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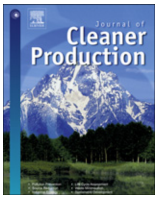

The brewing industry and environmental challenges

Abass A. Olajire

Industrial and Environmental Chemistry Unit, Department of Pure and Applied Chemistry, Ladoke Akintola University of Technology, Ogbomoso, Oyo, Nigeria

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ABSTRACT

The brewing industry is one of the largest industrial users of water. In spite of significant technological improvements over the last 20 years, energy consumption, water consumption, wastewater, solid waste and by-products and emissions to air remain major environmental challenges in the brewing industry. This article reviews some of these challenges with a focus on key issues: water consumption and waste generation, energy efficiency, emission management, environmental impact of brewing process and best environmental management practices which do not compromise quality of beer. The review is meant to create an awareness of the impact of beer production on the environment and of, practices to reduce environmental impact.

1. Introduction

In the food industry, the brewing sector holds a strategic economic position with annual world beer production exceeding 1.34 billion hL in 2002 (FAO Source, 2003). Beer is the fifth most consumed beverage in the world besides tea, carbonates, milk and coffee and it continues to be a popular drink with an average consumption of 9.6 L/capita by population aged above 15 (OECD Health Data, 2005). Alcohol consumption per person by country is shown in Fig. 1.

The brewing process is energy intensive and uses large volumes of water. The production of beer involves the blending of the extracts of malt, hops and sugar with water, followed by its subsequent fermentation with yeast (Wainwright, 1998). The brewing industry employs a number of batch-type operations in processing raw materials to the final beer product. In the process, large quantities of water are used for the production of beer itself, as well as for washing, cleaning and sterilising of various units after each batch are completed. A large amount of this water is discharged to the drains. The main water use areas of a typical brewery are brewhouse, cellars, packaging and general water use. Water use attributed to these areas includes all water used in the product, vessel washing, general washing and cleaning in place (CIP); which are of considerable importance both in terms of water intake and effluent produced (van der Merwe and Friend, 2002).

Similarly, effluent to beer ratio is correlated to beer production. It has been shown that the effluent load is very similar to the water load since none of this water is used to brew beer and most of it ends up as effluent (Perry and De Villiers, 2003).

A mass balance is depicted in Fig. 2, which represents water and energy inputs and also the outputs with respect to residues and sub-products, liquid effluents and air emissions. Residues similar to urban residues, simple industrial residues, glass, paper, cardboard, plastic, oils, wood, biological sludge, green residues, etc. are classified as solid wastes; surplus yeast and spent grains are considered sub-products. Brewer's spent grains are generally used for the production of low value composts; livestock feed or disposed of in landfill as waste (Jay et al., 2004). Alternatively, the spent grains can be hydrolysed for the production of xylo-oligosaccharides (probiotic effect), xylitol (sweetener), or pentose-rich culture media (Carvalheiro et al., 2004, 2005; Duarte et al., 2004).

The brewing process is energy intensive, especially in the brewhouse, where mashing and wort boiling are the main heat-consuming processes with high fuel consumption. Fuel oil was considered a very interesting commodity at the end of 2010, and its price has been pushed continuously to higher levels by speculative investments. The situation remains the same till present, and there is no sign of a significant price decrease in the future. The conservation of fossil fuel resources will help reduce CO_2 emissions from fossil fuel combustion, greenhouse gas emissions, and possible climate changes due to these emissions (Buchhauser, 2006).

Cleaner production (CP) is continuously advocated for in Brewery industry in order to reduce consumption and emissions

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E-mail address: olajireaa@yahoo.com.

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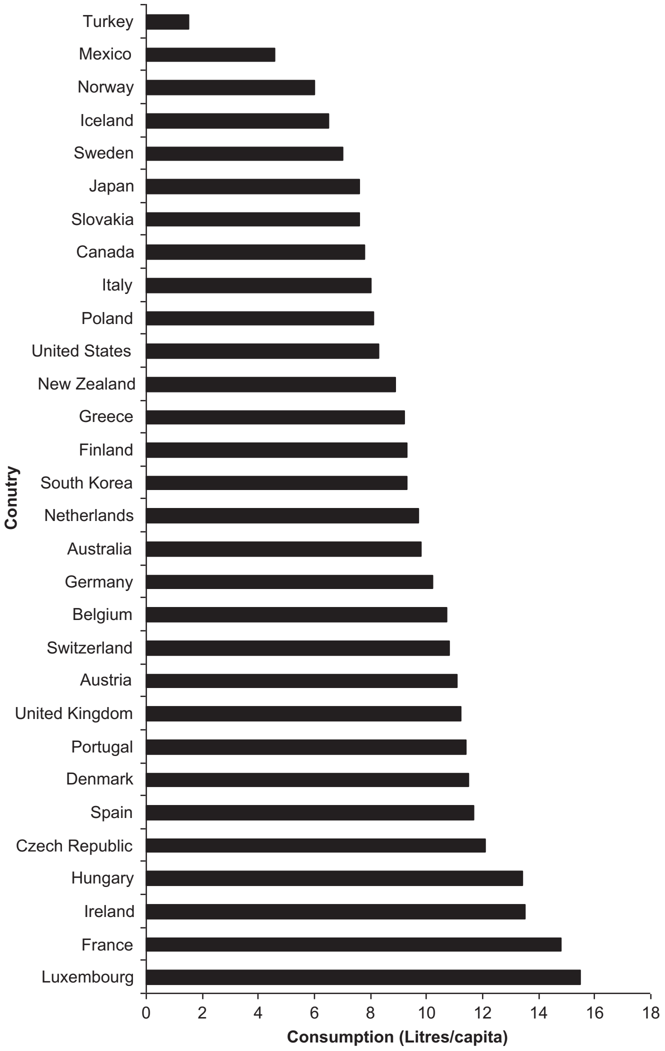

Fig. 1. Alcohol consumption per person aged above 15 years by country. Source: OECD Health Data, 2005.

from production process, products and services during production. One of the main ideas is that high consumption production facilities can reduce usage by 20–50% without investing in new equipment, but training and reengineering the processes could serve as a remedy. The preferred CP option is reduction of waste at source (Danbrew, 2007). For an effective CP, brewer should go green by adopting new brewing technology with efficient energy consumption, reduction in odour emission, efficient water consumption for cleaning and cooling purposes, the prevention of losses, and the reuse of treated wastewater (Walter et al., 2005; Robbins and Brillat, 2002).

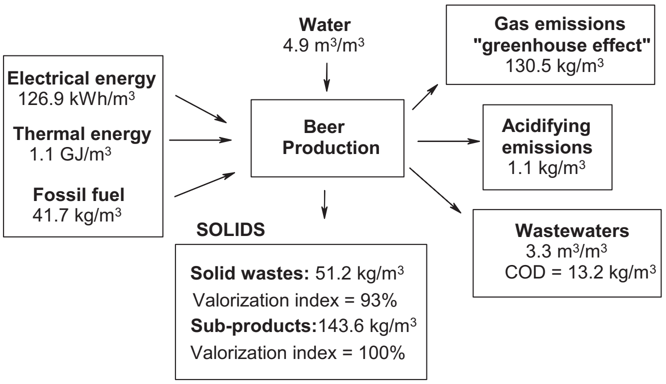

Fig. 2. Mass balance applied to Unicer SA breweries representing specific values, i.e., values per m^3 of produced beer (Unicer SA, 2005).

The value of the environment has been taken for granted by many individuals over the last decades. Most technologically advanced equipment and other human activities have extremely damaged the environment and its elements such as water, air, land and others. With this complexity, international organisations have been able to establish a system which ensures that all countries are adhering to the need for environmental sustainability. Environmental issues are a critical factor for today's industry competitiveness. Indeed, the society and the individual clients could set common model industries' commitment and engagement about the context of protecting the environment. Redesigning of the process; recovery of by-products or reuse of effluents are considered as some of the plausible actions towards an eco-efficient approach. Nonetheless, a point remains crucial in such mission: the ability to protect and guard natural ecosystems from polluted wastewaters. For such purpose, a wastewater treatment plant that maximises removal efficiency and minimises investment and operation costs is a key factor. Brewery and winery are traditional industries with an important economic value in the agro-food sectors. The most significant environmental issues associated with the operation phase of breweries include water consumption, wastewater, solid waste and by-products, energy use and emissions to air. Primarily, the goal of this paper is to critically review these environmental challenges faced by the brewery industry during brewing process and to provide suggestions on how to reduce the impact of brewing operations on the environment.

2. Beer production process

The brewing process uses malted barley and/or cereals, unmalted grains and/or sugar/corn syrups (adjuncts), hops, water, and yeast to produce beer. Most brewers use malted barley as their principal raw material. Depending on the location of the brewery and incoming water quality, water is usually pre-treated with a reverse osmosis carbon filtration or other type of filtering system. Fig. 3 outlines the main stages of beer production.

The first step of brewing, ***milling and carbon filtration***, takes place when malt grains are transported from storage facilities and milled in a wet or dry process to ensure that one can obtain a high yield of extracted substances (UNEP, 1996). Sometimes the milling is preceded by steam or water conditioning of the grain.

The mixture of milled malt, gelatinized adjunct and water is called mash. The purpose of mashing is to obtain a high yield of extract (sweet wort) from the malt grist and to ensure product uniformity. Mashing consists of mixing and heating the mash in the mash tun, and takes place through infusion, decoction or a combination of the two. During this process, the starchy content of the mash is hydrolysed, producing liquor called sweet wort. In the infusion mashing process, hot water between 160 and 180 °F (71–82 °C) is used to increase the efficiency of wort extraction in the insulated mashing tuns. The mashing temperature is dictated by wort heating using steam coils or jackets. In decoction mashing, a portion of the mashing mixture is separated from the mash, heated to boiling and re-entered into the mash tun. This process can be carried out several times, and the overall temperature of the wort increases with each steeping. Part of this mash is evaporated. This process requires an estimated 12–13 kBtu/barrel for medium-sized breweries (Hackensellner, 2000). The type of mashing system used depends on a number of factors such as grist composition,

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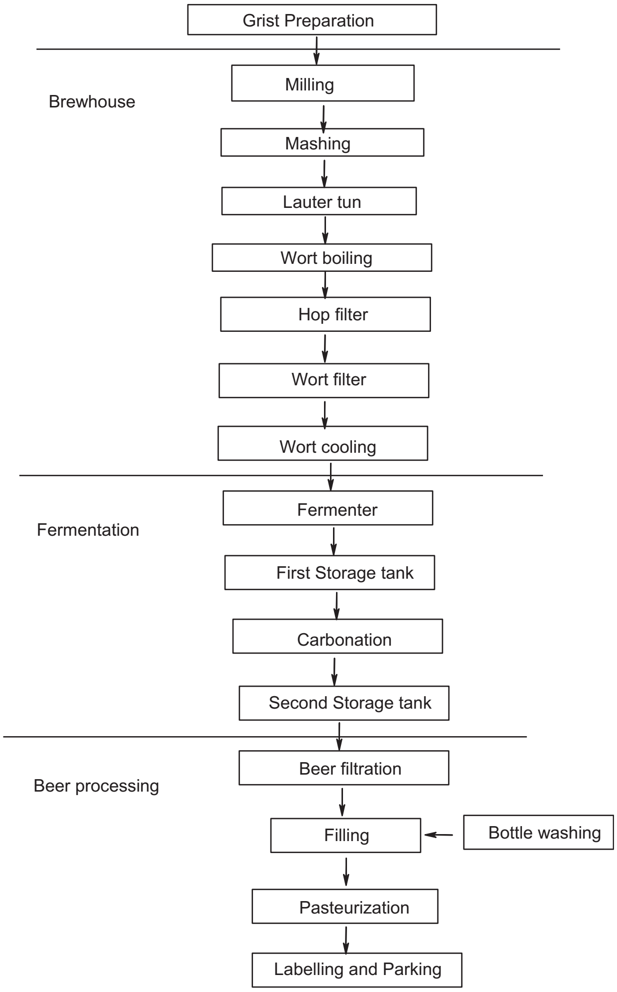

Fig. 3. Stages of beer production. Source: UNIDO, 2000.

equipment and type of beer desired (Hardwick, 1994). Infusion mashing is less energy intensive than decoction mashing requiring roughly 8–10 kBtu/barrel of fuel (Hackensellner, 2000).

Following the completion of the mash conversion, the wort is separated from the mash. The most common system in large breweries is a lauter tun or a mash filter (Galitsky et al., 2003; O'Rourke, 1999). A more traditional system is the use of a combined mash tun/lauter tun, usually termed a mashing kettle or vessel. In the combined mashing vessel, the wort run off is directed through a series of slotted plates at the bottom of the tun. The mash floats on top of the wort. This tends to be the slowest wort separation system although it is the lowest cost in terms of capital outlay (Galitsky et al., 2003; O'Rourke, 1999). With the use of the lauter tun, the converted mash is transferred to a lautering vessel where the mash settles on a false bottom and the wort is extracted. Lautering is a complex screening procedure that retains the malt residue from mashing on slotted plates or perforated tubes so that it forms a filtering mass. The wort flows through the filter bed (Hardwick, 1994; Galitsky et al., 2003). In both the combined mashing vessel and the lauter tun, the grains are also sparged (i.e., sprayed and mixed) with water to recover any residual extract adhering to the grain bed. The extracted grain, termed "spent grain," is most often used as animal feed. In a mash filter, the mash is charged from the mash mixer. The filter is fitted with fine pore polypropylene sheets that forms a tight filter bed and allows for very high extraction efficiency (in excess of 100% laboratory extract) (Galitsky et al., 2003; O'Rourke, 1999). However, the quality of the filtered wort may be affected through the use of a mash filter process and may not be applicable for all types of brewing.

