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ENVIRONMENTAL IMPACTS OF SMALL BREWERIES

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ABSTRACT

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Every human should dream of an environmentally, socially and economically sustainable world, where the challenges of climate change and loss of biodiversity are successfully addressed. This of course is an attainable dream, but the system is broken such that the current trend cannot help us attain this dream due to humanity's inappropriate behavior. Due to human activities through the unsustainable production and use of energy, water, food and other resources, which undermines efforts to promote sustainable development., our environment is changing on all scales, from local to global. Some of the environmental challenges faced today include damaging of the ozone layer, climate change, unprecedented rate of biodiversity decrease, increasing air pollution, water scarcity, and land degradation.

The brewing industry contributes to these environmental challenges through its use of raw materials and energy in the production and sales of beer. The process is energy intensive, uses large quantities of raw materials, chemicals and packaging materials, and generates different waste types. It is important to understand the environmental impacts and try as much as reasonably possible to minimize the impacts without compromising product quality. Unlike in larger breweries with automized processes, the craft brewing process is mostly controlled manually. For this, care must be taken with the implementation of Standard Operating Procedures (SOP's), and waste and energy management systems.

If decision makers understand the triple interdependence of economic, social and environmental factors, integrating them into policies and every one of us acts ethically, we can achieve economic growth within the constraints of social and environmental sustainability.

Key words

Craft brewery, Beer, Environment, Sustainability, Waste, Energy

CONCEPT DEFINITIONS

CIP - Cleaning in Place

SOP – Standard Operating Procedures

GHG – Green House Gasses

EI – Environmental Impact

COD – Chemical Oxygen Demand

BOD – Biological Oxygen Demand

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1 INTRODUCTION

With growing global population and challenging environmental problems, such as climate change, food shortage, droughts, the management of natural resources must be carefully planned in order to minimize the effects on the environment. The circular economy approach by which as little as possible waste is produced, and the reuse of resources must be encouraged in every aspect of society. This approach builds resilient economies, providing environmental and societal benefits.

The brewing industry being a very energy intensive industry and using large amounts of natural resources loads the environment through waste produced and through emissions. By first understanding the process and considering the circular approach, there is the possibility of minimizing the effects of the brewing process on the environment. In craft breweries, there are lower technological investments compared to larger breweries and as a result, inefficiencies in the processes. These inefficiencies result in more waste and emissions.

The environmental impacts of breweries can be considered as part of the life cycle assessment of beer. Life cycle assessment is a technique used to assess the environmental impacts associated with all stages of the life of a product from the extraction of raw materials to processing, manufacture, distribution, use, repair and maintenance. In this work, the part of the life cycle from when the raw materials are brought to the brewery to when the beer is ready for the market is considered. Although this part of the life cycle does not contribute to the environmental impacts as much as the manufacture and transportation of the raw materials for beer production, it cannot be overlooked.

This thesis is written from the review of literature and experience gathered during a four-month long internship performed at Kahakka Brewery in Kokkola, Finland. Established in 2018 with the vision to revolutionize the brewing industry, giving beer enthusiasts a chance to brew their own beer, Kahakka Brewery is a craft brewery in the Ostrobothnia area with over seven different products.

2 CRAFT (SMALL) BREWERIES AND THE BREWING INDUSTRY

Over the past years, the global beer market has been transformed by successes of craft brewers. These successes ended the dominion of few global multinational breweries and the homogenization of beer. Craft breweries entered the beer market offering large varieties of beers and today, there are few multinational breweries co-existing with many craft breweries. The terms "craft brewery" or microbrewery are usually used interchangeably to describe breweries which recently started on a small scale producing different types of beer. There are many different and contrasting definitions of craft brewery, but all definitions have used similar characteristics such as ownership, production process, scale, age and tradition. Craft brewery is defined by the American Brewers Association as a small, independent and traditional brewery (Garavaglia & Swinnen 2018, 5). The scale of a craft brewery is related to the size of the country of operation. For instance, in Italy the maximum size is 200,000 hl (170,502 barrels) meanwhile in the USA it is 6 million barrels (7,038,000 hl) per year, showing that craft breweries in the USA could be considered as a large brewery in most countries (Garavaglia & Swinnen 2018, 5).

Beer production, particularly craft beer, is partially dependent on the ingredients but also on the brewer. A study by Helaniemi (2016, 9) shows that craft brewers see themselves as (1) experimenters and explorers, as (2) analyst and critics, as (3) hedonists and connoisseurs, and as (4) teachers and gurus. This displays a well knowledgeable, analytic yet hedonistic person who has taste and whom others look up to.

Most attention has been devoted to the craft beer industry with few studies done to assess the characteristics, attitudes and behaviors of craft beer consumers. Craft beer consumers around the turn of the century were characterized as middle-aged white males having relatively high incomes but, it has however become diverse in recent years with consumption growing among young women and those with lower incomes. Being steeped in local communities/cultures, some have attributed the growth and popularity of microbreweries to be reflective of a larger societal shift towards localism (e.g., support for local goods and services, local branding) and environmental sustainability. (Slocum, Kline & Cavaliere 2018, 28.)

2.1 History/ Background

Prior to the craft beer revolution, there was a long period of consolidation and homogenization in the global beer industry for few reasons. Firstly, there was technological progress such as the automation of the beer production process, accelerated packaging and better distribution channels, leading to greater economies of scale. Secondly, bottom-fermented beers (lagers) where introduced which required artificial cooling for fermentation and maturation, leading to higher fixed costs than top-fermented beers (ales), causing smaller breweries to exit the market. Lastly, large-scale advertising which could only be paid by large breweries became even more popular with the introduction of network television. Beer brewing dates to the beginning of human existence with almost all civilizations having some record of consuming fermented beverages but as countries developed, some moved more towards wine and some spirits (Mittelman 2007, 6).

With the rise in craft breweries in the US, UK and other countries, the beer market diversified, variety of beer styles expanded, and this widened the consumer choice (Cabras, Higgins, & Preece 2016, 19). It is relatively easy to identify the start of the craft brewery revolution in some countries like USA, Netherlands, meanwhile in other countries, like Belgium and the UK, it is difficult because of their long histories of "specialty beers". The number of breweries is a good indication of the take-off of the craft beer sector as the number of breweries declined in all countries during the twentieth century and it was only when new craft breweries started that the number of breweries increased again. (Garavaglia & Swinnen 2018, 13.) These trends are shown in Tables 1 &2 below. From table 2, notice a sharp increase in microbreweries around the end of the 20th century and beginning of the 21st century, which reflects in the increase in the number of breweries during this period in table 1.

Table 1. Number of breweries 1950 – 2015 (Adapted from Garavaglia & Swinnen 2018)

Country	1950	1960	1970	1980	1990	2000	2005	2010	2015
Australia	19	13	10	9	39	47	97	176	363
Belgium	663	414	232	143	126	113	115	123	199
Canada				40	62			312	640
China[b]								592	515[a]
Colombia	39	32	10	1	1	5	8	40	119
Denmark		31	27	25	19	16	48	120	
Germany		2216	1778	1366	1232	1289	1276	1342	1388
Hungary	1			6		120	97	57	73
Italy	31	29	37	31	22	77	148	325	684
Japan	3	5	5	5	5	307	261	213	227
Nether-lands	70	25	18	13	25	62	89	125	390
Slovakia						12	9	19	50
Spain			54		32				
UK	567	358	220	142	279	500	570	828	1424
USA	358	173	65	43	270	1491	1601	1766	3500

Notes [a] indicates that the number of breweries in 2014 was used
[b] indicates that only the number of microbreweries was used

From table 2, notice a sharp increase in microbreweries around the end of the 20th century and beginning of the 21st century, which reflects in the increase in the number of breweries during this period in table 1.

