Conclusions

There is a growing awareness in breweries of water consumption and waste management. Looking at the water intensity of beer production because of the high hygiene standard and energy requirement, breweries increasingly strive to reduce costs in an attempt to foster the brewery's resiliency. In addition to this emergent recognition of resource inefficiencies, many countries are experiencing a revolution in their brewing sector with an explosion of the number of breweries, whose aim is not quantity. However, contrary to large-scale breweries, these emerging microbreweries owing to their reduced capacity and novelty do not always have the opportunity to improve their resource management. Capitalising on those opportunities could prove to be decisive for their survival.

The purpose of this paper was to investigate sustainability in the microbrewing sector in Belgium by revealing the true cost of water and waste used for brewing as well as discovering the contribution of local culture to sustainability when establishing microbreweries in Belgium. In addition, the research aims at disseminating knowledge already available in Belgium among breweries.

8.1 Revisiting the Research Questions

The focus was set on Belgium due to the recent revolution its brewing sector has been undergoing and owing to the fact that Belgium is perceived as one of the godfather countries of beer. The researched breweries were selected to reflect the diversity of Belgian breweries, geographically, in terms of size and in order to represent different styles of beers. The collected data was then presented before being discussed and structured according to four research questions.

What is the true cost of water and waste in Belgian breweries?

It was found that for breweries using municipal water, as the municipality's water price is obliged to reflect the true cost of water purification and wastewater treatment, the cost of water could vary depending on the region and localities. In many microbreweries, water does not undergo treatment prior to its usage in the brewery. In those cases, it was concluded that the TCEC of water ranged from 3.35 to 4.65 EUR per m³. When breweries treat incoming water with chlorine dioxide to a level of 15mg/L, water's TCEC amounts to 5.33 EUR per m³.

Waste was divided into organic and inorganic waste. Organic waste's TCEC was not calculated since the waste is the result of a beer recipe's raw material and is inherently difficult to decrease without affecting a beer's taste. Inorganic waste on the other hand, is the product of inefficiencies in the packaging area. It reflects an economic loss ranging from 0.134 to 0.136 EUR per 0.33 L bottle, including the cost of the bottle, cap and waste disposal. For breweries able to sell their glass and metal waste, the TCEC was estimated to range from 0.046 to 0.056 EUR per 0.33 L bottle. Where a brewery uses screen-printed bottles, the TCEC is equal to 0.331 EUR per 0.33 L bottle. Unfortunately, it was not possible to determine nor estimate the TCEC of other types of inorganic waste generated in breweries, such as plastic, cans or cardboard.

What are the common cleaner production and pollution prevention techniques and practices in place in the Belgian brewing sector?

It was found that water consumption in the Belgian brewing sector ranges from 3.94 to 15 L_w/L_B, mirroring the variation in cleaning procedures and other water consuming techniques. Although treatment of water prior to usage was not often observed in microbreweries, water

filtration and purification technologies adopted in larger-scale breweries consume significant volumes of water. As ultrafiltration and reverse osmosis retain a fraction of water; around 15% of the input water is lost.

Being extremely water intensive, improvements in cleaning procedures can bring about significant water efficiency gains. Yet, at the same time, those gains should not come at the cost of quality or at the risk of spoiling beer batches. Consequently adjustments in cleaning procedures should be made carefully. Two patterns were identified, one common among breweries producing less than 500 hL and another present in large-scale breweries. Very small-scale breweries often clean their equipment with a three-step cleaning procedure where after a first rinse, a detergent is used for the caustic cleaning and sterilisation is done by water vapour. Where microbreweries usually implement one cleaning technique, larger scale breweries developed several procedures. However, they are generally geared around the following five steps:

1. First rinse;
2. Cleaning with caustic soda, 1.5% to 4%, at a temperature between 70 and 85°C;
3. Intermediate rinse;
4. Sterilisation with peracetic acid and/or hydrogen peroxide, 0.2% to 2%, at a temperature between 70 and 80°C; and
5. Final rinse.