The next step, ***wort boiling***, involves the boiling and evaporation of the wort (about a 4–12% evaporation rate) over a 1–1.5 h period. The boil is a strong rolling boil and is the most fuel-intensive step of the beer production process. Hackensellner (2000) estimates 44–46 kBtu/barrel is used for conventional wort boiling systems in Germany. The boiling sterilizes the wort, coagulates grain protein, stops enzyme activity, drives off volatile compounds, causes metal ions, tannin substances and lipids to form insoluble complexes, extracts soluble substances from hops and cultivates colour and flavour. During this stage, hops, which extract bitter resins and essential oils, can be added. Hops can be fully or partially replaced by hop extracts, which reduce boiling time and remove the need to extract hops from the boiled wort. If hops are used, they can be removed after boiling with different filtering devices in a process called hop straining. As with the spent mashing grains, some breweries sparge the spent hops with water and press to recover wort. In order to remove the hot break, the boiled wort is clarified through sedimentation, filtration, centrifugation or whirlpool.

After clarification, the cleared hopped wort is cooled. Cooling systems may use air or liquids as a cooling medium. Atmospheric cooling uses air stripping columns (used by Anheuser-Busch) while liquid cooling uses plate heat exchangers. Wort enters the heat exchanger at approximately 205–210 °F (96–99 °C) and exits cooled to pitching temperature. Pitching temperatures vary depending on the type of beer being produced. Pitching temperature for lagers run between 43 and 59 °F (6–15 °C), while pitching temperatures for ales are higher at 54–77 °F (12–25 °C) (Bamforth, 2001). The amount of heat potentially recovered from the wort during cooling by a multiple stage heat exchanger is 35–36 kBtu/barrel (Hackensellner, 2000). Certain brewers aerate the wort before cooling to drive off undesirable volatile organic compounds. A secondary cold clarification step is used in some breweries to settle out trub, an insoluble protein precipitate, present in the wort obtained during cooling.

Once the wort is cooled, it is oxygenated and blended with yeast on its way to the fermentor. The wort is then put in a fermentation vessel. For large breweries, the cylindrical fermentation vessels can be as large as 4000–5000 barrel tanks (Bamforth, 2001). During fermentation, the yeast metabolizes the fermentable sugars in the wort to produce alcohol and carbon dioxide (CO_2) as shown in the equation below:

$$C_6H_{12}O_6 + 2PO_4^{3-} + 2ADP \rightarrow 2C_2H_5OH + 2CO_2 + 2ATP$$

where ADP, adenosine diphosphate; ATP, adenosine triphosphate.

Behind this simplified chemical reaction is a series of complex biochemical reactions. These reactions, known as the "Glycolytic pathway" or "Embden-Myerhof-Parnas pathway", involve a number of enzymes and the reactions take place anaerobically inside the cells of brewing yeast. There are five sugars which may be present in wort which are readily utilized by standard brewer's yeast in fermentation, and these include glucose, fructose, sucrose, maltose and maltotriose. These sugars are the main source of carbon compounds for all the structural materials of yeast cells. The sugars are always taken up by the yeast in the same sequence; first glucose, fructose and sucrose then maltose and lastly maltotriose. Sucrose is hydrolysed by the invertase enzyme in the yeast's cell wall and splits into one glucose molecule and one fructose molecule, both of which may be assimilated into the glycolytic pathway. The enzymes responsible for the transport of maltose and maltotriose through the yeast cell membrane (permeases) are 'blocked'

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by the presence of the simpler monosaccharides and so their uptake is delayed. The production of alcohols other than ethanol is linked with nitrogen uptake by yeast. The yeast requires nitrogen (in the form of amino acids extracted from the malt) in order to make protein and other nitrogenous cell components. Examples of higher alcohols formed as by-products of nitrogen metabolism are propanol, isobutanol and isoamyl alcohol. All these by-products have some environmental implications if the effluents are discharged into the environment.

The fermentation process also generates significant heat that must be dissipated in order to avoid damaging the yeast. Fermenters are cooled by coils or cooling jackets. In a closed fermenter, CO_2 can be recovered and later reused. Fermentation time will vary from a few days for ales to closer to 10 days for lagers (Bamforth, 2001). The rate is dependent on the yeast strain, fermentation parameters (like the reduction of unwanted diacetyl levels) and taste profile that the brewer is targeting (Bamforth, 2001; Anheuser-Busch, 2001).

At the conclusion of the first fermentation process, yeast is removed by means of an oscillating sieve, suction, a conical collector, settling or centrifugation. Some of the yeast is reused while other yeast is discarded. Some brewers also wash their yeast. Some brewing methods require a second fermentation, sometimes in an aging tank, where sugar or fresh, yeasted wort is added to start the second fermentation. The carbon dioxide produced in this stage dissolves in the beer, requiring less carbonation during the carbonation process. Carbonation takes place in the first fermentation also. Yeast is once again removed with either settling or centrifugation.

Beer aging or conditioning is the final step in beer production. The beer is cooled and stored in order to settle yeast and other precipitates and to allow the beer to mature and stabilize. For beers with a high yeast cell count, a centrifuge may be necessary for pre-clarification and removal of protein and tannin material (UNEP, 1996). Different brewers age their beer at different temperatures, partially dependent on the desired taste profile. According to Bamforth (2001), ideally, the beer at this stage is cooled to approximately 30 °F (−1 °C), although this varies in practice from 30 °F to 50 °F (−1 °C–10 °C) (Anheuser-Busch, 2001). Beer is held at conditioning temperature for several days to over a month and then chill proofed and filtered. A kieselguhr (diatomaceous earth) filter is typically used to remove any remaining yeast. Brewers use stabilizing agents for chill proofing. Colouring, hop extracts and flavour additives are dosed into the beer at some breweries. The beer's CO_2 content can also be trimmed with CO_2 that was collected during fermentation. The beer is then sent to a bright (i.e., filtered) beer tank before packaging. In high gravity brewing, specially treated water would be added during the conditioning stage. This can be a significant volume, as high as 50% (Anheuser-Busch, 2001).

Finally, the beer must be cleaned of all remaining harmful bacteria before bottling. One method to achieve this, especially for beer that is expected to have a long shelf life, is pasteurization, where the beer is heated to 140 °F (60 °C) to destroy all biological contaminants. Different pasteurization techniques are tunnel or flash pasteurization. Energy requirements for pasteurization can vary from 19 to 23 kWh per 1000 bottles for tunnel pasteurization systems (Hackensellner, 2000). Other estimates are 14–20 kBtu/barrel (Anheuser-Busch, 2001). An alternative approach is the use of sterile filtration (Bamforth, 2001). However, this technology is new, and some believe these systems may require as much extra energy as they save (Todd, 2001).

3. Water consumption and waste generation in brewery

A large amount of water is used for cleaning operations. Incoming water to a brewery can range from 4 to 16 barrels of water per barrel of beer, while wastewater is usually 1.3–2 barrels less than water use per barrel of beer (UNEP, 1996). The wastewater contains biological contaminants (0.7–2.1 kg of BOD/barrel). The main solid wastes are spent grains, yeast, spent hops and diatomaceous earth. Spent grains are estimated to account for about 16 kg/barrel of wort (36 lbs/barrel), while spent yeast is an additional 2–5 kg/barrel of beer (5–10 lbs/barrel) (UNEP, 1996). These waste products primarily go to animal feed. Carbon dioxide and heat are also given off as waste products.

3.1. Water consumption

Water is a very substantial ingredient of beer, composing of 90–95 percent of beer by mass. Water is utilized in almost every step of the brewing process (van der Merwe and Friend, 2002). The chemistry of the water can influence not just the taste but also the brewing efficiency. Therefore, it is essential that water supply by local water authorities is converted into acceptable brewing liquor. This can be achieved by the removal of unwanted ions and addition of required levels of desirable ions. Water consumption for modern breweries generally ranges from 0.4 to 1 m^3/hL of beer produced (Hannover, 2002). The water consumption varies depending on the type of beer, the number of beer brands, the size of brews, the existence of a bottle washer, how the beer is packaged and pasteurized, the age of the installation, the system used for cleaning and the type of equipment used. Bottling consumes more water than kegging. Consumption levels are high for once through cooling systems and/or losses due to evaporation in hot climates. Water consumptions for individual process stages, as reported for the German brewing industry, are shown in Table 1 below.

An efficient brewery will use between 4 and 7 L of water to produce 1 L of beer (EC, 2006). In addition to water for the product, breweries use water for heating and cooling, cleaning packaging vessels, production machinery and process areas, cleaning vehicles, and sanitary water. Water is also lost through wort boiling and with spent grains. Large quantities of good-quality water are needed for beer brewing (van der Merwe and Friend, 2002).

3.2. Brewery wastewater

Wastewater is one of the most significant waste products of brewery operations. Even though substantial technological improvements have been made in the past, it has been estimated that approximately 3–10 L of waste effluent is generated per liter of beer produced in breweries (Kanagachandran and Jayaratne, 2006). The quantity of brewery wastewater will depend on the production and the specific water usage. Brewery wastewater has high organic matter content; it is not toxic, does not usually contain appreciable quantities of heavy metals (possible sources: label inks, labels,

Table 1
Water consumption for different brewery processes.

Department	Specific water consumption (m^3/hL beer produced)	
	Measured[b]	Literature[a]
Brewhouse	0.13–0.23	0.17–0.26
Cold storage		0.11–0.24
Fermentation cellar	0.03–0.05	0.04–0.08
Storage cellar	0.02–0.07	0.01–0.06
Filtering cellar	0.03–0.11	0.01–0.08
Bottling cellar	0.06–0.16	0.09–0.10
Cask cellar	0.01–0.06	0.01–0.12
Miscellaneous	0.20–0.204	0.03–0.40
Total process	0.49–0.89	0.47–1.33

[a] Estimates.

[b] Brewery figure. Source: Hannover, 2002.

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herbicides) and is easily biodegradable (Brewers of Europe, 2002). Wastewater from breweries is divided into three types; viz:

(a) Industrial Process wastewater (PWW)
(b) Sanitary wastewater (SWW) from toilets and kitchens; and
(c) Rain water.

The brewery's SWW will contribute only small loading whether measured as organic material or as flow, but it will require attention in regard to the clogging of pumps and screens. Rain water should be discharged to a separate drainage system, as it can interfere with the operation of a wastewater treatment plant (Brauer, 2006; Huige, 2006; Porter and Karl, 2006; USEPA, 2004).

The amount of PWW from a brewery will depend on the extent of production and the efficiency of water usage. The pollutant load of brewery effluent is primarily composed of organic material from process activities. Brewery processes also generate liquids such as the weak wort and residual beer which the brewery should reuse rather than allowing to enter the effluent stream. The main sources of residual beer include process tanks, diatomaceous earth filters, pipes, beer rejected in the packaging area, returned beer, and broken bottles in the packaging area (Brewers of Europe, 2002). The concentration of organic material depends on the wastewater-to-beer ratio and the discharge of organic material as wastewater. The concentration of organic material is usually measured as chemical oxygen demand (COD) or biological oxygen demand (BOD) (Wen et al., 2010). If not otherwise indicated, BOD is measured for a five-day period, which is considered a standard incubation period. Large discharges can occur, and may be attributable to discharge of surplus yeast, trub or other concentrated wastes, which could be disposed of in a better ways.

Nitrogen and phosphorus levels are mainly dependent on the raw material and the amount of yeast present in the effluent. Nitrogen concentration will often be in the range of 30–100 g N/m^3 (Brewers of Europe, 2002). Nitrogen comes from malt and adjuncts. Nitric acid used for cleaning may contribute to the total nitrogen content. However, the concentration will depend on the water ratio, amount of yeast discharged, and the cleaning agents used.

Phosphorus can also come from cleaning agents. Concentrations vary, but are usually in the range of 30–100 g P/m^3 (Brewers of Europe, 2002) as with nitrogen, the actual phosphorus concentration will depend on the water ratio and the cleaning agent used. The concentration of heavy metals is normally very low (Wen et al., 2010). Wear on machines, especially conveyors in the packaging line, can be a source of nickel and chromium. Table 2 gives summary of the characteristics of brewery wastewater while Fig. 4 shows the technological process in breweries and the main waste generated (Unicer SA, 2005; Varmam and Sutherland, 1994).

3.3. Brewery solid wastes

Solid waste consists of organic material residuals from the process including spent grains and hops, trub, sludge, surplus yeast, diatomaceous earth slurry from filtration (Kieselguhr sludge), and packing materials.

Table 2
Characteristics of brewery wastewater.

Characteristics	Amount
pH	6.5 ± 0.4
COD (mg/L)	1250 ± 100
NH_3–N (mg/L)	16 ± 5
TN (mg/L)	24 ± 3
SS (mg/L)	500 ± 50
Heavy metal	Very low
Water to beer ratio	4–10 hL water/hL beer
Wastewater to beer ratio	1.3–1.8 hL/hL less than water to beer ratio

Source: Wen et al., 2010; Brewers of Europe, 2002.