Table 2. Number of microbreweries, 1985 – 2015 (Adapted from Garavaglia & Swinnen 2018)

Country	1985	1990	1995	2000	2005	2010	2015
Australia	3	34	26	43	93	172	358
Canada	4[a]	33				277	610
Colombia			5	4	7	39	118
Germany[b]	894	867	1005	1024	1062	1112	1148
Germany[c]	632	639	759	844	894	987	1058
Hungary				110	90	50	64
Italy		1	7	60	132	311	670
Japan			17	302	256	208	222
Netherlands	7	15	30	51	78	115	380
Slovakia						14	45
Spain		1	2			46	409
USA	37	249	998	1469	1591	1756	3490

Notes [a] indicates that the number of microbreweries in 1984 was used

Germany[b] and Germany[c] are the number of microbreweries if micros are defined, respectively, as “breweries that produce less than half of average production” and “breweries with yearly production <10,000hl”.

2.2 The Brewing Process

Sugar containing liquids are used to produce alcoholic beverages by alcoholic fermentation. Alcoholic fermentation is the process by which yeast transforms sugars in wort to mainly ethanol and carbon dioxide, as shown by equation below,

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

The sugars which are fermentable by yeast are either present or are generated from processing the raw material. Brewing involves the use of germinated barley (malt), hops, yeast and water (Belitz, Grosch & Schieberle 2004, 892). The beer quality depends on the quality of these raw materials. Malt made from barley is the main component and should have a high starch content with the husk still attached to the grain. Hops give beer the aroma and bitter taste while yeast activity ferments the alcohol producing beer. Water as the most abundant raw materials affects beer character and quality and it is also used in cleaning. Other than barley, starch and /or sugar containing raw materials such as wheat, corn, and rice can also be used. (Belitz, Grosch & Schieberle 2004, 892.)

The brewing process simply involves incubating and extracting malts with hot water, then the solution obtained is boiled with hops, clarified and cooled. Yeast is added to the cooled liquid for fermentation and the fermented beer is then clarified and packaged. Even if the essentials of design and construction of brewing equipment remained unchanged over the years, brewers found themselves in buildings of better quality and using kettles, troughs and other implements of better quality. (Unger 2001, 108.)

2.2.1 Milling

Malts are stored in breweries according to their demands. Care must however be taken during storage of malts in the brewery. Temperature and moisture contents must be monitored in storage containers to prevent the development of insect colonies. Weevils and grain beetles can develop in the grains and their metabolism yields water, carbon dioxide and heat. Disinfection of storage containers and grain handling equipment is necessary from time to time to prevent contamination. Before milling, the malts are passed through magnetic separators and destoner during which metallic particles, stones and dust which might cause spark and damage to the mills are removed. In most craft breweries, these are not available and so there is high risk involved in the milling process. Milling is aimed at crushing malt particles in order to give malt enzymes the opportunity to act on malt contents and break them down during mashing. It is important that the grain husk remains as whole as possible, because if it is badly disintegrated, it is less effective in forming a permeable filter bed during wort recovery from the mash. (Hough 1985, 55-56.)

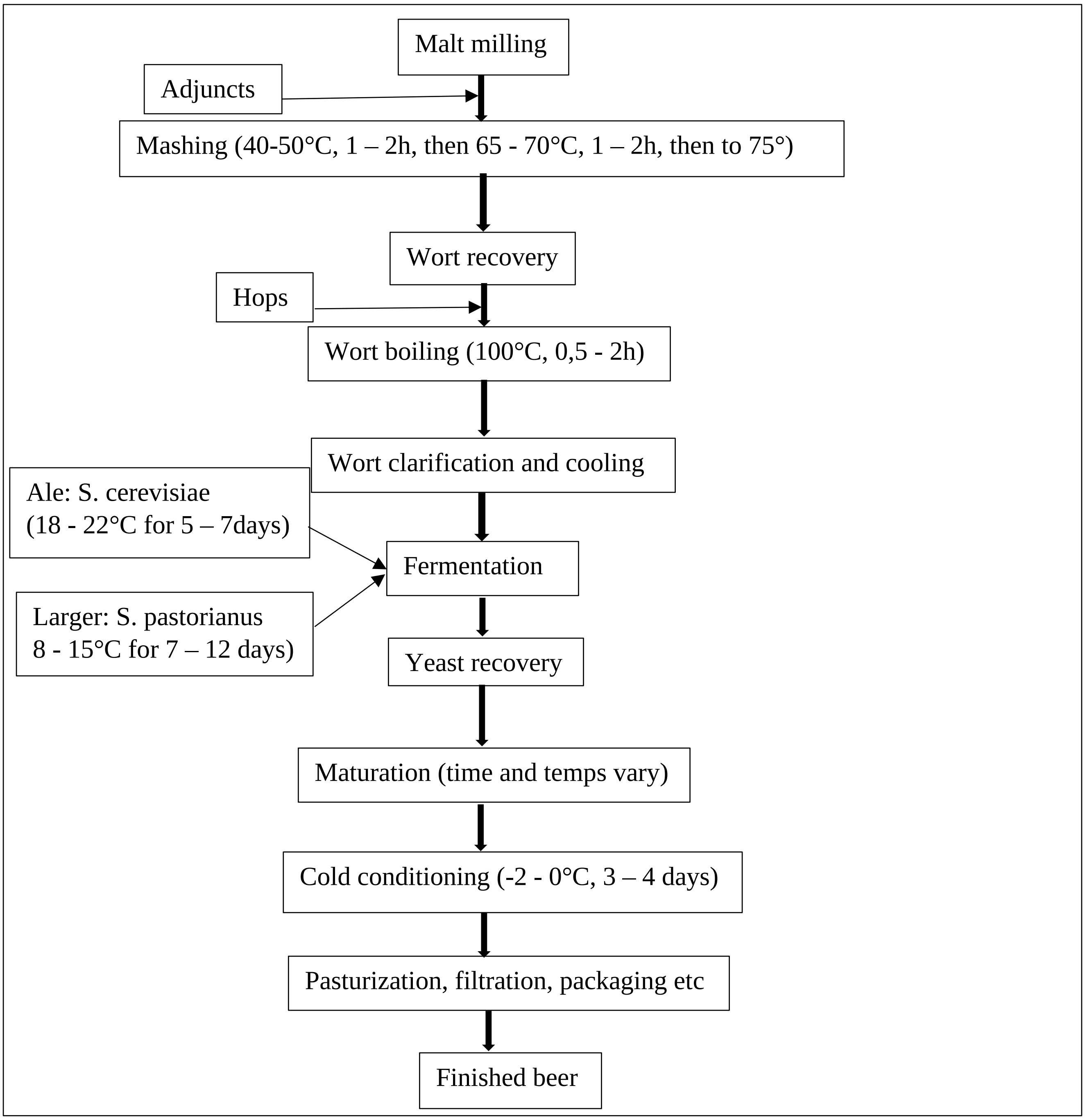

Figure 1. The brewing process (Adapted from Hill 2015, 427)