Other breweries usually had implemented cleaning procedures inspired by this five-steps cleaning pattern, with minor adjustments dependent on their size and technology.

It is very common for the organic waste created during brewing to be recycled or reused by farmers, either as fodder for various kinds of animals or to be spread onto fields, which is particularly the case of spent hops. Breweries that are GMP certified have, in addition to benefiting from free disposal costs, the opportunity to sell their organic waste for around 0.045 EUR per ton of dry matter for spent grains and hops and 0.4 EUR per ton of dry matter for spent yeast. Regarding, inorganic waste, it is mandatory for any Belgian brewery to sort their waste stream into cardboard, plastic, metal, glass and residual waste. Contrary to the organic waste, inorganic waste has an annual disposal cost vacillating between 490.2 and 1 661.4 EUR, including all fractions of waste. On the other side of the spectrum, large-scale breweries, partly owing to the large volumes of waste generated, are able to receive 0.21 EUR per kilo of inorganic waste. Yet, this does not disincentivise large-scale breweries as the generated waste still embodies an economic loss as well as resource inefficiencies.

To lower their water consumption, breweries have implemented several recycling and reuse practices. One major improvement and investment carried out by breweries of all sizes is CIP tanks. The most basic CIP technology continuously reuses the cleaning solution during the cleaning procedure, allowing for a more than 60% water reduction compared to a total loss cleaning system. Advanced CIP technology, in addition to the continuous reusing of the water, enables the recuperation of the intermediate and final rinsing waters to be recycled in subsequent cleanings as intermediate and pre-rinse water. This latter CIP can avoid up to 80% of water consumption compared with a total loss cleaning system.

Packaging proved to be an area of the brewing process that was identified by some breweries as harbouring great potential for water recycling and reuse. Water used to rinse new or single-use bottles can easily be reused for another application as the water contains little to no impurities, because bottles have previously already been washed and sanitised. Similarly, breweries sometimes give a short shower to their filled and capped beer bottles, yet those bottles are clean with the exception of some unusual and minor beer spill over. Consequently,

that water could potentially easily be reused. Contrary to one-way bottles, reusable bottles need to undergo a thorough cleaning procedure including a series of hot and caustic bathes, before entering the bottling line. This can be a source of high chemical load for the wastewater treatment facility and generates a large quantity of wet labels containing glue, which are sorted separately from other waste streams. To remedy these issues, breweries recycle their water and cleaning solution in a counter-current fashion. Optimised bottle-washing machine consume between 0.22 to 0.25 litres per 0.33 L bottle. It was observed that one microbrewery, owned a relatively small size bottle-washing machine that consumes 0.66 litres per 0.33 L bottle. However, as the brewery has opted for screen-printed bottles, they are avoiding having to deal with large quantities of wet label or label pulp.

The most efficient way to reduce water consumption is simply not to use it, therefore by optimising the cleaning process and avoiding unnecessary washing, breweries can reduce up to 25% of water. Large-scale breweries often run their CIP tanks until the electric conductivity meets the previously set requirements. Breweries are also able to cut down on water utilisation in the packaging area by optimising the bottle filling procedure. Starting the filling of clearer and weaker beers before moving on to darker and stronger beers makes it sufficient to only lightly rinse the bottle-filling washing between different styles of beer. It was also observed that some breweries only ran a simplified cleaning procedure on a daily basis and, less frequently, a complete cleaning procedure for the bottle-filling washing to reduce water use.

Breweries almost all cooled down their wort, after the wort-boiling stage with either used water or with water that is to be used at a relatively high temperature which, in addition to reducing water consumption, also prevents energy from being wasted. Finally, as floors require a less systematic and methodical cleaning, breweries sometimes reuse water and cleaning solutions from a cleaning procedure to wash and sanitise the floor.