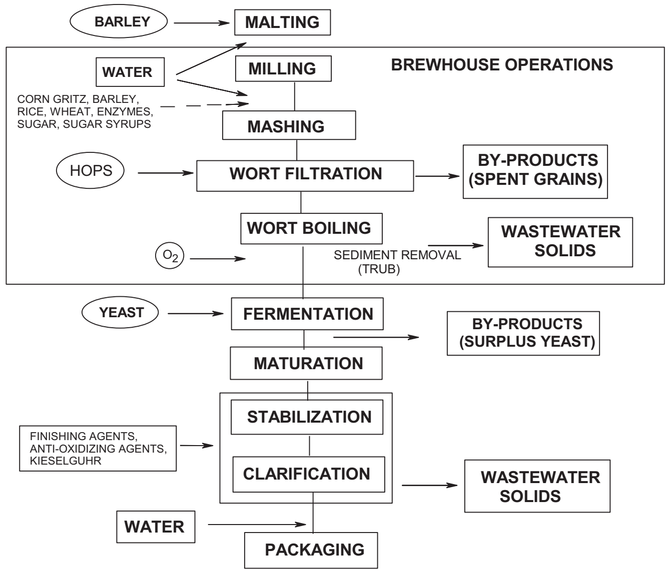

Fig. 4. Technological process in breweries and main waste generated. Source: Unicer SA, 2005; Varmam and Sutherland, 1994.

3.3.1. Spent grains

Beer production results in a variety of residues, such as spent grains, which have a commercial value and can be sold as by-products for livestock feed. The nutritional value of spent grain is much less than that of the same amount of dried barley, but the moisture makes it easily digestible by livestock. The amount of spent grains is normally 14 kg/hL wort with a water content of 80% (Isaacs, 2001; IFC, 2007; Fillaudeau et al., 2006).

3.3.2. Trub

Trub is slurry consisting of entrained wort, hop particles, and unstable colloidal proteins coagulated during the wort boiling. It is separated prior to wort cooling and represents 0.2–0.4% of the wort volume with a dry matter content of 15–20%. Its content of wort and extract depends on how efficiently the wort and trub are separated. The BOD value of trub is around 110,000 mg/kg wet trub (van der Merwe, 2000; EC, 1997; Fillaudeau et al., 2006).

3.3.3. Spent yeast

In brewing, surplus yeast is recovered by natural sedimentation at the end of the second fermentation and maturation. Only part of the yeast can be reused as new production yeast. Surplus yeast is very high in protein and B vitamins, and may be given to animal feed industry as a feeding supplement. This brewing by-product has dry matter content close to 10% w/w and generates beer losses (or waste) of between 1.5 and 3% of the total volume of produced beer (Fillaudeau et al., 2006; IFC, 2007).

3.3.4. Kieselguhr sludge

Diatomaceous earth slurry from the filtration of beer also constitutes a very large category, which is high in suspended solid (SS) and BOD/COD. Different methods for regeneration are under development, but presently they are not capable of totally replacing new diatomaceous earth. Diatomaceous earth has various advantages for filtration in brewing process as reported by Baimel et al. (2004). The conventional dead-end filtration with filter-aids (Kieselguhr) has been the standard industrial practice for more

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than 100 years and will be increasingly scrutinised from economic, environmental and technical standpoints in the coming century (Knirsch et al., 1997; Hrycyk, 1997). The conventional dead-end filtration with filter-aids consumes a large quantity of diatomaceous earth (1–2 g/l of clarified beer) and carries serious environmental, sanitary and economic implications (Fischer, 1992). At the end of separation process, diatomaceous earth sludge (containing water and organic substances) has more than tripled in weight. 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 Kieselguhr (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. The disposal routes of Kieselguhr sludge are into agriculture and recycling with an average cost of 170 €/ton. Disposal costs vary widely from one brewery to another with a positive income of 7.5 €/ton up to a maximum charge of 1100 €/ton of Kieselguhr purchased (Fillaudeau et al., 2006).

3.3.5. *Packaging materials*

Other solid wastes include label pulp from the washing of returnable bottles, broken glass, cardboard, bottle caps, and wood that is usually disposed of at sanitary landfills. These wastes should be avoided or at least limited since they are not simple papers but wet-strength paper impregnated with caustic solution.

4. Brewery wastewater treatment

Wastewater treatment is an end-of-pipe means of controlling water pollution. The beer brewing process often generates large amounts of wastewater effluent and solid wastes that must be disposed off or treated in the least costly and safest way so as to meet the strict discharge regulations that are set by government entities to protect life (both human and animal) and the environment (Simate et al., 2011). It is widely estimated that for every one liter of beer that is brewed, close to ten liters of water is used; mostly for the brewing, rinsing, and cooling processes. Thereafter, this water must be disposed off or safely treated for reuse, which is often costly and problematic for most breweries. As a result, many brewers are today searching for ways to cut down on this water usage during the beer brewing process, and/or means to cost-effectively and safely treat the brewery wastewater for reuse (Simate et al., 2011).

4.1. *Physical treatment*

Physical treatment is for removing coarse solids and other large materials, rather than dissolved pollutants. It may be a passive process, such as sedimentation to allow suspended pollutants to settle out or float to the top naturally. The sequence of physical treatment of wastewater is as given below.

4.1.1. *Flow equalization*

Flow equalization is a technique used to consolidate wastewater effluent in holding tanks for "equalizing" before introducing wastewater into downstream brewery treatment processes or for that matter directly into the municipal sewage system.

4.1.2. *Screening*

Typically, the wastewater is first screened to remove glass, labels, and bottle caps, floating plastic items and spent grains.

4.1.3. *Grit removal*

After the wastewater has been screened, it may flow into a grit chamber where sand, grit, and small stones settle to the bottom.

4.1.4. *Gravity sedimentation*

With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or chemical flocculation.

4.2. *Chemical treatment*

Among the chemical treatment methods, pH adjustment and flocculation are some of the most commonly used at breweries in removing toxic materials and colloidal impurities.

4.2.1. *pH adjustment*

The acidity or alkalinity of wastewater affects both wastewater treatment and the environment. Low pH indicates increasing acidity while a high pH indicates increasing alkalinity (a pH of 7 is neutral). The pH of wastewater needs to remain between 6 and 9 to protect organisms. Alkalis and acids can alter pH thus inactivating wastewater treatment processes.

4.2.2. *Flocculation*

Flocculation is the stirring or agitation of chemically-treated water to induce coagulation. Flocculation enhances sedimentation performance by increasing particle size resulting in increased settling rates.

4.3. *Biological treatment*

After the brewery wastewater has undergone physical and chemical treatments, the wastewater can then undergo an additional biological treatment. Biological treatment of wastewater can be either aerobic (with air/oxygen supply) or anaerobic (without oxygen).

4.3.1. *Aerobic wastewater treatment*

Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO_2, NH_3, and H_2O). Aerobic treatment utilizes biological treatment processes, in which microorganisms convert nonsettleable solids to settleable solids. Sedimentation typically follows, allowing the settleable solids to settle out. Common types of aerobic wastewater treatment plant (WWTP) systems for the treatment of PWW are discussed below.

4.3.1.1. Activated sludge process. In the activated sludge process, the wastewater flows into an aerated and agitated tank that is primed with activated sludge. This complex mixture containing bacteria, fungi, protozoans, and other microorganisms is referred to collectively as the biomass. In this process, the suspension of aerobic microorganisms in the aeration tank, are mixed vigorously by aeration devices which also supply oxygen to the biological suspension.

4.3.1.2. Attached growth (biofilm) process. The second type of aerobic biological treatment system is called "Attached Growth (Biofilm) Process" and deals with microorganisms that are fixed in place on a solid surface. This "attached growth type" aerobic

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biological treatment process creates an environment that supports the growth of microorganisms that prefer to remain attached to a solid material. The three types of biofilm process are described below.

4.3.1.2.1. Trickling filter process. In the trickling filter process, the wastewater is sprayed over the surface of a bed of rough solids (such as gravel, rock, or plastic) and is allowed to “trickle down” through the microorganism-covered media.

4.3.1.2.2. Biofiltration towers. A variation of a trickling filtration process is the biofiltration tower or otherwise known as the biotower. The biotower is packed with plastic or redwood media containing the attached microbial growth.

4.3.1.2.3. Rotating biological contactor process. The rotating biological contactor process consists of a series of plastic discs attached to a common shaft.

4.3.1.3. Lagoons. These are slow, cheap, and relatively inefficient, but can be used for various types of wastewater. They rely on the interaction of sunlight, algae, microorganisms, and oxygen (sometimes aerated).

4.3.2. Anaerobic wastewater treatment

Anaerobic wastewater treatment is the biological treatment of wastewater without the use of air or elemental oxygen. Anaerobic treatment is characterized by biological conversion of organic compounds by anaerobic microorganisms into biogas which can be used as a fuel-mainly methane 55–75 vol% and carbon dioxide 25–40 vol.% with traces of hydrogen sulfide (Briggs et al., 2004).

4.3.2.1. Upflow anaerobic sludge blanket. In the upflow anaerobic sludge blanket (UASB) reactor, the wastewater flows in an upward mode through a dense bed of anaerobic sludge. This sludge is mostly of a granular nature (1–4 mm) having superior settling characteristics (>50 m/h). The organic materials in solution are attacked by the microbes, which release biogas. The biogas rises, carrying some of the granular microbial blanket.

4.3.2.2. Fluidized bed reactor. In a fluidized bed reactor (FBR), wastewater flows in through the bottom of the reactor, and up through a media (usually sand or activated carbon) that is colonized by active bacterial biomass. The media provides a growth area for the biofilm. This media is “fluidized” by the upward flow of wastewater into the vessel, with the lowest density particles (those with highest biomass) moving to the top.

4.4. Microbial fuel cell technology

Traditional treatments, such as aerobic sequencing batch reactor and upflow anaerobic sludge blanket reactor, require a high energy input and are thus costly. New approaches for wastewater treatment which not only reduce cost but also produce useful side-products have recently received increasing attention. The microbial fuel cell (MFC) technology offers a valuable alternative to energy generation as well as wastewater treatment (Bennetto, 1984).

MFC is a device to treat wastewater and produce electricity at the same time (Habermann and Pommer, 1991). A variety of readily degradable compounds such as glucose and acetate, and various types of wastewater such as domestic, starching and paper recycling plant wastewater, have operated successfully as substrate in MFC (Melhuish et al., 2006; Freguia et al., 2007; Kargi and Eker, 2007; Liu and Li, 2007; Min and Angelidaki, 2008; Venkata-Mohan et al., 2008). Most could achieve a considerable chemical oxygen demand (COD) removal efficiency accompanied with electricity generation. Among these studies, landfill leachate was treated using MFC at a hydraulic retention time (HRT) of 18.7 h, and biological oxygen demand (BOD) decreased from 630 to 269 mg/L with a low power density of 1.35 mW/m^2 (Greenman et al., 2009). A comparable result of 80% in COD removal efficiency was obtained by Liu et al. (2004) using domestic wastewater, accompanied with a maximum electrical power of 26 mW/m^2.

Currently, abiotic cathodes are the most commonly used cathodes in MFCs, which complete the circuit as electron acceptors, but do not perform direct wastewater treatment. Since concentrations of organic matters after anaerobic treatment in anode chamber are relatively high, deep aerobic treatment is expected to degrade wastewater further to achieve the wastewater discharge standard. It is noticeable that MFC is a combined system with anaerobic and aerobic characteristics. It can be regarded not only as an anaerobic treatment process in anode chamber, but also a complete unit with an aerobic treatment process in the cathode chamber. Consequently, a combination of anaerobic–aerobic process can be constructed using a double-chambered MFC, in which effluent of anode chamber could be used directly as the influent of the cathode chamber so as to be treated further under aerobic condition to improve wastewater treatment efficiency. Freguia et al. (2008) have constructed a sequential anode–cathode MFC to treat artificial wastewater, and reported that this configuration could improve cathodic oxygen reduction and effluent quality of MFCs.

5. Energy efficiency and emission in breweries

Energy efficiency is an important component of a company’s environmental strategy (Grossman, 2010; Jürgen, 2011). End-of-pipe solutions can be expensive and inefficient while energy efficiency can often be an inexpensive opportunity to reduce criteria and other pollutant emissions. Energy efficiency can be an effective strategy to work towards the so-called “triple bottom line” that focuses on the social, economic, and environmental aspects of a business. The concept of the “triple bottom line” was introduced by the World Business Council on Sustainable Development (WBCSD). The three aspects are interconnected as society depends on the economy and the economy depends on the global ecosystem, whose health represents the ultimate bottom line (Galitsky et al., 2003).

5.1. Energy use and utilities system

The typical cost of energy and utilities amount to between 3% and 8% of a brewery’s general budget, depending on brewery size and other variables (NRC, 2010). Brewery processes are relatively intensive users of both electrical and thermal energy. Thermal energy is used to raise steam in boilers, which is used largely for wort boiling and water heating in the brewhouse, and in the bottling hall. The process of refrigeration system is typically the largest single consumer of electrical energy, but the brewhouse, bottling hall, and wastewater treatment plant can account for substantial electricity demand. A well-run brewery would use from 8 to 12 kWh electricity, 5 hL water, and 150 MJ fuel energy per hectolitre of beer produced. To illustrate, one MJ equals the energy content of about one cubic foot of natural gas, or the energy consumed by one 100 W bulb burning for almost three hours, or one horsepower electric motor running for about 20 min (NRC, 2010). The specific energy use of a brewery is heavily influenced by utility system and process design; however, site-specific variations can arise from differences in-product recipe and packaging type, the incoming temperature to the brewery of the brewing water and climatic variations.

Natural gas and coal account for about 60% the total primary energy used by the malt beverages industry (EIA, 1997; NPC, 2003).