Due to the friability of the grain husk, breweries use different milling methods depending on their requirements. The most used methods include dry, conditioned and wet milling. Most larger breweries use six rollers dry mills arranged in 3 pairs of different diameters, with the first pair aimed at cracking the husk which is sieved away to bypass subsequent rollers with small diameters. In dry conditioned milling, a small amount of water or steam is added before milling, raising the moisture content of the husk by about 10% by weight, making it flexible and preventing it from shattering. In wet milling, the malt is steeped before milling. The husk absorbs moisture and becomes elastic, making it possible for the internal component to be easily squeezed out leaving the husk intact and better for mash separation. Milling conditions will be designed to maximize the yield of the desired component, thereby imparting desired characteristics while limiting any deleterious effects. (Morris & Bryce 2002, 162.)

2.2.2 Mashing

Being the most important process in wort production, during mashing, the grist and water are mixed to bring the contents of the malt into solution with the help of enzymes. The grist and brewing liquor, both flowing at controlled rates are mixed thoroughly into the side of the mashing vessel, in order to minimize splashing at an exactly controlled temperature. The substances of the malt, which go into the solution are known as extracts and are only partially soluble. It is therefore necessary to convert the insoluble materials to soluble materials during mashing. Sugars, dextrin, inorganic substances and certain proteins are examples of the soluble substances while insoluble substances include starch, cellulose, part of the high molecular weight proteins and other substances that remain at the end of the lautering process as spent grain. This is aimed at converting as much insoluble materials as possible, into soluble ones increasing wort yield, but the quality of the extract is also important. (Briggs, Boulton, Brookes & Stevens 2004, 2.)

Enzyme activity during mashing involves breaking of chemical bonds and this activity depends on temperature and pH. The optimum activity of malt alpha-amylases is from 70 to 75 °C, at pH of 5.6 to 5.8 and of malt beta- amylases from 69 to 65 °C, at pH of 5.4 to 5.6, while malt of endopeptidases is optimum from 50 to 60 °C, at pH 5.0 to 5.2. Inactivation of the enzymes occurs rapidly at higher temperatures because of unfolding the three-dimensional structure of the enzyme (denaturation) and as the optimum temperature is exceeded, the inactivation and destruction of the enzyme activity is greater. At temperatures lower than optimum temperatures, the enzyme works relatively slower. At optimal pH, each enzyme activity reaches an optimal value and decreases at lower or higher optimum pH, but the effect of pH on enzyme activity is not as significant as temperature. (Belitz et al 2004, 899.)

2.2.3 Lautering

After mashing, it is necessary to separate the liquid wort from the solid residues of the malts. The process of separation of wort from insoluble materials is known as lautering and this occurs in the lauter tun. The lauter tun is a circular stainless-steel vessel with a very high diameter to height ratio. The true bottom maybe flat or contain a series of valleys with the wort outlet piercing the real bottom through which the wort is transferred into the wort-boiling kettle. The false bottom is made of stainless steel and is designed to hold the spent grain, allowing clear wort to filter into the real bottom, through which it is transferred After the strong wort is transferred, the spent grains are sparged with the help of rakes mounted vertically on a crossbeam that is on a vertical shaft and spray nozzles from above the tank at a controlled rate. After wort transfer, the spent grains are removed from the tank through the tank opening by the side of the tank. (Bamforth 2006, 218.)

2.2.4 Wort boiling and hopping

The important materials for brewers in hops are resins and essential oils. Nevertheless, small amounts of tannins, proteins, amino acids and sugars are extracted during brewing. Table 3 below shows the composition of commercial hops. Many brewers use hop cones in their dried but natural state as well as pellets produced from a simple pelleting process of breaking up bales, blending hop varieties according to brewers request, hammer milling and pelleting them in a die into dark green sticks (about 20mm long and 10mm in diameter). Hop pellets are easier to store and hardly deteriorate through oxidation even in ambient temperatures. (Hough 1985, 81.)

Table 3. Composition of commercial hops (Hough 1985, 79).

Water	10.0
Total resins	15.0
Essential oils	0.5
Tannins	4.0
Monosaccharides	2.0
Pectin	2.0
Amino acids	0.1
Proteins (N x 6.25)	15.0
Lipids and wax	3.0
Ash	8.0
Cellulose, lignin etc	40.4
Total	100

Wort boiling vessels were originally built from copper and as such were called copper but nowadays, they are made from stainless steel, some of which are directly heated, and some steam heated. The older directly heated kettle have burning of fuel beneath, while the newer steam heated kettles have a steam jacket. The wort from the lautering tun filtered into the boil kettle is boiled for about 60 to 90 mins with hops and other adjuncts added usually though a hop bag to ease the removal of the hop particles after boiling. Boiling concentrates the wort, coagulates proteins, solubilizes hop ingredients, converts the bitter components to their isoforms and inactivates enzymes. In the modern processes, whirlpool kettles with external cookers are used, achieving a better quality of beer with shorter boiling times. Continuous process models including heat exchangers are used to save energy and make the process more environmentally friendly. In this model, after wort boiling, the wort is transferred through a heat exchanger into fermentation tanks. During the process, heat is recovered from the wort thereby cooling it to the required temperature. The heat recovered is used for example in heating water for the hot liquor tank. Due to lack of resources, most craft breweries may not be able to afford this modern equipment or may be reluctant to change their equipment for economic reasons. (Belitz et al 2004, 900.)

2.2.5 Fermentation and maturation

The transformation of wort into beer occurs when the sugar in the wort are fermented by enzymes in the yeast to ethanol and carbon dioxide. During these processes, byproducts are formed and again broken down, which affect the taste, aroma and other beer characteristics. Most craft breweries use batch fermentation which is initiated by pitching (inoculating) the cooled hopped wort with a selected yeast in a fermentation tank. Enclosed fermentation tanks are safer as carbon dioxide produced during fermentation can be harmful causing asphyxiation at even low volumes and has the tendency to cause small losses in ethanol. When open fermentation tanks are used, proper ventilation is ensured to disperse the gas. When yeast is introduced into the wort, it is a whole new environment and so it requires time to adapt. The yeast is allowed to ferment the wort to generate alcohol, with the fermentation regulated by control of parameters such as starting strength of wort (°Plato, which approximates to percentage sugar by weight), amount of viable yeast (pitching rate), quantity of oxygen introduced and temperature. (Bamforth 2005, 70.)

Yeast is a brewers most important partner, but it is not the brewer who determines how the yeast functions. Rather, the brewer must understand the functioning of different yeast strains in order to make decisions depending of the beer quality and properties required. Ethanol and carbon dioxide, which are required by the brewer are toxins to yeast cells and must be gotten rid of. While for the yeast cell, it is the energy recovery, which is vital for its survival. Therefore, optimal conditions are required to achieve desired results. Yeast behavior varies during fermentation as some strains tend to flocculate and as a result, they trap carbon dioxide and rise to the top. Other strains which do not flocculate, sink to the bottom. Several styles of larger are produced by bottom fermentation while top fermentation is used for many types of ales and stouts. (Kent & Evers 1994, 226.)