Analysing the difference between the water use and wastewater generation ratio demonstrated that water lost or trapped during the brewing process ranges from 1.4 to 1.95 L_w/L_B . In general, around 1 L_w/L_B ends up in the final product, of which a small portion evaporates. In addition, between 0.14 and 0.39 litres of water per litre of beer is trapped in the wet organic waste engendered by the brewing process. The remaining segment of the difference between the two ratios depends on the machinery installed in the facility, which can encompass input water for elements such as steam boilers, cooling circuits or other closed loop systems, which inevitably experience some water losses. From the results, it was concluded that for microbreweries approximately 1.95 L_w/L_B is lost or trapped during the brewing process.

What is the role of culture with regard to sustainability in the microbrewery sector?

The MSS of beers and breweries in Belgium was divided into a cultural heritage and neolocalism dimension. Cultural heritage took the form of the old traditions and craftsmanship of brewing beer permeating the whole Belgian beer sector. The neolocalism component was further sub-divided into a link to the community and the creation of a sense of place. However, from the discussion it was concluded that the neolocalism component perceived in today's brewery builds on the accumulated Belgian tangible and intangible cultural capital. This cultural capital manifests itself in the variety of beer brewed, the brewing location and the name of the beer. Moreover, MSS, defined by Vallance et al. (2011) as traditions, preferences and places that people would like to see maintained can be perceived to be strong and even gaining importance in Belgium with the emergence of microbreweries, often seeking to identify themselves as part of the cultural heritage.

Lastly, the research attempted to investigate whether the local environment influenced a beer's taste, or in other words the existence of a terroir of a beer. It was only in the case of spontaneous fermentation beers that the hypothesis was found to be correct, as the yeast inoculation is dependent on the yeast present in the air during the brewing process. Although this leads to the conclusion that the terroir of beer only exists for spontaneous fermentation beers, the interviews brought forth a novel definition of terroir, where diversity, density and craftsmanship bring to life a terroir. This last definition sees competition and rivalry as a driving force for the recognition of a certain craft. Moreover, here terroir is not restricted to the beer craft but embodies all crafts pertaining to a certain province or locality. A few breweries exemplified the fact that beer craft could be a vehicle of communication for other types of crafts. This was expressed through the incorporation of crafts into one another, such as food pairing or beer using locally produced goods (e.g. beer with speculoos) and sharing of communal space, where one craft brings attention to another one. The label 'Streek Product – Regio en Traditie', personifies this idea of terroir. In conclusion, the emergence of microbreweries passing on and representing the values, beliefs, traditions and craft of a province or locality can contribute to sustaining the cultural capital of that region.

How could small Belgian breweries further optimise their water consumption and waste generation patterns?

Unsurprisingly, it was witnessed that the breweries' principal purpose was to brew beer, and to prevent any contamination or deterioration of a beer's quality. Some microbreweries, because of the lack of automation or technology, might be tempted to put into place extensive cleaning procedures. Yet, for the sake of avoiding superfluous water consumption and waste generation as well as wasting financial capital, it is of great importance for breweries to develop cleaning procedures optimally achieving the hygiene standards. Furthermore, small additional investment with a short payback period can be made in order to easily decrease the water bill. Other investments with longer payback periods, such as CIP tanks, have the additional advantage of facilitating a brewer's life by decreasing the burden of cleaning tanks, while still contributing to a significant decrease in water consumption.

Adopting a new mind-set with regard to water, waste and wastewater management by accounting for the TCEC of the natural resource has the potential to reveal the true cost behind resource inefficiencies. In reality, it appears that breweries start to tackle inefficiencies significantly only once they have reached the 4 000 hL per year threshold. However, the emergence of microbreweries that are not aiming at producing large volumes of beer could, theoretically, negatively impact the environmental footprint of the brewing sector. Consequently, it is important for breweries to, early on, embrace a holistic approach towards water consumption and waste generation in their facility to ensure the brewery's resilience and the sustainability of the brewing activities.