These fuels are primarily used as inputs to boilers to produce steam for various processes and for on-site electricity generation (Table 3). Other uses include direct process uses, such as process heating, cooling, refrigeration and machine drive, and direct non-process uses such as facility heating.

The relative importance of electricity costs, in addition to the high steam demand in the brewery sector, prompted investment into the generation of on-site electricity at various manufacturing facilities. Cogenerated electricity (the production of both heat and power, also called combined heat and power or CHP) by German brewery in 1994 was 644 million kWh (EIA, 1997). Accounting for all of the electricity uses (net demand), cogenerated electricity accounts for 22% of the total electricity used on-site. This share of cogenerated electricity is relatively high compared to other industries in the U.S. The largest uses of electricity are in machine drives for the use of pumps, compressed air, brewery equipment, and process cooling (Table 4).

Table 5 identifies energy use for specific brewery processes based on surveys conducted by the Energy Technology Support Unit (ETSU) in the United Kingdom for a Kegging brewery (Sorrell, 2000). As the table indicates, the vast majority of thermal energy is used in brewing operations and pasteurization, while electricity consumption is more evenly divided among fermentation, beer conditioning and space and utilities. Anheuser-Busch estimates that 64% of thermal energy is used in brewing (Meyer, 2001).

5.2. *Energy efficiency improvement for breweries*

The brewing process is energy intensive, especially in the brewhouse, where mashing and wort boiling are the main heat-consuming processes. The imperative to reduce energy consumption has led to the development of new processes and technical solutions that consume less energy (Unterstein, 1992). These include dynamic wort boiling with an internal boiler (Michel and Vollhals, 2003) and use of the Jetstar (Huppmann GmbH, Germany) internal boiler for a simmering boil, with a submerged wort flow and stripping phase to reduce undesired volatiles, are good examples of sustainable improvement in wort boiling combined with reduced thermal stress and increased wort quality (Michel and Vollhals, 2002).

International retail groups are increasingly concentrating on “The Natural Step” (TNS), especially carbon footprint of their food and beverage producers, and consumers are increasingly more aware and interested in the energy expended on the product they use in their daily life. For some global brewers, private medium-sized breweries, or even small-scale breweries, TNS is already a significant part of their business philosophy and their sustainable environmental policy (Swallow, 2012; Fendler, 2008; Heathcote and Naylor, 2008; Grossman, 2010; Xenia, 2011a). The target for every brewing industry should be the development of a sustainable process with efficient energy consumption to achieve savings in fuel and energy costs. Fuel oil is considered a very interesting commodity and its price has been on the increase, with no sign of a significant price decrease in the future. The conservation of fossil fuel resources will help reduce CO_2 emissions from fossil fuel combustion, greenhouse gas emissions, and possible climate changes due to these emissions. The brewhouse is the major consumer of thermal energy in a brewery. Reduction of energy usage in the brewhouse requires an integrated approach: improvement of energy efficiency, implementation of energy recovery, and, finally, development of additional energy sources (Scheller et al., 2008). The three main types of plant energy reduction, with particular reference to brewery industry are discussed below.

Table 3
Proportion of overall energy used in malt beverages.

	Expended	
	TBtu	(%)
Net electricity (purchased)	8	12
Power losses	16	24
Distillate fuel oil	0	0
Natural gas	22	33
Coal	17	25
Other fuels	4	6
Total	67	100

Source: EIA, 1997.

Table 4
Uses and sources of electricity in the brewery sector.

Uses	Million kWh	Percent (%)
Boiler/hot water/steam generation	59	2
Process cooling/refrigeration	943	32
Machine drive (pumps, compressors, motors)	1360	46
Facility heating, ventilation, air conditioning (HVAC)	201	7
Lighting	214	7
Other	198	7
Total	2975	100
Sources	Million kWh	Percent (%)
Purchases	2323	78
Cogeneration	644	22
Other (on-site generation)	8	0
Total	2975	100

Source: EIA, 1997.

5.2.1. *Energy efficiency and conservation*

Energy efficiency which has become a household word globally is generally defined as “all changes that result in decreasing the amount of energy used to produce one unit of domestic activity… or to meet the energy requirements for a given level of comfort (Alharthi and Alfehaid, 2007). Strictly speaking, energy efficiency is considered from point of view of the first and second laws of thermodynamics. While the first law is limited to considerations involving energy conservation, a second level of efficiency relates to the coupling of the first and second laws of thermodynamics which recognizes energy quality and irreversibility inherent in real systems. Nevertheless, stripped of rigorous thermodynamic considerations, rational use of energy or energy efficiency is simply defined as “ doing more with the same or less energy input or better still, improving the ratio of energy outputs to energy inputs” (Clancy, 2006).

Table 5
Estimated percentage energy use for various brewing processes.

Thermal energy	
Brewhouse	30–60%
Packaging	20–30%
Space heating	<10%
Utilities	15–20%
Electrical energy	
Refrigeration	30–40%
Packaging	15–35%
Compressed air	10%
Brewhouse	5–10%
Lighting	6%
Other	10–30%

Source: Sorrell, 2000.

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On the other hand energy conservation defined as “an attempt to reduce the amount of energy used for domestic and industrial purposes”. Energy conservation is obviously synonymous with energy efficiency. Energy conservation is further defined as “ the strategy of adjusting and optimizing energy using systems and procedures so as to reduce energy requirements per unit of output (or wellbeing) while holding constant or reducing total costs of providing the output from these systems” (Unachukwu and Onyegegbu, 2000; Unachukwu, 2003).

In general terms, energy efficiency is achieved through the application of technology, such as insulation upgrades, compact fluorescent bulbs (CFLs), high-efficiency furnaces, and so forth. Energy conservation is achieved through behavioural changes, such as turning off lights when not needed, using household appliances differently, carpooling, and so forth.

Energy conservation should be a strategic focus of any company (DME, 2004; Thollander and Ottosson, 2010; Brush et al., 2011). Improving energy efficiency in a brewery could be approached in several ways. First, breweries use equipments such as motors, pumps and compressors. These require regular maintenance, proper operation and replacement with more efficient models, when necessary. Thus, a critical element of plant energy management involves the careful control of cross-cutting equipment that powers the production of a plant. A second and equally important area is the proper and efficient operation of the process. Process optimization and ensuring the most productive technology in place are keys to realizing energy savings in a plant’s operation. The methodology of the Green Brewery concept includes detailed energy balancing, calculation of minimal thermal energy demand, process optimization, heat intergration and finally the intergration of renewable energy based on exergetic considerations (Muster-Slawitsch et al., 2011). The authors reported that a brewery with optimized heat recovery can potentially supply its thermal energy demand over own resources (excluding space heating).

Energy monitoring and process control systems can play important roles in energy management and in reducing energy use. These may include sub-metering, monitoring and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency and optimize process operations.

Improving the efficiency of raw material use or reduction of product losses results in the indirect reduction of energy use (material efficiency). For example, the reduction of beer wastes can reduce the need for processing an equivalent amount of raw materials, resulting in energy savings in the brewhouse and other process steps. Materials use reduction also results in lowered production costs due to fewer charges for solid and liquid waste disposal.

Although technological changes in equipment can help to reduce energy use, changes in staff behaviour and attitude also can have a great impact. Staff should be trained in both skills and the company’s general approach to energy efficiency for use in their day-to-day practices. Personnel at all levels should be aware of energy use and objectives for energy efficiency improvement. Often this information is acquired by lower level managers but not passed to upper management or to other staff (Caffal, 1995). Programs with regular feedback on staff behaviour, such as reward systems, have had good results. Though changes in staff behaviour, such as switching off lights or closing windows and doors, save only small amounts of energy at a time, when taken continuously over longer periods, they may have a much greater effect than more costly technological improvements. Most importantly, companies need to institute strong energy management programs that oversee energy efficiency improvement across the corporation. An energy management program will ensure all employees actively contribute to energy efficiency improvements.

5.2.2. *Energy conversion*

The cost of fossil fuels has increased significantly over the last 10 years worldwide and continues to spiral upward today. Limited fossil fuel resources, the increasing demand for energy worldwide, speculation in the fossil energy commodities market connected with globally rising prices, and the ambition of the countries that signed the Kyoto Protocol to achieve the requested reduction in CO_2 emissions has led to the target to partially substitute fossil fuels with renewable energy sources or combustion of energy-rich waste for heat generation.

The demand for heat energy in the brewery can be reduced through the use of waste heat as process heat or energy-rich by-products or waste material for thermal energy (Ledwig et al., 2007). The combustion of spent grains is one possibility for generating thermal heat and electrical power (Kepplinger and Zanker, 2001; Russ and Meyer-Pitroff, 2002). Two installations for heat generation through spent grain combustion are currently in operation, but the technique for partial dewatering of spent grains and design of the combustion box must be improved.

Another possible substitute for fossil fuel is the anaerobic fermentation of brewery wastewater and biogas production (Ahrens, 2007). The biofuel can be utilized in efficient combined heat and power (CHP) units and numerous other applications such as fuel substitution etc., (Raabe and Henkel, 2003). The electricity produced can be used in the brewery, and any surplus can be sold to the local electricity provider. The wastewater treatment process at Sierra Nevada Brewing Company produces a methane-rich biogas. A recovery system captures this gas and sends it to fuel our boilers to offset the natural gas needed to run the system. This lowers their natural gas utility consumption and cost while reducing greenhouse gas emissions (Grossman, 2010). Muster-Slawitsch et al. (2011) also reported that the energy produced from biogas from biogenic residues of breweries and wastewater exceeds the remaining thermal process energy demand of 37 MJ/hL produced beer.

The sun can be seen as the lowest cost energy provider. In past years, many manufacturers have put great effort into the development of photovoltaic and thermal energy collectors (Weiss and Muller, 2005; Grossman, 2010; Xenia, 2011b). Current medium-temperature collectors contain flat-plate, compound parabolic concentrator, parabolic trough, and linear concentrating Fresnel collectors. With the new type of vacuum collectors developed for solar thermal energy collection, not only can hot water up to 90 °C be generated, but hot water up to 160–300 °C and live steam for process heat also can be produced (Weiss and Rommel, 2005). Many breweries worldwide are located in sunny regions where it makes sense to think about the installation of solar collectors to take advantage of cheap solar energy (Buchhauser, 2006; Grossman, 2010). In the European Union, some small-scale and medium-sized breweries have invested in such systems, and the EC plans to subsidize a few pilot installations in brewing industry in the coming years (EC, 2008a,b; Meyer, 2007). Solar thermal energy can be used for heating processes in CIP plants, bottle washing machines, and pasteurizers or for cooling processes with absorption chillers (Weiss and Rommel, 2005; Kruger et al., 2002 Xenia, 2011a).

5.3. *Energy auditing*

The purpose of an energy audit is to establish and evaluate energy consumption in a brewery, and, at the same time, uncover opportunities for energy savings, i.e., for improvements of energy efficiency (DME, 2004; BAC, 2010). For the audit to have the maximum value, it should address and express in quantified ways:

(a) Examination and evaluation of the energy efficiency of all energy-consuming systems, processes and equipment.
(b) Indication of process management inefficiencies with negative impact on energy consumption.

The scope of the audit is established by the brewery's management. The audit boundary may be visualized as a "black box" enclosing the audit area, and then to focus on the energy streams flowing into and out of the box, and examine what happens to them within the box. The "black box" can be viewed as the entire brewery or a particular operation, e.g., brewing (BAC, 2010a). Other practical considerations in setting the energy audit scope include: the brewery's staff size, staff's capability and availability, outside consultant's capability, money and time available. Securing resources and collaboration of the brewery's personnel is essential. The audit scope should not be stretched beyond what is reasonable to accomplish. An attempt to cover too many facilities/processes with a limited number of resources will affect the effectiveness of the audit and its results.

The key requirements of the audit objective(s) and scope should be thought through very carefully. Energy auditors determine the breadth and depth of the audit, and the physical coverage of the audit. They also determine the manpower requirements (i.e., costs) for the audit's execution.

The audit may point out several ways in which electrical energy is wasted, or why payments for power used are needlessly high. Lack of monitoring and controlling peak demand and power factor may often be highlighted by the auditor. The auditor pays attention to the process equipment and how it is used; and account for energy losses. For example, assess washers and pasteurizers, conveyors, ventilation, the state of their repair; etc. Energy audit results may give the brewery very concrete directions regarding energy management.

5.3.1. *The standard EINSTEIN audit methodology*

The EINSTEIN thermal energy audit and design of improved energy systems is based on a standard EINSTEIN audit methodology subdivided in 4 phases and 10 audit steps (Fig. 5) (Brunner et al., 2010; Xenia, 2011c). The audit begins outside the company with few quick preliminary activities that can be done in the office, the so-called "pre-audit". It allows the auditor to improve his/her knowledge on the status quo (i.e., on the actual energy demand profile, thermal processes in operation, equipments in use, energy bills, etc.) and to get ready before going to the company. Data can be collected already by distance for a first rough evaluation of the energy demand, and of the areas of potential improvements. This preliminary phase is simple, quick but fundamental to save time afterwards: to prepare the company and the auditor for the on-site energy audit.

The second phase (walk-through audit) includes two implementation steps: an on-site walk-through visit to the company and analysis of on-site results calculated running the Einstein software tool. The aim of the walk-through audit at the company is mainly to acquire the information still missing, through interviews and direct measurements; to inspect plants and hydraulics schemes, etc. Back to the office, with the help of EINSTEIN the auditor will be able to check the consistency and completeness of the data acquired; estimate (re-call for) the figures that are still missing; elaborate a detailed breakdown of the heat consumption by process, temperature levels, fuels, etc.; analyse the real operation performance of existing equipments; benchmarking.