2.2.6 Packaging

Environmental issues influence packaging, and these are stronger in some countries than others, with most countries now having packaging legislations that seek to control the use of packaging materials and reduce waste. Packaging is the most labor-intensive part of brewing process and now, the machinery for packaging is becoming progressively more complex with the objective of reducing labor cost while preserving product quality. The efficiency of the packaging operation is critical for profitability as it requires high capital and packaging influences product attractiveness. This process must be closely monitored from an environmental and sustainability viewpoint, as almost all waste types from a brewery are generated from this process, such as wood, plastics, metals, glass, wastewater, emissions, etc. In larger breweries, packaging could be handled in a department dedicated for that purpose but in craft breweries, the brewer and few workers must handle all this. If not properly managed, they may become overwhelmed as time passes by and especially when production increases. (Briggs, Boulton, Brookes, Stevens & Roger 2004, 759.)

The chilled, filtered and pasteurized beer is transferred into the desired container either manually or by automated systems. Depending on the target market, beer is canned, bottled and kegged. Glass bottles have the advantage that they are neutral in taste, impermeable to gas, heat resistant and cannot be deformed but are heavy and breakable. Cans are lighter, can be easily deformed and their filling requires specific equipment, mostly used by larger breweries. Larger breweries have automated systems for filling but in some craft breweries, this is done manually. There are many problems associated with these manual pressured fillers and cockers such as breaking of bottles, beer spilling into drainage and other safety hazards to the operators. In developed countries, there are rewarded bottle and can return systems to control the disposal and recycling of these containers. Less developed countries lack this system and so there is improper disposal and no system to recycle these containers, which are mostly disposed in water bodies causing pollution. The filled bottles are labelled with adhesive labels placed on the bottles, while cans come with labels pre-printed on them. Beer packaging is one of the most expensive stages of the brewing process in terms of raw materials and labor. (Bamforth 2005, 75.)

3 BREWING WASTE AND THEIR ENVIRONMENTAL IMPACTS

In this chapter, the different classes of brewing waste are discussed, focusing on their origin, handling and proper disposal, outlining the philosophy, approaches and tools for a good environmental management system. It is important that breweries and their workers understand these subjects and are ready to take the required actions at the right time. Companies on their part try to economize with environmental management in order to reduce cost while workers on their part try to dodge from environment, health and safety issues in order to save time and most times because of negligence. It is important that there are strict management systems to monitor environment, health and safety issues, as they are beneficial to the companies in the end. Breweries generate waste, by-products, pollutants and effluents such as noise, heat, odors, dust, plastic waste, broken glass, domestic and laboratory waste, carbon dioxide, spent grains, spent yeast, and labels. These must be dealt with in the least costly manner and in some cases profitably in order to save space, minimize the risk of microbial contamination and reduce cost. (Briggs et al 2004, 68.)

All companies should be concerned about environmental economics as it is the cornerstone, if not the foundation for responsible environmental management. Many companies often ignore it and those that concern themselves with the matter are mostly doing so for reasons of compliance. In developed countries, where there are strict environmental laws and monitoring systems, the situation is better controlled than in less developed countries where even with these environmental laws, the application and monitoring systems are greatly flawed. In the brewing industry, due to large amounts of waste being produced from the process, this translates to high costs for compliance. Most larger breweries will be just willing to invest as much as is required for them to comply with the environmental legislations in order to reduce costs. For craft breweries, it is likely that costs from the start of operations are quite low, but it is important for them to consider the future if their production increases. Smart companies or so-called green companies approach environmental economics by looking beyond complains and more towards financial returns from their environmental infrastructure through the adoption of principles and practices that rely on life-cycle analysis, circular economy and pollution prevention. When companies pay close attention to environmental regulations, they are acting in a responsible manner as environmental regulations are designed to establish a minimum level of protection to the public, workforce, and to the environment. Meeting statutory requirements enables the company to operate as a business but does not necessarily mean that the company is eliminating the many negative impacts of its operations to the neighboring communities, the workforce and the environment. Environmental protection through smarter management of the environmental impacts of a company's operation in reducing waste, institutionalizing environmental practices, greening supply chain, reducing carbon emissions and measuring impacts. Customers and investors certainly recognize these as there are overwhelming demands for people to consume and invest more in companies that strive toward the greening of their business. Wise business strategists who are keeping track of emerging market forces will react once they notice something on their environmental-scan radars, ensuring that their companies are ready to respond pragmatically and capitalize on them, rather than being blindsided by them. (Willard 2005, 89.)

Environmental impact can be defined as any change of the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services. On April 18, 2018, the European parliament adopted a legislative package (the Circular Economy Package), which was also adopted by the EU council on May 22, 2018. This package amends The Waste Framework Directive (2008/98/EC), The Landfilling Directive (1999/31/EC), The Directives on end-of-life vehicles (2000/53/EC), on batteries and accumulators, waste batteries and accumulators (2006/66/EC), and on waste electrical and electronic equipment (2012/19/EU). The overall goal was to improve waste management in the EU. Thereby, encouraging the prudent and rational use of natural resources, which contributes to the protection, preservation and improvement of the quality of the environment. The directives aim to implement the concept of "waste hierarchy", depicted in figure 2 below, with priority order of preventing, preparing for re-use, recycling, other recovery and disposal. This hierarchy promotes a shift to a more sustainable circular economy. (European Commission on Environment 2019.)

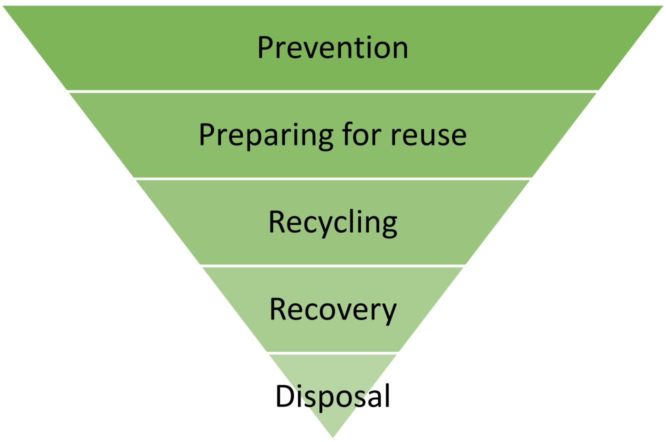

Figure 2: Waste hierarchy (Adapted from European Commission on Environment 2019).

3.1 Brewery Wastewater

Water used in brewing is referred to by brewers as brewing liquor. Beer contains about 90% water and it's taste and flavor depends on the water quality. Depending on the process for which the water is required, water characteristics may vary. So, water used in brewing must be of good quality and it is necessary to adjust the brewing liquor specifications early in the process to ensure the best quality of beer. Some properties of brewing liquor which brewers are interested in and which affect the brewing process include ions such as calcium, pH, alkalinity, and hardness. Table 4 below shows the effects of some ions on beer which can help brewers in adjusting their brewing liquor according to their requirements. The quality of brewing liquor influences the character of the beer made from it. (Briggs et al 2005, 2.)