8.2 Suggestions for Future Research

The research principally focused on the environmental performance of one country, whereas many other countries are currently facing similar challenges as they are experiencing a comparable emergence of microbreweries and craving for truly local beers. From the literature, both the USA and UK were identified as countries having triggered this revolution in the brewing industry. However, after visiting a Swedish brewery it can also be concluded that the two former countries did not only prompt a rebirth of brewing but actually also triggered a first-hand craving for local breweries in countries where beer is less tied to history and culture. Therefore, researching the instigator of this trend could provide more insights in the environmental challenges faced by those breweries. Yet, analysing the multiple ripple

effects and the newly created beer market all over the world has the potential of widening the understanding of forthcoming environmental challenges for the brewing industry.

Comparing the results of Belgian breweries to that of the Swedish brewery demonstrated that there are differences between the two countries. The reviewed Swedish brewery recycled a lot of dairy machinery and tanks, which was not observed in Belgian breweries. Moreover, the Swedish brewery's organic waste generation is nearly twice as high as the Belgian median generation and water costs are much lower. Subsequently, comparing different countries with beer producing markets at different stages of maturity could provide information on potential further development possibilities. At the same time, it could help assess the impact of such differences on the main drivers and barriers to economic and environmental sustainability in the brewing sector.

From a more holistic and long outlook, it is also necessary to consider how climate change will affect hops growth and malt production, a factor that might directly have deep repercussions for the global brewing industry.

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Appendix

Appendix I

- What are the driver behind the creation of this label ?
- Does the initiative come as a response to a breweries' demand or was it completely developed by the APAQ-W?
- What are the aims set by the APAQ-W for this label?
 - What percentage of Wallonian breweries do you hope to enroll?
- What are the criteria set to enlist for the label?
 - Are the criteria simply based on the local aspects or are there other criteria part of the BBW?
- How is the label perceived by the brewers, if it is not a breweries' demand driven initiative?
- For the moment, the label seems to aim at informing the consumer, will other criteria be added in the future with regard to the production and quality?
- Will, in your eyes, the tracability and the valorization stemming from the BBW label provide a similar appellation to the Protected Designation of Origin already available for wines?
- When extrapolating the idea behind the label, is it possible to think that it might lead to a terroir of beer?
- Do similar labels exist for the regions of Flanders and Brussels?
- Do other labels with criteria specific to the brewing industry exist?

Appendix II

The pollution tax is calculated according to the following formula:

$$R = N \times T$$

Where R is the total amount due (EUR), N is the number of pollution units and T is the fee per pollution unit (EUR). The number of pollution unit is calculated on basis of the following formula:

$$N = n_1 + n_2 + n_3 + n_4 + n_5$$

Where n_1 is the pollution unit linked to SS, n_2 is linked to heavy metals present in the effluents⁴¹, n_3 is a function of the BOD and COD level, n_4 depends on the temperature difference between the receiving water body and the effluents, n_5 is linked to toxicity. Moreover in that case, the tax is levied on the water intake of the brewery minus the water contained in the beer; a rough estimation of a brewery's effluents levels.

⁴¹As mentioned before brewery's effluent are characterised by very low levels of heavy metals, therefore n2 can be estimated close to zero (EIPPCB, 2006; Olajire, 2012).

Appendix III

Date (D.M.Y)	Brewery	Beer production [hL]	Water consumption [m3]	Water Use	Cost of water extraction or pumping [€]	Costs of water treatment [€]	Costs of wastewater treatment [€]	Total Corporate Environmental Cost of Cater [€/m3]	Effluent [m3]	Wastewater use
05.06.2015	A	500,00	450,00	9,00	1,20	-	-	2,40	360,00	7,20
18.06.2015	B	4.000,00	4.200,00	10,50	1,58	1,98	-	5,33	3.480,00	8,70
23.06.2015	C	9.765,00	4195,00	4,30	2,62	-	-	4,56	2.288,00	2,34
26.03.2015	D	2.000,00	3.000,00	15,00	2,29	-	-	3,95	2.640,00	13,20
30.06.2015	E	88.618,11	40.321,24	4,55	1,45	-	-	4,34	24.242,00	2,74
02.07.2015	F	850.000,00	334.900,00	3,94	-	-	-	-	212.500,00	2,50
06.07.2015	G	80,00	64,00	8,00	2,89	-	-	2,89	49,60	6,20
07.07.2015	H	233,33	350,00	15,00	2,89	-	-	4,75	308,00	13,20
09.07.2015	I	131.406,00	92.191,00	7,02	-	-	-	-	73.835,00	5,62
13.07.2015	J	2.200,00	1.037,00	4,71	2,62	-	-	2,62	641,00	2,91
14.08.2015	K	1.000,00	1.500,00	15,00	2,00	-	-	4,00	1.320,00	13,20