Once the auditor has a clear picture of the actual energy flows and inefficiencies of the company, she/he can count on EINSTEIN also for the implementation of the third phase of this auditing procedure: the design and evaluation of energy-efficient alternatives: preliminary design of integral energy and cost saving measures, and energy targets definition; calculation of the energetic performance and analysis of the environmental impact of the feasible solutions; analysis of economic and financial aspects.

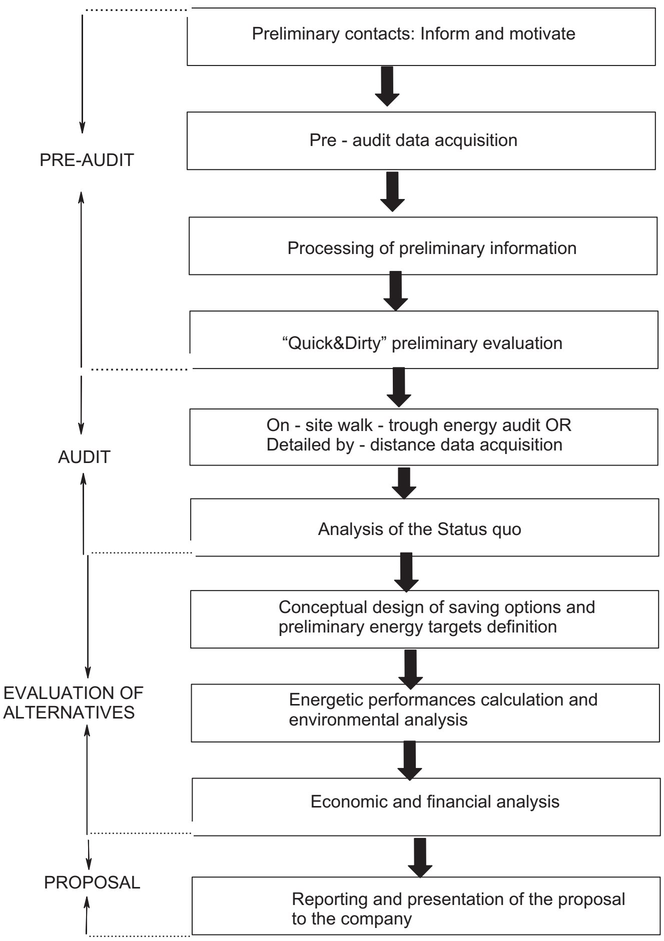

Fig. 5. EINSTEIN's ten steps towards energy efficiency. Source: Brunner et al., 2010.

Finally, there is all the information available required to perform a clear and effective presentation of the results of the audit. The four phases of an EINSTEIN energy audit can be subdivided into 10 EINSTEIN audit steps shown in Fig. 5. Each of these audit steps is described in detail the in the EINSTEIN audit guide (Schweiger et al., 2008). For each audit step the different tasks are described of which it is composed, the indications are given on how to carry out each of these tasks, and which of the tools from the EINSTEIN tool-kit can be used (Andrea, 2011).

5.4. *Energy and utility management systems*

Energy and utility management enable the formalisation of monitoring, evaluating and targeting energy use consumption as well as providing sector-specific benchmarking information (Alex, 2010). Successful utility and energy management depend on a team effort starting with a firm commitment from the Plant Manager and his or her management team. Within industrial and commercial applications, the concept of energy and utility management must embody other key areas, including Training, Motivation & Awareness, Green Accounts (where companies audit the environmental performance of their operation, as well as its economic performance).

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Energy and utilities management is based on the principles of monitoring and targeting (M&T). The M&T process begins with dividing the brewery into energy-accountable centres (EACs), some of which convert energy and others that use it. An EAC should correspond to an existing management accounting centre such as the brewhouse. For obvious reasons, EACs should not straddle different managers' jurisdictions. Within each EAC, energy expended, e.g., use of steam, electricity, etc., is monitored. For additional control, energy might be monitored in specific areas within the EAC. For each item monitored such as boiler efficiency, a suitable index is needed against which to assess performance. For each index, performance standard needs to be derived from historical data that take into account those factors (e.g., production) that can significantly affect efficiency. Again, the managers involved must agree upon the derived standards. Targets are derived, just as standards are. They represent improvements in energy use efficiency. To insure that the process will work, the managers having their consumption targeted must agree that the targets are realistic. Examples of the parameters (specific consumption figures) that could be measured are shown in Table 6. Measuring requires installation of meters at key points in the system, especially at equipment with large energy or utility consumption (such as the brew kettle, bottle washer and can filler). Since the primary goal is financial savings, managers must understand the principles of economics and run their department as if it were their own business. These days, because breweries often have narrow profit margins, energy and utilities management may be vitally important. Despite the fact that financial gains from energy efficiency improvements may seem modest compared to the value of sales or to the overall budget, they can contribute considerably to the brewery's net profit (NRC, 2010). The Strategy will support the proliferation of energy management and the establishment of necessary information, including the introduction of Monitoring & Targeting and "Green accounts".

Indicators are effective means to measure progress towards objectives. They facilitate benchmarking comparisons between different organizational units overtime. One of the more important aspects of energy efficiency and conservation is measuring and accounting for energy expended. Measurement is the basis for the U.K. Brewers' Society M&T energy and utilities management system (NRC, 2010). It is a disciplined and structured approach, which ensures energy resources are provided and used as efficiently as possible. The approach is equally applicable to other utilities, such as water, CO_2, nitrogen, effluent, etc.

M&T does not imply any changes in the specifications of processes. It does not seek to stress the importance of energy management to any greater or lesser extent than is warranted by its proportion of controllable costs. The fundamental principle of M&T is that energy and other utilities are direct costs that should be monitored and controlled in the same way as other direct production-related costs such as labour and malt. As such, actual energy use should be included in the management accounts in the same way as labour or malt is included. Accountability for controlling energy usage should rest with the people who use it, namely the brewery's departmental managers. The plant controller should also be involved since this is the person who will want to know how these controllable costs are managed. The direct benefits of M&T have been shown in the brewing and other industries to range between 4% and 18% of the fuel and electricity bills (NRC, 2010). Other, intrinsic benefits lie in beneficial change in the culture in the brewery, increased employee awareness, a sense of ownership, an improved environmental posture of the brewery, and the application of the newly acquired energy saving habits in other aspects of production. The costs of implementing an M&T system will depend on the extent of installed metering, the coverage desired and the methods used for recording and analysing energy use. Scope can be adjusted in-line with the savings expected. The M&T concept is sound, and many industrial sectors have benefited substantially from it.

Table 6
Typical example of deployment of M&T.

Brewery	Measurement
Brewhouse	Consumption/hL cold wort
Fermenting	Consumption/hL cold wort
Cellars/beer processing	Consumption/hL bright beer
Packaging	Consumption/hL shippable beer
Energy centre	**Measurement**
Refrigerator	Consumption/GJ cooling
Steam production	Consumption/GJ heat
Air compressors	Consumption/Nm^3 air
CO_2 collection	Consumption/kg treated CO_2
Other functions	Consumption/week

Source: BAC, 2010.

Two simple performance indicators have been developed to evaluate how well or otherwise energy is being managed. The first is energy per unit of production or specific energy used expressed mathematically as:

$$\text{Energy per unit of production} = \frac{\text{Energy used}}{\text{Production}} \tag{1}$$

While the other alternative is production per unit of energy, again expressed as a ratio:

$$\text{Production per unit of energy} = \frac{\text{Production}}{\text{Energy used}} \tag{2}$$

A change in either of these indicators is regarded as a change in efficiency; that is, if energy per unit of production falls or production per unit of energy rises, then it is regarded that energy is being used efficiently. Therefore, if energy is to be managed effectively, a company has to know how much energy use is due to controllable actions and how much is due to factors outside their control. Factors that tend to decrease specific energy expended include increasing production levels, improving plant-running efficiency, producing components of lower energy intensity, decreasing scraps and reducing the fixed energy components of plant. The best measure of energy efficiency varies depending on the end-use and even for a single end-use; there can be several different measures. As a result, energy efficiency improvements must be examined case by case for each type of end-use.

5.5. Benefits of energy efficiency measures

From global experience benefits generally derivable from energy efficiency measures are highlighted below.

5.5.1. Financial/Economic benefits

Energy represents cost; therefore saving energy through efficient use saves production cost. In most businesses, the initial stages of raising energy efficiency can be achieved through little or no capital investment. Correct and timely maintenance can have a substantial effect on improving energy efficiency (e.g., replacing broken or inadequate insulation on hot or cold piping). Boilers and furnaces can usually be operated more efficiently by ensuring that the proper combustion conditions are maintained at all times. In some factories or buildings, the boiler/furnace operators might lack the necessary skills (and proper testing instruments) to know how this may be achieved. However, training programmes and the installation of a few simple low-cost devices could typically pay for

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themselves in a matter of a few weeks. High-efficiency light bulbs are another example of a modest investment that typically pays off in a very short time. All these would result to a considerable savings in terms of energy and running cost (Unachukwu, 2010; The Carbon Trust, 2003).

5.5.2. Reduces environmental impact

Improving energy efficiency is one of the most effective means of improving capacity for compliance with environmental demands. Reduced environmental impact can also serve as a significant marketing tool for efficient companies, as public perception of “green” companies takes an increasing role in purchasing decisions. Environmental benefits include many elements, such as reduced local pollution through burning less fuel, lower greenhouse gas emissions, less use of firewood and hence less destruction of forests.

Even where company output is increased (e.g., through expanding manufacturing capacity) energy efficiency improvements can contribute significantly in most cases to reducing the negative impact of energy consumption per unit of output. Any increase in pollutant emissions will thus be minimized (The Carbon Trust, 2003).

5.5.3. Resource savings

Energy efficiency and conservation measures act as a quicker and cheaper way to save scarce energy and material resources. For instance, in boiler operations, a 3 mm diameter hole on a pipe line carrying 7 kg/cm^2 steam would waste 32,650 L of fuel oil per year. A simple house keeping measure that fixes the hole saves that amount of resources (Unachukwu, 2010; Craig, 1981; Chan et al., 2007).

5.5.4. Enhances competitive edge

Energy-efficient companies can gain a competitive advantage over less efficient companies, allowing them to increase their profits at current product prices, or lower their prices to gain market share, or a combination of these items. For example a dairy industry in the U.K. made an annual savings worth £14,230 and savings on water worth a further £17,750 with an initial capital outlay of only £5940 by monitoring its energy consumption and putting in place a number of good housekeeping measures. Yet another is making £12,000 a year by simply putting in place a system to identify and repair leaks in its compressed air system. These examples demonstrate that more energy-efficient practices can effectively reduce operating cost and enhance competitive edge for a relatively small investment (The Carbon Trust, 2003; Phil Harding, 2010).

5.5.5. Promotes sustainable industrial development

There is evidently no gainsaying that energy efficiency and conservation measures will be a very effective pathway of promoting sustainable development which has been described as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. In a rule of thumb sustainable industrial development can similarly be described as “keeping the industries working today, tomorrow and in the future through a systematic approach to energy efficiency measures that meets the needs of the present without compromising the needs of upcoming generations.” Therefore increasing energy availability through rational use is one way to ensure sustainable industrial development in the world (Phil Harding, 2010; Craig, 1981).

5.5.6. Promotes corporate social responsibility

Corporate social responsibility is a concept focusing on the business contribution to sustainability. It is a process by which companies manage their relationships with a variety of stakeholders who can have real influence on their license to operate. Energy efficiency measures can therefore provide industries with instruments to deal with new challenges and requirements to meet with global expectations particularly curtailing CO$_2$ emissions and other pollutants (The Carbon Trust, 2003). Energy efficiency measures also minimizes personnel fluctuations and improves personnel attitudes.

5.5.7. Promotes increased productivity

Energy efficiency measures leads to better positioning in production chain and reduces industrial hazards and risks to worker health (SMEWorld, 2012).

5.6. Common barriers to implementation of energy efficiency measures

Despite the fact that energy efficiency appears to make good sense in many situations; both in terms of cost savings and reductions in environmental damage, it is often very difficult to get managers of companies (and individuals) to take action. It is even more difficult to achieve effective implementation over a long period. All stakeholders are inclined to accept the status quo, which is usually a less efficient scenario, and only respond in terms of energy efficiency once a crisis forces the issue, such as in the case of insufficient energy supplies. For private firms, other priorities are often quoted, such as capital investments to increase plant capacity and market share, leaving no funds for energy efficiency expenditures. This inherent inertia against acting to improve energy efficiency is reinforced by numerous institutional, financial and technical barriers to energy efficiency programmes, either real or perceived. These barriers are reviewed below.

5.6.1. Policy and regulatory barriers

Policy and regulatory oversight systems can influence the priorities and manner in which energy efficiency measures are implemented. In the case of policies, these include both national and local government policies. In many countries, especially in Africa, there simply is no policy or, if there is, it can be indifferent (and thus perhaps counter-productive) to energy efficiency. Regulations that support inappropriate tariffs can limit interest in energy efficiency. For example, it is common to see tariffs that provide for declining energy prices for incremental energy consumption by big consumers. This acts as a disincentive for such consumers to undertake energy efficiency actions. Supportive policy and regulatory environments for energy efficiency include setting targets, either mandatory or voluntary should be considered, from which strategies for encouraging increased levels of energy efficiency can be developed.