Table 4. Effects of ions on beer (Adapted from Barth 2013, 76).

Ion	Formula	Effect
Bicarbonate	HCO_3^-	Increase pH
Calcium	Ca^{2+}	Decrease pH
Chloride	Cl^-	Sweetness, fullness, balance sulfate
Iron (II)	Fe^{2+}	Metallic, astringent
Hydronium	H_3O^-	Decrease pH, enhance bitterness
Magnesium	Mg^{2+}	Required by yeast
Sodium	Na^+	Sweet, sour at higher levels
Sulfate	SO_4^{2-}	Dryness, astringency, enhances bitterness

Interestingly, water usage per unit of beer produced in craft breweries are relatively higher than in large breweries. This is because in larger breweries most processes are automated, but in craft breweries most processes are performed manually, and efficiency is very low. Another reason for the higher water usage in craft breweries is that since beer is brewed in batch processes, an entire washdown of the facility is required after every batch. With water being the most abundant raw material in brewing, apart from water which is contained in the final beer or by-products, lost during evaporation and cooling, the rest turns out as wastewater. The economics of water usage and disposal in breweries directly affects the brewing business, with rising costs for fresh water and wastewater forcing breweries to save water. Proper management is required in order to reduce these costs. This can be achieved through improved water management, recovery and reuse, and partial on-site treatment of wastewater when no discharge to sewer is practical. Recording water consumption and wastewater production at each separate point of usage makes it easy to identify points for saving water. The adoption of clean technological processes and water reuse for several industrial activities are imperative in order to ensure preservation of water resources. (Gertsen & Sønderby 2009, 4.)

Water is involved in a continuous cycle, with the sun causing water to evaporate from the surface of exposed water and ground, which later falls back to the earth as rain or snow. Part of the water which falls evaporates directly or is taken up by plants. However, this process varies with climatic conditions and different times of the year. Due to human and some natural activities, this cycle is distorted, leading to environmental issues such as water scarcity, drought and floods. To address these issues, environmental legislations are passed and implemented strictly to control human activities to minimize the effects. Wastewater from the brewing industry contains different substances which can disrupt this cycle. Depending on local legislation on the levels of acceptable wastewater load, some breweries may be required to pretreat their wastewater before disposal. The control measures for water quality must balance between the needs of water supply systems and effluent discharge requirements. (Tebbutt 1997, 10.)

3.2 Brewery Wastewater Treatment

In wastewater treatment technology, parameters such as pH, suspended solids, Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) are used to determine the concentration and treatment technologies required for the wastewater. The pH, which measures the acidity or alkalinity of the wastewater are critical in that sewers can be corroded, and biological treatment processes disrupted if the pH values are not adjusted. Suspended solids are materials which do not settle after 30 minutes. If discharged into water bodies, suspended solids can smother bottom living aquatic and plant life. BOD measures the amount of oxygen required by microorganisms to break-down the organic matter in the wastewater while COD measures the amount of oxygen required to oxidize the chemical compounds present in the wastewater. If properly treated, brewery wastewater can be reused as primary water (water used directly in the brewing process) and /or as secondary water (water that does not have any physical contact with beer), without harming public health and the environment. (Hill 2015, 426.)

The method of brewing wastewater treatment will depend on the quantity and characteristics of the wastewater. These characteristics depend significantly on different times and locations around the brewery. As water moves through the brewery, it carries along or dissolves many substances. Brewery wastewater can be thought to contain beer and wort residues, yeast, caustic and acids from CIP plants, fats and oils from lubricants, insoluble substances such as plastics and soluble substances such as adhesive, caustic and metal salts. These substances increase the wastewater concentration, which when multiplied by the quantity of the wastewater, gives the wastewater load on which wastewater costs are dependent. These loads results in increased wastewater charges as it becomes more difficult to treat the water at wastewater treatment plants. Here, the dissolved oxygen in the receiving water is consumed at a greater rate than it can be replenished, leading to oxygen depletion and thus severe consequences on the biota (Rashed 2011, 168). Wastewater costs can be reduced by preventing these substances from entering wastewater as much as possible and by some pretreatment before disposal. Nevertheless, brewing wastewater contains mostly organic material, is nontoxic, does not contain high amounts of heavy metal and is easily biodegradable. (Hill 2015, 426.)

Substances contained in brewing wastewater which are considered harmful to the environment include all oxidizable substances, phosphorus in the form of phosphates, nitrogen in the form of nitrates, organic halogen compounds, and salts of metals such as mercury, lead, cadmium and chromium. Oxidizable substances require oxygen to be degraded and if they pass into drainage systems untreated, they may not be fully degraded due to insufficient oxygen. This results in putrefaction producing foul smells and killing living organisms. Phosphates and nitrates promote the growth of algae in surface water. Nitric acid used in CIP to dissolve beer stones in tanks pass on nitrate into wastewater which increasingly pollute soils. Organic halogen compounds used for disinfecting purposes in the brewery have soil and groundwater polluting effects. Effluents from breweries have high BOD and even higher COD strength. Biological treatment plants which are required to reduce BOD and COD are unfortunately the most expensive parts of effluent treatment plants. (Herzka & Booth 1981, 151.)

3.2.1 Wastewater Pretreatment

Due to large variations of brewing wastewater, legislations are in place to control the disposal. In larger breweries, where disposal into municipal sewer is not allowed, primary and secondary treatment methods are applied. Craft breweries are mostly permitted to discharge into municipal sewers. So, pretreatment is required to meet municipal laws. In some cases, no pretreatment is required but sewer discharge fees are imposed on effluent volumes, suspended solids and organic loads. Pretreatment is aimed at altering the physical, chemical and biological properties of the feed water so that the municipal wastewater is not stressed by the introduction of this feed water. Wastewater pretreatment is done through physical, chemical or biological methods and through a combination of these. (Simate, Cluett, Iyuke, Musapatika, Ndlovu, Walubita & Alvarez 2011, 237.)

Physical pretreatment is always the first unit operation applied to wastewater whereby physical forces are applied to remove contaminants. Coarse solid materials are removed through a passive process through sedimentation or flotation. The physical pretreatment step is only in preparation for the other stages as it does not remove any dissolved pollutants. Unlike the physical process where no dissolved contaminants are removed, the chemical process removes dissolved contaminants through chemical reactions which occur as a result of the addition of chemicals to the wastewater. The added chemicals help in pH adjustments, coagulating and flocculating dissolved contaminants in the wastewater. One disadvantage of this chemical process is that it adds dissolved components into the wastewater, contradicting its aim. Due to tighter water quality regulations coupled with unsatisfactory results from these pretreatment methods, intensive treatment processes are necessary if brewery wastewater is to be reused. (Hill 2015, 432.)

Biological pretreatment of wastewater involves the reduction of organic and inorganic compounds. Biological pretreatment depends on the activities of different microorganisms acting on the wastewater, breaking down the biodegradable organic and inorganic pollutants. The activities of these microorganisms result in the removal of the carbonaceous organic matter, nitrification, denitrification and stabilization of the wastewater. These different microorganisms operate in different conditions. In the presence of air/oxygen, the process is referred to as aerobic while without oxygen, it is referred to as anaerobic. A similar process to anaerobic pretreatment, anoxic process is used in the removal of nitrogen from wastewater. Compared with the physical and chemical pretreatment methods, the biological treatment technology is a well-developed technique with high COD and BOD removal efficiency at low costs of investment. (Hill 2015, 431.)