	Average spent grains/50hL batch [kg]	Costs of handling spent grains [€/kg]	Costs of handling spent grains [€]	Average spent hop/50h L batch [kg]	Costs of handling spent hop [€/kg]	Costs of handling spent hop [€]	Average surplus yeast/50h L batch [kg]	Costs of handling surplus yeast [€/kg]	Costs of handling surplus yeast [€]	Total waste organic generated/50hL batch [kg/hL]	Total organic waste generated/hL [kg/hL]	Total costs of handling organic waste [€/year]	Size of Batch [hL]
A	3.640,00	-	-	160,00	0,06	96,00	200,00	-	-	4.000,00	80,00	96,00	5,50
B	2.000,00	-	-	100,00	-	-	-	-	-	2.100,00	42,00	-	50,00
C	2.000,00	-	-	4,50	-	-	200,00	-	-	2.204,50	44,09	-	50,00
D	2.000,00	-	-	28,75	-	-	150,00	-	-	2.178,75	43,58	-	10,00
E	897,00	-	-	-	-	-	162,00	-	-	1.059,00	21,18	-	160,00
F	2.022,75	-0,000045	-1.547,40	2,70	-0,000045	-2,07	-	-0,40	-	2.025,45	40,51	-1.549,47	200,00
G	1.650,00	-	-	45,00	-	-	150,00	-	-	1.845,00	36,90	-	5,00
H	1.150,00	-	-	-	-	-	150,00	-	-	1.300,00	26,00	-	50,00
I	881,28	-	-	18,65	-	-	319,53	-	-	1.219,46	24,39	-	200,00
J	1.875,00	-	-	18,75	-	-	549,30	-	-	2.443,05	48,86	-	20,00
K	1.000,00	-	-	125,00	-	-	100	-	-	1.225,00	24,50	-	20,00

	Quantity of glass waste [kg]	Costs of handling glass waste [€]	Quantity of plastic waste [kg]	Costs of handling plastic waste [€/year]	Quantity of metal waste/50hL batch [kg]	Costs of handling metal waste [€]	Quantity of cardboard waste [kg]	Costs of handling cardboard waste [€]	Quantity of residual waste [kg]	Costs of handling residual waste [€]	Total inorganic waste produced [kg]	Inorganic waste produced/hL of beer produced [kg/hL]	Total waste produced/hL [kg/hL]	Total costs of handling inorganic waste [€]
A	-	-	-	-	-	-	-	-	-	-	-	-	80,00	-
B	-	-	300,00	300,00	-	-	3.000,00	300,00	30.000,00	3.000,00	33.300,00	8,33	50,33	3.600,00
C	-	-	-	-	-	-	-	-	-	-	-	-	44,09	-
D	-	-	-	-	-	-	-	-	-	-	-	-	43,58	-
E	-	-	-	-	-	-	-	-	-	-	-	-	21,18	-
F	-	-	102.027,00	-21.425,67	256.080,00	53.776,80	183.869,00	-38.612,49	172.691,00	-36.265,11	714.667,00	0,84	41,35	-150.080,07
G	-	-	-	-	-	-	-	-	-	-	-	-	36,90	-
H	-	-	-	-	-	-	-	-	-	-	-	-	26,00	-
I	129.960,00	-	-	-	-	-	72.960,00	-	19.860,00	-	222.780,00	1,70	26,08	-
J	-	-	-	-	-	-	-	-	-	-	-	-	48,86	-
K	-	-	-	-	-	-	-	-	-	-	-	-	24,50	-