5.6.2. Lack of awareness and information

This barrier is the most common problem in almost all countries. Easy access to up-to-date and relevant information is typically lacking even in developed countries. Generally industries are not aware of the economic and social benefits of energy efficiency measures. This is made worse by the low level of exposure in the areas of energy efficiency of technicians and engineers that man energy consuming equipment in most of the industries in some countries. Operators tend to stick to old ways of doing things without being aware of the energy wastes inherent in such practices. A vivid example is a case of frequent boiler blow-down based just on a standing instruction to do so without any knowledge of the level of dissolved solids. The lack of awareness syndrome is also visible in several other areas of industrial operations, such as equipment idling, leaving lights on in broad day lights, overlooking

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compressed air leaks because air is free, and not being aware that about five horsepower of electricity are expended to generate one horsepower of compressed air (Engler and Jasinowski, 2005).

5.6.3. *Lack of initiatives to emphasize energy management*

This barrier is particularly important for the industrial and commercial sectors. Since energy management is a continuing process, it is essential that it becomes part of total management system. Most industries have management systems that address production, accounting, maintenance, environment and safety, but many do not include energy management as part of their management systems. As energy management requires a knowledge and skills base, medium and small industries often claim to have no staff resources to undertake energy management tasks and thus information on energy consumption to improve efficiency of use is lacking.

5.6.4. *Lack of technical capacity*

There is a lack of qualified individuals and organizations to identify energy efficiency projects in many companies. Required skills include the ability to carry out energy audits, analyse performance data, from which opportunities to implement effective actions can be evaluated and properly justified in terms of the benefits achievable compared with the costs involved. This barrier is particularly relevant to most African countries. In some countries, there are organizations that address this barrier by offering services to conduct energy audits or advising clients on energy efficiency measures. These service organizations need to:

(a) Have a knowledge and understanding of energy efficiency systems and opportunities, especially in the local context
(b) Be aware of proper financial evaluation techniques and be experienced in analysing rates of return, life cycle costing, etc.
(c) Demonstrate the quality and comprehensiveness of their work
(d) Have knowledge of the production and safety constraints of the client plant/company.

A lack of technical capacity within such service organizations could result in an incorrect assessment and misdirected measures, which would be counter-productive. In many African countries there will be a need for training at a national level and for a technical certification scheme in order to improve technical capabilities and provide incentives for acquiring official qualifications.

5.6.5. *Financial and investment barriers*

The cost of implementing energy efficiency measures in industry, commercial or residential sectors is sometimes said to be a barrier to effective energy efficiency. Often however, a manager will have little or no ability to evaluate energy efficiency measures properly and may not appreciate that no-cost/low-cost measures are available that require very little capital to implement. All too often the lack of awareness of potential benefits from energy efficiency actions prevents management from doing the no-cost measures first and using the cost savings to build up capital for reinvestment later in energy efficiency. In some cases of course, there are companies that really do not have funds to undertake even modest investments, even though the measures might have very short payback periods. For example, energy suppliers may need to invest in upgrading to more efficient electricity generators or transmission lines, while energy users may need to upgrade to more efficient appliances or install capacitors to increase power factors (and hence reduce the power needed for induction motors). Unfortunately these investments may not be made because there is a genuine lack of capital and interest rates on loans may not be favourable enough in most African countries to justify borrowing.

5.6.6. *Technology barriers*

While great progress in achieving energy efficiency improvements is almost always made by improving energy management, there will be on occasions a real need for tackling deficiencies from a technology point of view. A barrier may be encountered because of a lack of availability of high-efficiency equipment made to good modern standards in any particular country. There may also be insufficient cooperation amongst researchers or research organizations, making it difficult to build effective energy efficiency research, development and demonstration programmes, particularly in a local context in Africa. Thus even where research may have been effectively conducted, there can be difficulty in transferring research prototypes into industrial scale working products. Examples of technology barriers include the continuing use of obsolete and inefficient equipment in the industrial, commercial and residential sectors. At times this is due to unavailability of more energy-efficient technologies. It is perhaps more likely that weak marketing strategies exhibited by equipment manufacturers or importers are contributing to the problem, especially where these do not address the inertia of customers who are reluctant to move away from obsolete and traditional products. Lack of confidence in local installers of new technologies can also be a barrier. Certainly inadequate marketing will do little to promote efficient energy use even though better technologies might actually be available in Africa.

5.7. *Case studies of energy and utility management in brewing process*

The following are examples of case studies of energy and utility management in breweries (DoE, 1991; EEO, 1995 & 2008; Dockrill and Friedrich, 2000; Galitsky et al., 2003; CIPEC, 2005, 2009a,b; BAC, 2009, 2010 a,b,c; Nyboer, 2011).

5.7.1. *Case study 1: pre-heating boiler combustion air with stack waste heat*

A 300 HP natural gas boiler was drawing air from the outside that resulted in unnecessary fuel consumption to heat the combustion air. The boiler used 56,787 Therm per year and was operating at 82% efficiency. A high-quality heat recuperator could recover up to 60% of waste heat, or 6133 Therm per year. At $0.95312 per Therm, the savings amounted to $5846 annually.

For natural gas, the following formula is used in the calculations:

$$CS = EC \times (1 - \eta) \times RC \tag{3}$$

where; CS = cost savings, \$/y; EC = energy consumed, Therm/y; η = boiler efficiency, %; RC = energy recoverable by recuperator, %.

The installed cost of the recuperator was $19,980 (at the time), and the simple payback was 3.4 years. However, the payback time could be reduced significantly, should the operating time increase from larger production and more shifts.

5.7.2. *Case study 2: refrigeration fault diagnosis system*

A one million hectolitre per year brewery capitalized on resident expertise and, with the aid of a consulting firm, developed and installed a Refrigeration Fault Diagnosis Expert System to evaluate refrigeration plant status and to advise on appropriate remedial action when there is a fault. An investment of $36,000 for the purchase of a computer, development of software, customization and operator training (dated costs) brought in savings that allowed the brewery to recoup its investment in eight months, during the training phase. Savings resulted from reducing electricity consumption by 29.5%. From the system's several modules monitor key measurements and data, coefficient of performances (COPs) can be calculated, faults analysed; and a preferred actions for

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establishing the best combination of cooling equipment packages and loads to meet current cooling duty, given the ambient temperature could then be recommended.

5.7.3. *Case study 3: waste heat recovery with a heat pump*

A Canadian Maritime brewery installed a heat pump system to recover hot water for boiler feed and brewing makeup. The system has four major components: an ammonia condenser, water preheater, heat pump and water storage tanks. The ammonia condenser is a shell and tube heat exchanger, which uses water to cool ammonia gas from existing refrigeration equipment. Heat recovered is then used twice – first to pre-heat the boiler feed water, then as a source of energy for a high temperature heat pump. As per design, the use of the heat pumps allows process water to heat to a temperature well above the level at which the heat is recovered from the refrigeration system. A hot water storage tank provides a buffer between the waste heat supply and hot water demand in the brewery. The use of low-cost waste heat reduces fuel consumption by $40,000 to $50,000 a year. However, the practical experience has brought out a lesson: do the design calculations carefully. The heat pump portion of this system was decommissioned due to higher operating costs of the compressor. Still, the ammonia condenser portion is used to pre-heat the boiler feed water.

5.7.4. *Case study 4: lowering air pressure in compressors*

A 60 HP air compressor was being operated at 760 kPa (110 psi), although the maximum pressure required from any process machinery was just 620 kPa (90 psi). Consequently, by a simple adjustment of the pressure regulator, the compressor discharge air pressure could be lowered to 655 kPa (95 psi). The horsepower output would be reduced by 7.5%. Lowering the operating pressure of a compressor reduces its load and operating brake horsepower. Using an appropriate chart to plot the initial and lowered discharge pressures, an approximate decrease (in %) of the brake horsepower can be determined. Savings are calculated using the formula:

$$CS = (HP : \eta) \times LF \times H \times S \times WHP \times CF \tag{4}$$

where; CS = anticipated cost savings for the compressor, $/y; HP = (nominal) horsepower of the compressor (i.e., 60 HP); η = efficiency of the electric motor driving the compressor, %; S = estimated horsepower reduction (i.e., 7.5%); H = annual operating time in hours; LF = average partial load (e.g., 0.6); WHP = conversion factor (0.7459 kW/HP); CF = electricity consumption cost, $/kWh.

The simple payback on savings of $480 per annum (at the time) was immediate.

5.7.5. *Case study 5: repairing compressed air leaks*

One significant air leak (6 mm diameter) and three small ones (each 2 mm diameter) were found in the compressed air system, through a plant inspection during a period of no production. The total loss was 137 kg air/h. The mass flow out of a hole is calculated using Fliegner's formula (BAC, 2010):

$$m = 1915.2 \times k \times A \times P \times (T + 460)^{-0.5} \tag{5}$$

where; m = mass flow rate; k = nozzle coefficient (e.g., 0.65); A = area of the hole; P = pressure in the line at the hole; and T = temperature of the air in the line.

Savings are calculated using the formula:

$$CS = P \times L \times HR \times LF \times CF \tag{6}$$

where; CS = cost savings, $/y; P = energy required to raise air to pressure, kWh/kg; L = total leak rate, kg/h; HR = yearly operating time of the compressed air system, h/y; LF = estimated partial load factor (e.g., 0.6); CF = electricity consumption cost, $/kWh.

Fixing the leaks (even temporarily with a clamp over the leak) realized annual savings of $1360 (at the time) and a simple payback of 12 days.

5.7.6. *Case study 6: redirecting air compressor intake to use outside air*

A 60 HP air compressor drew air from the engine room where the temperature was 29 °C. The annual average outside air temperature was 10.5 °C. Redirecting the air intake to the outside (north side of the building) resulted in drawing cooler and therefore denser air. The compressor worked less to obtain a given pressure increase as less reduction of volume of air was required. The power savings amounted to 7.1%. The calculation to reduce compressor work from a change in inlet air temperature involves the following formula:

$$WR = (WI - WO) : WI = (TI - TO) : (TI + 460) \tag{7}$$

where; WR = fractional reduction of compressor work; WI = compressor work with indoor inlet; WO = compressor work with outdoor inlet; TI = annual average indoor temperature, °F; and TO = annual average outdoor temperature, °F.

Savings from using the cooler intake are calculated using the formula:

$$CS = HP \times (1 : \eta) \times LF \times H \times WHP \times CF \times WR \tag{8}$$

where; CS = anticipated cost savings, $/y; HP = horsepower for the operating compressor, HP; η = efficiency of the compressor motor, %; LF = average partial load factor (e.g., 0.6); H = annual operating time, h; WHP = conversion factor, 0.7459 kW/HP; and CF = electricity consumption cost, $/kWh.

The annual savings amounted to $445 (at the time). With the cost of installation (PVC schedule 40 pipe and some rolled fiberglass insulation), the simple payback was 10 months.

5.7.7. *Case study 7: minimization of water usage used for cooling air compressor*

A 60 HP air compressor was being cooled by an unrestricted flow of water through the compressor cooling coils. The water was heated from 18 °C to 29 °C, and the compressor oil was at 32 °C; it was supposed to operate at 66 °C. The two options for reducing water consumption were: install a gate valve and/or recirculate water through a small cooling tower.

In the case of the gate valve, a small hole calibrated to guarantee the necessary minimum flow rate acceptable to the compressor manufacturer was drilled through the gate. This guaranteed that the water would not be accidentally shut off, yet there was a provision to adjust the future flow rate as necessary and to flush the line from time to time to remove sediment. The cooling tower would permit rejection of heat gained by the cooling water and its recirculation. The flow rate of cooling water could be reduced to the point where the water would exit at 63 °C, allowing the oil to remain at 66 °C. The new flow rate is determined by the formula:

$$NF = \{(29\ ^\circ C - 18\ ^\circ C) : (63\ ^\circ C - 18\ ^\circ C)\} \times OF \tag{9}$$

where; OF = old flow rate, L/h; NF = new flow rate, L/h.

Savings are calculated using the formula:

$$CS = L \times HR \times CF \tag{10}$$

where; CS = cost savings, $/y; L = OF–NF, expressed in m^3; HR = yearly operating time of the compressor in hours, h/y; and CF = cost of water consumption, $/m^3.

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The simple payback for just the gate valve installation was 1.4 days; for the more complex cooling tower installation (costing $7600), it was 1.2 years.

5.7.8. *Case study 8: optimizing a hot water system in the brewhouse*

In a European brewery with annual production of one million hectolitres, the wort was cooled with water in a heat exchanger, then heated to 60 °C and used as brewing water. The surplus hot water was drained. A new $120,000 wort cooler with a larger heat transfer area was installed and produced 85 °C water from the wort cooling. A larger water buffer tank was also installed. The 85 °C water was used for mashing, for makeup water in the bottle washer and as hot water supply for CIP plants in the brewery. Reduced water consumption of 40,000 m^3 and reduced fuel oil consumption of 340 t/y generated a simple payback period of approximately 3 years.

5.7.9. *Case study 9: installing cooling tower for a tunnel pasteurizer*

A 500,000 hL-/y brewery, which used an open-loop cooling system for the tunnel pasteurizer, installed a cooling tower to change to a closed-loop system. The use of the cooling tower, which required an investment of $45,000, resulted in savings of 50,000 m^3/y and a simple payback period of 1 year.