Aerobic biological pretreatment occurs when aerobic microorganisms, mainly bacteria, metabolize the organic matter in the wastewater, producing more microorganisms and inorganic end-products such as carbon dioxide, ammonia and water. The microorganisms convert non-settleable solids into settleable ones which then sediment and are separated. This method can be achieved through an activated sludge process, attached growth (biofilm) process and trickling filter process. In the activated sludge process, the wastewater flows into tanks primed with activated sludge, constantly aerated to homogenize the wastewater and prevent sludge settling. In the biofilm process, microorganisms are fixed on a solid material, creating an environment that supports the growth of microorganisms that prefer to stay attached to the solid surface. In the trickling filter process, the wastewater is sprayed over the surface of immobilized biomass which is constantly supplied with oxygen and allowed to tickle down through the microorganism covered media. Handling and dewatering of excess sludge are one of the most expensive steps in wastewater treatment. These aerobic treatment systems generally produce large quantities of sludge, which requires disposal. (Hardwick 1994, 543.)

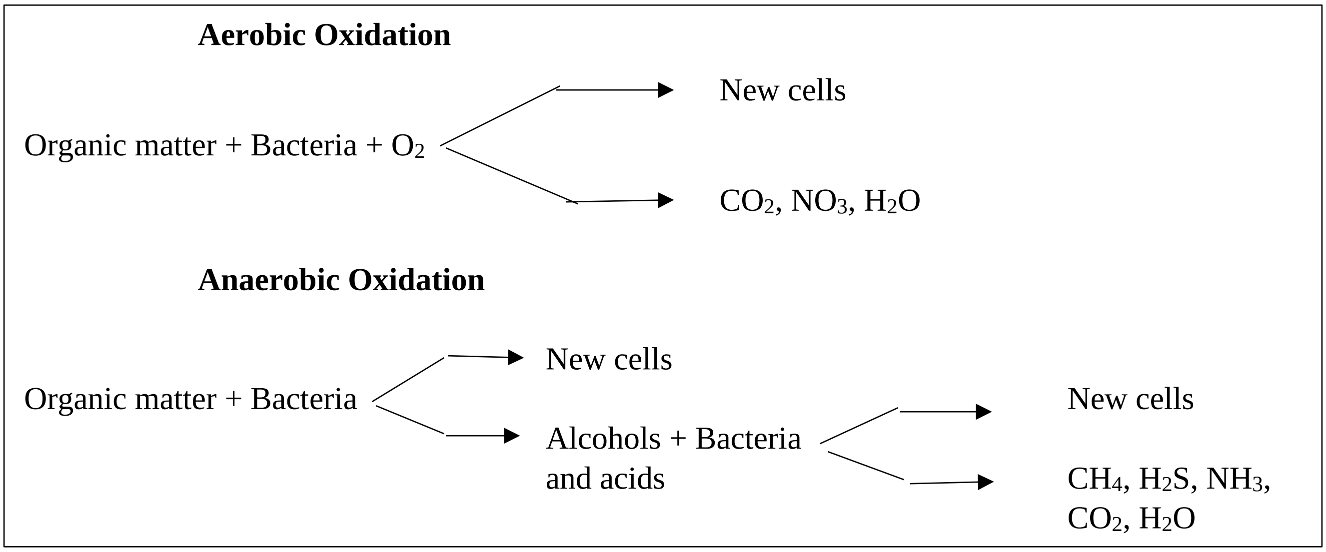

Figure 3. Modes of biological oxidation (Adapted from Tebbutt 1997, 63).

Anaerobic wastewater treatment unlike aerobic treatment occurs in the absence of oxygen, whereby inorganic microorganisms convert organic compounds into biogas, mainly methane, and carbon dioxide with traces of hydrogen sulfide. Anaerobic treatment can either be through an Upflow Anaerobic Sludge Blanket (UASB) or through a Fluidized Bed Reactor (FBR) process. In the UASB process, which is most popular, wastewater enters a vertical tank through the bottom, passing through a dense bed of anaerobic microorganisms which attack the organic materials in the wastewater, releasing biogas. As the gas rises, it is separated by a 3-phase (gas-liquid-solid) separator from the biomass and wastewater. Figure 4 below illustrates the principle of the UASB process. Anaerobic treatment is preferred to aerobic treatment because it is highly successful in treating highly polluted wastewaters and does not require energy, rather energy can be recovered from the process. On the other hand, aerobic treatment requires a great deal of energy. (Kunze 2014, 803.) Table 5 below shows a comparison between anaerobic and aerobic treatment processes, showing anaerobic process as a low resource requirement process, with high value outputs.

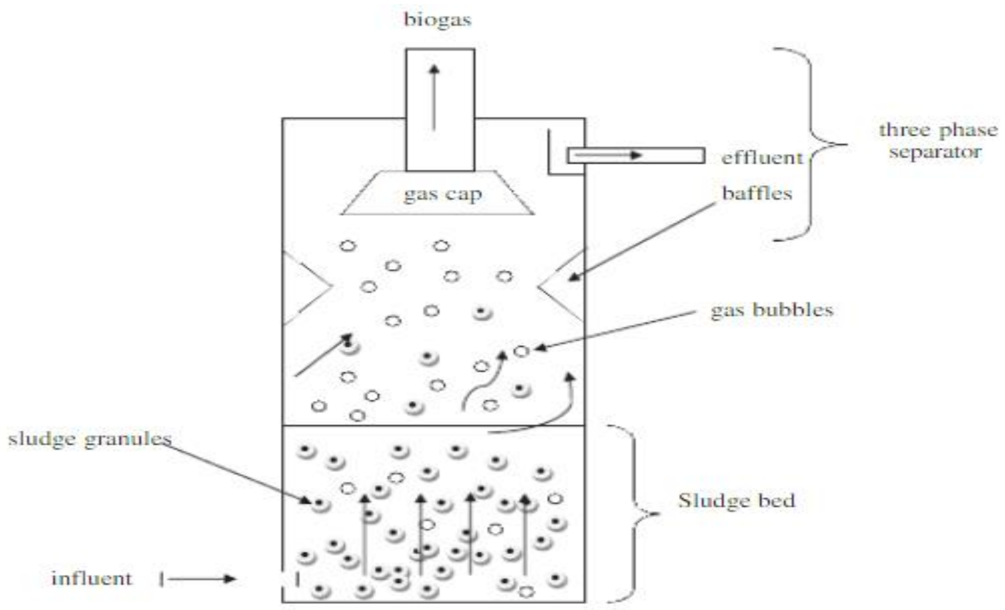

Figure 4. Upflow Anaerobic Sludge Blanket Process. (Adapted from Simate et al 2011, 239.)

Table 5. Anaerobic treatment as compared to aerobic treatment (Adapted from Simate et al 2011, 239).

	Aerobic systems	Anaerobic systems
Energy consumption	High	Low
Energy production	No	Yes
Biosolids production	High	Low
COD removal (%)	90 – 98	70 – 85
Nutrients (N/P) removal	High	Low
Space requirement	High	Low
Discontinuous operation	Difficult	Easy

3.3 Brewery Solid Waste

Apart from wastewater which is the highest amount of waste produced from brewing beer, there are other waste streams such as grain dust from milling, spent grain (brewers' grain) from mashing, spent yeast from fermentation, trub from wort clarification, and glass, plastics, wood, metals from packaging and related processes. Some of these solid waste types are biodegradable while others are not. Therefore, brewing waste have different applications and disposal methods. It is therefore important to understand the origin of these waste types and their properties for proper handling and disposal. Many technological advancements have helped breweries to reduce the quantities of these waste types but still some of them such as spent grains have not been possible due to the requirements of further processes. Craft breweries located in city areas have the advantage of proximity of waste management services, though at a cost. Meanwhile, those located in rural areas find ways to dispose their waste. With substantial amounts of waste that must be dealt with by every brewery, some breweries succeed to do so cheaply but increasing costs compel more breweries to decompose the waste materials themselves. (Kunze 2004.)

3.3.1 Grain Dust

Grain dust occurs during storage and milling of grains. Grain handling in large breweries is well contained to prevent the spreading of dust particles in the breweries. In most craft breweries, handling and feeding of mills occurs manually, leading to the generation of dust. The dust particles settle on walls and floors of milling rooms. Dust build-up affects the respiratory system of workers, attracts insects and rodents, and can cause an explosion if an ignition source is present. The Master Brewers' Association of the Americas proposes as control measures the prevention of dust buildup, dust migration and ignition source. Other proposed preventive measures such as regular dust removal and training of employees on safe work practices for example the use of personal protective equipment. (MBAA.)

3.3.2 Spent Grains

After mashing, when the soluble constituents of the malts are extracted with hot water as sweet wort, the insoluble parts of the malt grains soaked with wort stay in the lauter tun and are extracted as spent grain. Due to their high content in organic matter, brewers ensure that no part of the grains go into the sewer with wastewater as this increase's wastewater cost. The major components of the spent grains are the walls of the husk-pericarp-seed coat, which are rich in cellulose and non-cellulosic polysaccharides and lignin, some proteins and lipids. (Musatto, Dragone & Roberto 2006, 3.)

Breweries, especially craft breweries in some areas, face challenges in disposing spent grains. Due to their high moisture content, extra energy is required to dry them. These breweries are not willing to make the investment because they are not sure of any return. Storing spent grains in wet conditions can be particularly demanding as there is the possibility of spoilage bacteria growth which can cause smell, thereby polluting the environment. There are many investigations on possible applications for spent grains, many of which are hindered by one property or the other. Spent grains are used as a food ingredient for animal and human nutrition, energy production by direct burning or for biogas by anaerobic fermentation, charcoal production, paper manufacture, absorbent and other biological processes. Though the nutritional value of spent grains is much less than dried barley, the high moisture content makes them easily digestible by livestock and so, they are widely used in animal feed. (Goldammer 2008.) Picture 1 below shows an accident at a craft brewery during the extraction of spent grains from the mash tun. In this situation, some of the spent grains go through the drains increasing the organic content of the wastewater.

Picture 1. Spent grain removal accident (Photo by Cedric Agyingi)

3.3.3 Spent Yeast

Yeast is added to the sweet wort for the fermentation of the sugars. When oxygen is supplied, the yeast amount multiplies about 3 to 5 times of the original yeast mass. During maturation process, the yeast mass precipitates, and it is removed from the tank. The yeast is reused if it does not affect the beer quality to reduce the amount of new yeast being used. The yeast is eventually disposed when it is no longer required. Spent yeast contains proteins, carbohydrates, lipids, minerals, B-vitamins, enzymes and RNA. Currently, spent yeast is mostly used to make animal feed and mixed with spent grains to increase nutritional value. (Mathias, Mello, & Servulo 2014,4.)

3.3.4 Packaging Materials

The waste materials from the packaging include paper/cardboard, wood, glass, metals and plastics, which are brought to the brewery from vendors of packaging materials. For example, glass bottles from suppliers are wrapped in plastics and stacked on wooden pallets. Other waste production occurs during the packaging process such as broken glass bottles, and wrongly placed labels. Sorting and separation of these waste types is essential for effective warehousing, reuse and disposal. Due to this, all brewery workers must be trained on waste handling. In areas with local recycling services, recycling of these materials is easy but breweries in area which do not have local recycling services must do so at their own expense. This may lead to improper disposal as they try to minimize the cost. With rapid industrialization, waste mountains are increasing in many countries, therefore, increasing attempts must be made to take care of all waste types and recycle as much as possible. (Kunze 2004, 810.) Picture 2 shows different packaging material waste from craft brewery. Damaged corks from manual bottling, plastics from bottle pallets from bottle suppliers and outdated bottle labels.

Picture 2. Packaging waste (Photo by Cedric Agyingi)

4 BREWERY ENERGY

The brewing industry is a significant user of energy due to the requirements for heating and cooling of its products during manufacture and storage. Energy is also required for other operations such as lighting and powering equipment. Over the past century, there has been increased use of different energy sources for industrial purposes. Some common examples are coal and wood. Coal, which transformed society, is a low cost high performing fuel, producing more heat, less ash and smoke than wood. With the fight against the emission of greenhouse gas, most of these non-environmentally friendly energy sources are being abandoned for more environmentally friendly ones. More legislation is enforced to cut the use of these fuels and tariffs placed to promote the use of less environmentally polluting fuel sources. Rapid increase in world energy prices from 2003 to 2008 and concerns about environmental impacts of greenhouse gas emissions led to renewed interest in alternatives to fossil fuels - particularly nuclear power and renewable resources. (Souza 2012, 1.)

When considering the present economics of industrial fuel use, craft brewers, being an innovative segment of the greater brewing industry are using innovative solutions for energy usage and GHG reduction opportunities. To maximize their expenditures on their creative brewing process, craft brewers should prioritize reducing energy spending. Looking from the general process view, it is difficult to make these reductions as there is no clear understanding of the energy requirements from each process step. A closer look at each process step gives the brewers better understanding and helps in decision making. Energy reduction can be achieved through understanding fluctuation energy costs and developing a purchasing strategy that matches individual operational needs. A clear guide will be to have a proper energy management system. The ISO 50001, depicted in figure 5 below, is an International Standard which enables organizations to establish the systems and processes necessary in improving energy performance, use, consumption and intensity and it’s implementation should lead to reductions in energy cost, greenhouse gas emissions, and other environmental impacts. The impetus to reduce greenhouse gas emissions and promote renewable and efficient use of energy sources should provide a strong rationale for the development of an energy management system. (Eccleston, March, & Cohen 2012, xxii.)