5.7.10. *Case study 10: replacing standard fluorescent lighting with energy-efficient tubes*

A brewery had 956 standard lamps (75 W, 8 feet), using them on average 8 h a day, 5 days every week. They had a ballast factor of 1.1, electricity cost of $0.09/kWh and a demand charge of $13.60/kW per month. The use of high-efficiency lamps, saving 15 W per tube, generated annual savings of $5140. Immediate replacement would result (at a standard cost of $8.42 and a high-efficiency tube cost of $9.87) in a simple payback period of 1.8 years. Incremental replacement of only those 17% of tubes that burn out annually would generate full annual savings only after six years. However, the incremental replacement generated a first-year simple payback of 3 months, second year of 1.6 months, etc., until all savings were completed in the sixth year.

5.7.11. *Case study 11: replacing standard drive belts on large motors with high-torque drive belts or energy-efficient cog belts*

Every electric motor has some inherent inefficiency. Further losses are incurred on torque power transmission onto machinery by the use of a standard V-belt. Losses come from slippage, bending, stretching and compressing of the V-belt, which has a maximum efficiency of 94%, but under well-maintained conditions only about 92%. Replacing these with cog belts, which slip less and bend more easily than V-belts, or with belts with teeth in conjunction with replacing pulleys with sprocketed grooves (i.e., essentially “timing chains”) increases the efficiency of cog belts, conservatively, about 2% and high-torque drive belts (HTD) by at least 6%. Moreover, cog belts last about 50% longer than standard V-belts. The following formulae are used in the calculations:

$$PS = (HP : \eta) \times LF \times S \tag{11}$$

and

$$ES = PS \times H \tag{12}$$

where; PS = anticipated reduction in electric power, kW; ES = anticipated energy savings, kWh/y; HP = total horsepower for the motors using standard V-belts, kW (1 horsepower = 0.746 kW); η = average efficiencies of the motors (e.g., 0.85); LF = average load factor, %; H = annual operating time, h; and S = estimated energy savings (e.g., 2% for cog belts, 6% for HTDs).

Using the electricity cost of $0.09/kWh and a demand charge of $13.60/kW per month, 16 motors totalling 152.5 HP operating 8 h a day, 5 days a week, 52 weeks a year would have total annual power savings (consumption plus demand charges) of $1040 for cog belts and $3300 for HTD belts. The simple payback is immediate for cog belts at replacement time. Assuming an installation cost of $300 per set of pulleys, the simple payback for HTD in the above example is 1.5 years.

5.7.12. *Case study 12: variable voltage, variable frequency inverters*

Variable voltage, variable frequency (VVVF) inverters are well established in induction motor control. A Japanese 2.2 million hL/y brewery investigated the use of VVVF inverters for its 3300 induction motors, used for pumping and other applications. The VVVF inverters allow pump motor speed to be continuously varied to meet load demand. The development of a standardized motor assessment procedure and detailed evaluation of 450 motors preceded a pilot installation. Five pumps with annual electricity consumption of 1501 MWh were selected. After the VVVF inverters were installed, annual electricity consumption dropped to 792 MWh, a savings of 709 MWh. The corresponding payback was on average 1.9 years (at the time). The project also investigated the effects of noise interference on surrounding equipment and carried out measures to alleviate any problems that occurred.

5.7.13. *Case study 13: turning off equipment (motors) when not in use*

An audit of the packaging department revealed that many motors were running unnecessarily. Although demand spikes have to be avoided on restarting, consumption costs can be reduced by instructing personnel to make sure equipment runs only when necessary or by installing more sophisticated, automatic process controls. Energy savings from shutting off the motors when not in use can be calculated using the following formulae:

$$ES = \{(HP \times CV) : \eta\} \times HR \times IL \tag{13}$$

$$CS = ES \times EC \tag{14}$$

Where; ES = realized energy savings, kWh/y; HP = horsepower of motors left on during the day, HP; CV = conversion factor (0.7459 kW/HP); η = average efficiency of the motors, %; HR = annual hours of unnecessary idling time, h; IL = idle load horsepower consumption of the motors (e.g., 10%); EC = consumption cost of electricity, $/kWh; and CS = cost savings.

5.7.14. *Case study 14: the importance of maintenance*

5.7.14.1. Steam leakage. A leak that emits a hissing sound and a hardly visible cloud of steam, e.g., a leaking steam valve, can result in a loss of approximately 1 kg of steam per hour. On an annual basis, it corresponds to fuel consumption of approximately 700 kg of oil or enough energy to produce 200 hL of beer at low consumption. A leak that emits a hissing sound and a visible cloud of steam, e.g., a leaking seal, can result in a loss of 3–5 kg/h. This corresponds to fuel consumption of 2100–3500 kg oil per year, which is enough energy to produce 580–1000 hL of beer at low consumption.

5.7.14.2. Missing insulation. The insulation of just 1 m of 89 mm steam pipe used 6000 h/y will provide a savings of about 450 kg of oil per year, or enough energy to produce about 120 hL of beer.

5.8. *Brewery emissions*

In the recent past, the reduction of greenhouse gas (GHG) emission for climate protection has been pushed to the fore.

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International agreements such as Kyoto Protocol have led to national (CO_2 emission reduction) and communal regulations. As a result, renewable energies and combined heat and power plants are gaining more and more importance. Several greenhouse gases may be produced in the beer making process and these include;

(a) Carbon dioxide (a by-product of fermentation)
(b) Nitrous oxide (a by-product of the internal combustion engine); and
(c) Sulphur dioxide (fused during kilning).

In breweries, approximately 16 kg of CO_2 is generated in boilers burning fossil fuel for each hL of beer produced. This is much greater than the amount generated during fermentation, which is approximately 3 kg CO_2/hL of beer produced (UNEP, 1996). Gaseous emissions of a brewery can be divided into the following (EBC, 1997; Grossman, 2010);

(i) Emissions through the combustion of fossil fuel (oil, coal, wood etc).
(ii) Emissions specific to breweries (e.g., fermentation CO_2, air discharged from factory's sewage disposal plant, brewhouse vapors and vapors from bottle washers).
(iii) Emissions from purchased electricity,
(iv) Mobile combustion from all company-owned and leased vehicles
(v) Stationary combustion from natural gas and diesel fuel consumption
(vi) Process emissions from on-site fuel cells

(vii) Fugitive emissions from refrigeration units

(viii) Stationary combustion using biogas

Carbon dioxide produced during fermentation and maturation processes can be recovered, and carbon dioxide and/or nitrogen are stored and used in many brewery processes where inert atmospheres are required. Uncontrolled release of these gases or inadequate ventilation, particularly in confined or enclosed spaces such as fermentation and maturation rooms can result in accumulation of sufficient concentration to present asphyxiation risk (IFC, 2007). Breweries often have large refrigeration systems, typically using ammonia refrigerant which is toxic and can form explosive mixtures in air.

Odour and dust are the most significant air emissions from breweries. The wort boiling process is the main source of odour emissions from a brewery. The main sources of dust emissions are the use and storage of grains, sugar, and kieselguhr.

6. Environmental impact of brewing process

6.1. Type of environmental impact

The major public concern of breweries has traditionally been about wastewater pollution from untreated discharges. Locally, the odour and the noise from the operation have caused public concern.

The environmental impact from breweries is shown in Fig. 6 and can be divided into 3 groups: resource availability, nuisances and toxic effects.

The resource utilisation is an issue which should be seen from a sustainable development perspective, scarcity of water resources, combustion of fossil fuels, utilisation of raw materials, emission of ozone depletion chemicals, CO_2, etc. Compared to other types of industries, the utilisation of resources is the most characteristic environmental impact from breweries. This means that optimisation of the resource utilisation will result in reduced environmental impact and operational costs.

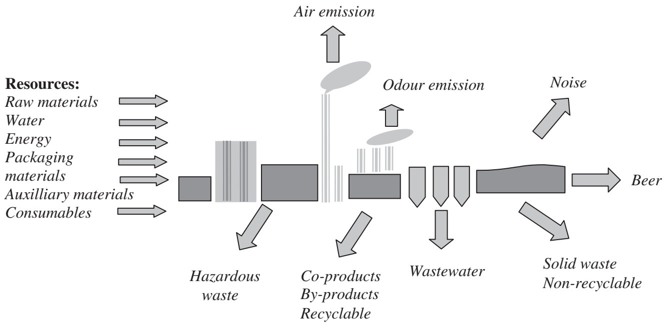

Fig. 6. Environmental impact from a brewery.

The nuisance impact is typically felt by the neighbours of a brewery and is related to the emission of noise, odour (even in cases of high acceptance rates) and dust mainly from handling malt and adjuncts. Reduction of the nuisance impact will often result in additional costs and is to some extent coupled with occupational health measures.

The toxic effect is more diverse as it covers the toxic impact from uncontrolled products or chemical spills into e.g., rivers and wastewater treatment plants. Potential toxic impact from breweries is often related to the evaluation of purchased goods and the contingency measures employed in order to reduce the effects of accidents.

6.2. Geographical impact

The environmental impact of brewing process can be viewed separately from a global, regional and a local perspective.

6.2.1. Global

From a global perspective, the environmental impact is primarily related to the breweries' consumption of energy generated from fossil fuels such as natural gas, oil and coal. In this relation it is emphasized that not only the actual energy consumption (in MJ) is considered, but also the environmental effects of compounds in the fuel and the combustion residuals such as the emission of CO_2, SO_2 and NO_x in the flue gasses. It should, however, be noted that the CO_2 emission from the fermentation process is not relevant as it concerns short cycle CO_2. In this cycle CO_2 is taken up from the atmosphere by the barley plants and during the fermentation process released again.

6.2.2. Regional

From a regional perspective, 3 subjects of concern are identified, i.e., water, wastewater and solid waste. The actual water consumption of a brewery may have an impact on the exploitation of the available water sources. Overexploitation of water resources can have effects such as deterioration of the water recipients and the quality of the water itself. In addition, handling of fuel oil, other oil products, chemicals and lubricants may constitute a risk for pollution of surface and ground water.

Untreated brewery wastewater discharged in surface waters can bring about a rapid deterioration of their physical, chemical and biological qualities. Their decomposition depletes the dissolved oxygen in the water that is vital for aquatic life. Release of nitrogenous and phosphorous compounds in the wastewater will stimulate aquatic plant growth contributing to eutrophication of water

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bodies. Further, due to turbidity and colour photosynthesis may be restricted and thereby affecting the primary link in the food chain. Generation of solid waste that cannot be reused or recycled requires disposal at a landfill even after possible utilisation of the energy in an incinerator. The hazardous waste generation in breweries is in general limited to spent laboratory chemicals.

6.2.3. Local

From the local perspective, 3 subjects of nuisance are identified: i.e., noise, odour and dust. In addition, the local surrounding may suffer an environmental impact due to risk activities (Evers and Bühler, 2005). Excessive noise may cause problems in the surrounding society, especially noise during the night. Noise from breweries comes from transport to and from the brewery, internal transport and noise from stationary sources such as cooling towers, conveyers and ventilation. For a brewery the odour is not noxious. The odour mainly comes from the wort boiling and has a bread-like smell. Fermentation, bottle washers, by-product storage tanks, silos and wastewater treatment plants are other possible odour sources.

Dust emission generated mainly through raw material conveying and kieselguhr handling can cause local problems. The risk activities in a brewery are associated with dust explosions from conveying and handling the raw materials, fire especially in connection with storage of fuel oils and the release of NH_3 from the cooling plant. Accidents caused by either of these activities may cause damage to the local environment. The activities are, however, regulated under local safety statutory orders.

7. Best environmental management practices

Best environmental management practices (BEMPs) emphasize the source control of all wastes generated at a facility through relatively inexpensive adjustments to process and/or operating procedures. Consequently, they can be seen to represent a multimedia approach to pollution prevention (EEC, 1995). Although substantial reductions in pollution creation may occur through simple modifications to the operation, or improvements to management practices, it should be stressed that in order to ensure the effectiveness and efficiency of a particular BEMPs, action in one area needs to be coordinated with those in others (UNEP, 1996). For breweries, in particular, BEMPs can be expected to include initiatives in production operations and management. The first priority of a brewing industry is to eliminate material losses, improve brewing and packaging efficiencies and determine cost-effectiveness, environmentally-preferable ways to managing waste. The following are some of the best environmental management practices.

7.1. Resource consumption

Traditionally, the focus of environmental protection measures has been on emission control and reduction; however, as in many other industries, the inefficient use of inputs (water, energy and raw materials) in a brewery can have environmental impacts. Therefore, the prevention and/or minimization of potential adverse environmental impacts resulting from industrial operations should not only include the improved management and control of emissions and discharges, but also a cutback in the consumption of process inputs such as water, raw materials and energy (Brewers of Europe, 2002; EC, 2006).

7.1.1. Water use

The reduction in the amount of water consumed in a brewery or winery will have several environmental and economic benefits, including conservation of water resources, and consequently, lower wastewater discharge volumes. This potentially allows less costly wastewater treatment equipment (RCL, 1995). Water conservation should not compromise beer quality, plant sanitation or safety considerations and should only be used in conjunction with initiatives intended to reduce the pollutant loadings in the effluent, such as resource and by-product recovery, and waste loadings reduction (Binnie and Partners, 1986; NCI, 1995). There are several production modifications that may be employed to reduce water consumption at a brewery or winery (Binnie and Partners, 1986; SRKCE, 1993; EC, 2006):

(i) Installation, monitoring and control of water meters at various sections of the operation;
(ii) Stopping water flow during breaks, with the exception of water used for cleanup;
(iii) Dry milling of malted barley in breweries;
(iv) Minimization of transfer of last runnings;
(v) Improved production efficiency, especially in the packaging lines;
(vi) Installation of low-flow nozzles or equipment sprays;

(vii) Reduction of water pressure on equipment spray nozzles;

(viii) Installation of flow control valves and an automatic valve to interrupt the water supply when there is a production stoppage; and,
(ix) Replacement of old equipment.