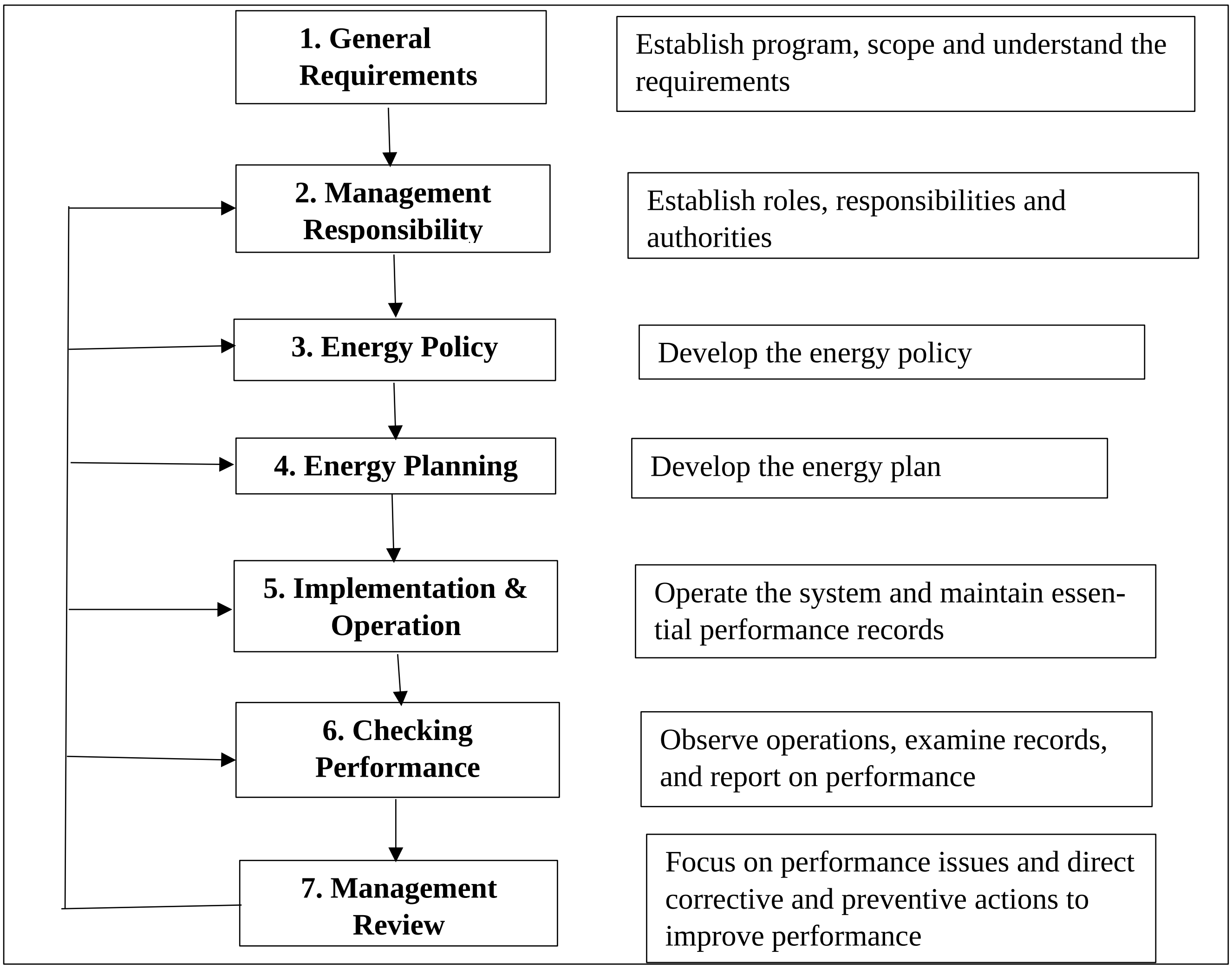

Figure 5. ISO 50001 flowchart (Adapted from Eccleston, March, & Cohen 2012, xiii)

4.1 Boiler Plants

In craft breweries, the energy used for heating is mainly thermal and electrical energy. Thermal energy obtained from the combustion of fossil fuels, mainly natural gas, is used to generate steam and hot water used for heating. Electrical energy is used for cooling, refrigeration, lighting and to drive necessary equipment. In the boiler plants, water is converted into steam which is used for heating. Steam has the advantage that it has a considerably higher heat content than water and can easily be transported. In the past, breweries used steam piston engines in which some of the steam was used to rotate a flywheel to drive an electric generator. The conversion rate of the energy content of the fuel was just about 12 – 14 %. Nowadays, these engines are found in museums. After this, steam turbines replaced the steam piston engines, in which continuously rotating rotors drive electric generators. These can still be found in some breweries. Nowadays, instead of the old steam engines, combined heat and power plants are widely used due to their higher efficiency. (Kunze 2004, 821 – 822.)

Combined heat and power plant (CHP) consist of a gas or diesel motor or a gas turbine, in which natural gas or fuel oil is combusted, with a gas motor attached to an electric generator. The system involves the simultaneous production of heat and electricity from a single energy input. Majority of the electrical output is from a gas-turbine cycle and the heat from the gas turbine is used for heating, thus the name heat and power plant. About 96% of energy from the natural gas can be used i.e. 33% by conversion to electricity, 58% as heat, and 5% from radiation, also used for preheating. (Kunze 2004, 822.)

4.2 Refrigeration Plants

Cooling is used in brewing during wort casting, fermentation, maturation and clear beer storage phases. Cooling is based on the principle that; when a liquid is evaporated, a liquid heat of evaporation is required, and this is taken from its surroundings. Consequently, the surroundings cool down. A substance which requires much energy for its evaporation is usually chosen. These substances are called refrigerants. Fluorinated hydrocarbons (FCs) and hydrochlorofluorocarbons (HCFCs) which were being used have been abandoned because of their ozone depleting activity. Because of its non-ozone destroying potential, ammonia is widely used. However, ammonia is a corrosive gas, explosive when mixed with air at high temperatures and is a water-endangering material. (Kunze 2004, 823 -824.)

5 CONCLUSION

There is a wide range of information available on raw materials and energy use, waste materials produced and their disposal on large breweries. However, since the craft brewery revolution has not occurred too long ago, there is not much information about craft breweries in this regard. For this reason, it is easier to assess the environmental impacts associated with beer production in larger breweries than in craft breweries. Many scientists and researchers are investigating the brewing process in craft breweries to understand the process from raw material selection, processing, waste generation, waste disposal and energy utilization.

Still, it has not been easy to settle on a definition of craft breweries but the one of a small, independent and traditional breweries is mostly acceptable. However, the raw materials for brewing, malt (mostly barley), water and energy, required in large quantities for the process are often not in excess supply. Barley, which is one of the world's most important cereals has other uses such as in animal feed. In almost every aspect of our daily lives, water and energy are required. The unsustainable use of these materials can lead to problems such as food, water and energy security.

By-products resulting from brewing operations vary in contents. Understanding the contents is important in determining further processing, use and disposal. The concept of circular economy encourages the development of new avenues and processes to use these brewing by-products for value added products. Particularly, since brewers' spent grain is a low-cost material readily available in large quantities throughout the year, its use as raw material will be very profitable economically and environmentally.

Brewery energy must be used as efficiently as possible. The use of non-environmentally friendly materials and substances must be abandoned for more environmentally friendly ones. Brewers must understand that sustainable use of energy is profitable for their business. This must also be considered for other raw materials such as water. Proper and active management systems to monitor and promptly take action must be implemented.

This work has certainly not had in depth considerations of these environmental concerns. It is more of an overview which can set the stage for more work to be done on this topic. More work can be done in the areas of sustainable water and energy use, waste disposal, wastewater treatment technologies, and applications of brewers' spent grains.

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