Close attention should also be paid to the consumption of water during cleanup procedures (Binnie and Partners, 1986; SRKCE, 1993; EC, 2006):

(a) use a closed system for cleaning operations;
(b) use a stiff broom or brush to remove attached solids prior to wash down, so as to reduce effluent pollutant loadings;
(c) use low-volume high-pressure washers, or use equipment for mixing water jet and a compressed air stream which will reduce water consumption by 50–75% when compared to a low-pressure system;
(d) compressed air should be used instead of water whenever possible; and,
(e) hoses should be fitted with shutoff nozzles to prevent wastage when not in use.

Substantial amounts of water can also be lost due to the lack of proper maintenance. Consequently, preventative maintenance is essential if water consumption within a brewery is to be kept low. Implementation of a preventative maintenance plan allows the facility to run more efficiently, and thus improve its productivity.

7.1.2. Raw materials

A reduction in the consumption of raw materials used (per unit of product) will not only save the company money in reduced purchasing costs, but it will also reduce the amount and cost (both financial and environmental) of waste production, lower effluent pollutant loadings, and reduce the strain on natural resources. In order to achieve this reduction, the following should be implemented (EC, 2006):

(a) Improve brewhouse yield through process changes, mill adjustments, lauter tun renewal, and/or the installation of alternative processes such as a new mash filter.
(b) Reduce resource consumption and waste pollutant loadings by preventing Kieselguhr from entering the drains. This can be achieved through the use of gravity settling or plate-and-fiame

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filters (Binnie and Partners, 1986), and reducing Kieselguhr consumption through improved yeast settling by:

- (i) selecting better quality malt;
- (ii) optimizing brewhouse procedures;
- (iii) using flocculent yeast strains;
- (iv) installing well designed storage and transfer equipment; and,
- (v) providing longer storage periods.

(c) Reduction of resource consumption by packaging modification, including the substitution of glass bottles with recyclable polyethylene terephthalate (PET) bottles, the use of waterproof labels, and a reduction in the use of glue (Binnie and Partners, 1986; SEPA, 1991).

7.1.3. Energy

A reduction in energy consumption is also an important consideration in a pollution prevention program and in lowering the operational cost. While energy conservation measures reduce the amount of pollution created in the production or use of energy (e.g., CO_2, NO_x, SO_x, ash, etc.), pollution prevention measures reduce the energy requirements for waste handling and treatment (SEPA, 1991). For optimization of thermal energy supply in industry, a holistic integral approach is required that includes possibilities of demand reduction by heat recovery and process integration, and by an intelligent combination of efficient heat and cold supply technologies (Grossman, 2010; Brunner et al., 2010).

Breweries can consume significant quantities of electricity in both production processes and operation of the facilities. However, there are several methods that can be employed to help conserve electricity in these facilities (Xenia, 2011a,b; USEPA, 1992; UNEP, 1996; EC, 2006), and these include:

(a) implementing good housekeeping measures such as turning off equipment and lights when not in use;
(b) using fluorescent lights and/or lower wattage lamps;
(c) using more efficient equipment when replacing old equipment (such as motors and heating units);
(d) installation of computerized controllers to better regulate motor output;
(e) installation of timers and thermostats to control heating and cooling; and,
(f) preventative maintenance of operational processes and pipes so as to improve efficiency and minimize losses.

The conservation of thermal energy is another significant concern for the reduction of energy consumption levels in breweries and wineries. The following are some measures that may be employed in attempt to control the loss of thermal energy (USEPA, 1992; Xenia, 2011a,b; EC, 2006):

(a) improving or increasing insulation on heating or cooling lines, pipes, valves or flanges, refrigeration systems, bottle washers and pasteurizers. Insulation represents a cheap and effective way to reduce energy consumption;
(b) instituting preventative maintenance to reduce leakages and avoid steam trap by-pass. For example, a leaking steam valve can emit approximately 1 kg of steam per hour, which corresponds to approximately 700 kg of oil per year, and a leaking seal can lose up to 3–5 kg of steam per hour, or 2100–3500 kg of oil per year (UNEP, 1996).
(c) using more efficient equipment, the adjustment of burners for optimal air/hel ratios, the insulation of steam pipes, and the systematic maintenance of process operations to ensure their efficiency (USEPA, 1992; UNEP, 1996);
(d) ensuring that hot water tank is of appropriate size so as to optimize hot water production; and,
(e) performing a hot water balance of the entire facility to determine when, where and how hot water is being utilized, and identify areas where reductions in consumption can be made.

The consumption of fuel (e.g., oil, coal, natural gas, etc.) can be reduced through minor adjustments to operating processes and implementing a preventative maintenance program (IFC, 2007). Preventative maintenance of steam pipes can represent a significant opportunity to reduce resource consumption and increase cost savings for a facility. Brewery operations should follow internationally-recognized food safety standards consistent with the principles and practice of Hazard Analysis and Critical Control Point (HACCP) (ISO, 2005). Table 7 provides examples of energy and water consumption indicators for efficient breweries. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas.

7.2. Emission reduction

An improvement of the emission can be reached in an existing plant with factors such as change in fuel, optimization of the burner or change of burner and smothering of flue gas. The sources of odour volatiles in brewhouse are well known, and some studies have been published on odour control in the brewing and food processing industries or, as the final target, the 'zero emission brewery' (Robbins and Brillat, 2002). Odour developments from the factory's sewage disposal plant are a concern for all breweries. An indirect discharger with only one anaerobic step is more problematic than an indirect discharger with only an aerobic pretreatment of the wastewater. Different measures are available to avoid any odour nuisance in the environment. Here, the discharged air can be cleaned by biofilters, biowashers or chemical washers. In addition to installing condensing systems for brewhouse vapors, some breweries in the European Union have invested in equipment that incinerates collected exhaust air or uses ionized air to reduce odour volatiles (Buhler and Michel, 2006; EC, 2006).

Emissions of fermentation CO_2 can be reduced or avoided with a CO_2 recovery plant. Carbon dioxide recovery enables breweries to economically recover CO_2 generated during the brewing process, as a substitute for purchased CO_2 which is required during the beer making process. In exceptional cases, a brewery can produce an excess of CO_2 and even sell it.

Ammonia belongs to the cooling agents, which are toxic, flammable or corrosive. This risk potential for humans is minimized by numerous requirements and regulations. Ammonia cooling systems are driven in closed systems. Ammonia belongs to the natural cooling agents and is environmentally friendly. Ammonia has the advantage that it can easily be located at very low concentrations (from 5 ppm) by its sharp, pungent smell; hence potential leaks can be repaired quickly (EBC, 1997).

Table 7
Energy and water consumption.

Outputs per unit of product	Unit	Benchmark
Energy[a]		
Heat	MJ/hL	85–120
Electricity	kWh/hL	7.5–11.5
Total Energy	MJ/hL	100–160
Water[a]		
Water consumption		4–7

[a] Input and output figures for large German breweries (capacity over 1 million hL beer). Source: EC, 2006.

7.3. Recycling/Global reuse

Brewing industry needs to focus on recycling all materials and by-products that are generated throughout the brewing processes; and with constant pushing of the boundaries of what and where they can recycle. Where possible, breweries can also resell these materials and by-products, which eliminate the need for disposal, as well as providing a source of revenue. Waste and by-product management can also be driven by the secondary market value of by-products. The secondary uses of brewery waste and by-products include:

(i) Malt husks and spent grain – Animal feed component
(ii) Wet and dry yeast – Animal feed component or food flavouring for human consumption
(iii) Labels and paper – Cardboard and paper manufacturing
(iv) Glass bottles – Glass manufacturing
(v) Metals – Various metal products, including aluminium cans
(vi) Wastewater sludge – Soil improvement and organic fertilizers.

7.4. Packaging

Packaging ensures the quality and safety of final products, and is part of attraction of these products for consumers and is essential to protecting the product when in transit. Brewing industry should work with suppliers, wholesalers and procurement and packaging experts to help in making decisions that minimize cost and environmental impact from packaging materials. Different types of product packaging are available, including bulk packaging such as beer kegs, crates and pallets that are almost always returnable and reusable. Other packaging includes boxes, glass bottles, cans and PET (polyethylene terephthalate). Packaging has to account for regulatory requirements, environmental impacts, available recycling facilities, available technologies, various market needs, labelling requirements and customer/consumer expectation. Brewery industry should implement packaging light weighting initiatives that will reduce cost, minimize the use of natural resources and lessen transportation-related impacts (EC, 2006).

7.5. Value chain

Brewery industries must recognise that brewing operations have an environmental impact across the entire value chain, which includes suppliers and a complex distribution network. Brewery industry should work to identify high priority areas for further efficiencies and environmental improvement, to establish goals to reduce those impacts and then work with suppliers and others along the value chain to encourage appropriate changes.

Quantifying a total value chain inventory is a lengthy and complicated process with numerous variables related to climate, geography, soil conditions and other agricultural variables, sourcing of raw materials, manufacturing, transportation, and consumer habits. Brewery industry should guarantee the purchase of all production that meets their quality parameters. They should also invest in barley research and development in order to create new varieties with better yields and to develop sustainable techniques that help improve the volume and quality of the barley produced by the farmers.

7.6. Ethical sourcing policy

Brewery should adopt an ethical sourcing policy, which includes standards on the environment. They should be committed to measuring and minimize their impact on the environment without compromising quality and encourage a similar emphasis on the part of their business partners, including:

(a) Measuring energy usage and committing to reducing it both in manufacturing operations and transportation
(b) Measuring and committing to reduce water usage and discharge
(c) Measuring and committing to reduce the production of non-hazardous solid waste
(d) Maintaining a list of hazardous and non-hazardous substances, and establishing procedures for the safe handling, transporting and disposing of waste in accordance with international, national or local regulations.

7.7. Health and safety

Employee health and safety is another important consideration of a pollution prevention program at a brewery or winery. In addition to an occupational safety policy and clear, well understood set of safety procedures, the following health and safety measures should also be implemented where necessary (UNEP, 1996; EC, 2006):

(a) the inhalation of, or contact with, caustic or acid may result in severe burns and damage to tissues. Therefore, emergency showers and eye rinsing equipment should be installed where caustic and acid are stored and access to tanks which are automatically cleaned should be strictly controlled;
(b) as inhalation of high concentrations of CO_2 may result in asphyxia and death, areas where CO_2 may be present should be clearly marked and equipped with CO_2 detection and emergency ventilation equipment;
(c) the inhalation of, or contact with ammonia, is extremely hazardous. Therefore, areas where ammonia may be present should be clearly marked, and automatic shutoff valves on piping and emergency ventilation systems should be installed;
(d) dust explosion precautions should be undertaken in the malt silo plant and conveyor system. In addition, as the inhalation of Kieselguhr dust may cause pulmonary disease, dust control equipment should be installed and workers should use protective breathing equipment;
(e) proper training in lifting, use of forklifts and other lifting equipment should be provided to prevent injuries. Areas where forklifts are in use should be clearly marked;
(f) exposure to noise levels in excess of 85 dBa for long periods of time may result in deafness. Therefore, noise reduction programs should be initiated and
(g) employees should wear suitable ear protection and have their hearing examined regularly. In addition, areas with high noise levels should be clearly marked and enclosed if possible;
(h) in wet areas, non-slip floors should be installed;
(i) while being filled, bottles are pressurized and may explode. Therefore, the bottle filler should be equipped with a screen, and workers should wear eye protection and gloves;
(j) bottle washers should be properly ventilated to avoid explosions that may result from hydrogen production when aluminium foil come in contact with caustic.

Employees should be informed about the hazards of chemicals handled in the facility and be trained in the proper management of these chemicals. Material Safety Data Sheets (MSDS) should be available for the workers. A centralized storage area for chemicals should also be designated to facilitate greater control.

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8. Conclusion

This article discussed recommended techniques for sustainable process technology in breweries, which include waste reduction, gaseous emission reduction and energy efficiency improvements and energy auditing, which does not compromise the quality of beer produced. The reduction of heat energy expended in the brewhouse by means of the technology discussed in this article is an important contribution to the preservation of fossil fuel resources and to significantly reducing CO_2 emissions. The natural step, especially carbon footprint of a brewery can be optimised further with spent grains combustion and the use of solar thermal energy. The technology and applied technique of biomass combustion must be improved for use in the brewing industry. Because of the impact of the wastewater of Brewery Company in environmental aspects as well as health of the individuals, the company should adhere to corporate social responsibility. In addition, the company should also consider the rules and regulations in solid and wastewater management and environmental sustainability. Brewery industry should embrace the framework of the natural step (TNS) for sustainable development. Brewery sector could evaluate their relative sustainability of their brewing process by considering the following sustainability salon: ecological footprints, carbon footprints, toxic release inventory, habitat and greenhouse gas mitigation. Environmental sustainability therefore encompasses the main tenets of sustainability including what is commonly termed the triple bottom line that is, economic, social and environmental outcomes (Diesendorf, 1997). In this regard, if people would want a desirable future, the main goal is to promote sustainability actions globally and at all levels of society while eliminating actions which lead to the deterioration of physical and social environment.

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