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Energy improvement options for a small-scale brewery: a literature study

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Preface

This thesis has been carried out thanks to,

My supervisor Nawzad Mardan, who has given me the opportunity and valuable guidance to do a literature study on a topic I find really interesting.

To professor Roland Forsberg, for having the idea of this thesis project, even if for particular issues the final result has been changed a bit.

To Mårten Sundling, manager of Bollnäs Bryggeri & Bränneri AB brewery who sadly was forced to close for economical issues related to the pandemic of Covid 19. I wish all the best to him and his family.

To my mother, father and brother who have provided me with motivation and discipline during my life and have given me the opportunity to finish this last stage of my studies.

To my friends who are far away and to the new ones I have made here, who have always been there in the best and worst moments.

Abstract

In the age of technology and development in which we live nowadays, it is inevitable to realise that this so-called progress is translated into pollution, damage to the environment and abuse of energy and fossil fuels. The companies and factories that produce the goods we need, use a lot of energy and pollute in massive ways, posing dilemmas such as how to make these companies more energetically and environmentally efficient, with the aim of decreasing the emissions and energy use. This literature review proposes a compilation and update of suggestions made to microbreweries after undergoing an energy audit. The information has been obtained by searching peer-reviewed articles in different databases and re-arranged in this article into sections on energy efficiency measures, waste treatment options and environmental impact. Several studies have been carried out on improving efficiency and trying to decrease the environmental impact of beer production processes. The main issues found during the process are energy efficiency and the generated wastewater. Both problems could be solved either by using an internal boiler that would generate less waste, applying renewable energies or by treating the residues in bioreactors, a field that needs further study. The choice of packaging material will be influenced by customer preferences and material recycling, being glass bottles and aluminium cans the most popular choices. The project aims to gather different suggestions for improvements in small-scale breweries in an attempt to make these companies more energy-efficient, competitive, economical and sustainable.

Keywords

Brewing industry, energy audit, energy efficiency, environmental impact, sustainability and energy recovery.

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1 Introduction

This literature review focuses on the analysis and search for energy savings in small-scale breweries, with the aim of summarising the different suggestions for energy efficiency that are currently being carried out nowadays in this type of small-scale companies. In other words, it is studied how the energy use, economy and environmental impact can be improved by carrying out energy studies in the factories.

1.1. Background

In the age of technology and development in which we live nowadays, it is inevitable to realise that this so-called progress is translated into pollution, damage to the environment and abuse of energy and fossil fuels. The companies and factories that produce the goods we need, use a lot of energy and pollute in massive ways, posing dilemmas such as how to make these companies more energetically and environmentally efficient, with the aim of decreasing the emissions and energy use.

Indeed, the cost of fossil fuels has risen significantly over the last 10 years worldwide and continues to rise even nowadays. Last decade the price of fuel oil for industrial consumers in the European Union increased by approximately 35%, and the price of natural gas by approximately 40%. This is due to the limited fossil fuel resources, the increasing energy demand in developing countries and the ambition of reducing the CO_2 emissions according to the Kyoto Protocol. All of this has led to the goal of partial substitution of fossil fuels by renewable energy sources or by reusing energy-rich waste for heat generation (Funk, 2008).

The industrial sector consumes about 50% of primary energy globally (Thollander et al., 2013). Therefore, optimising energy use in the industrial sector is a key tool to reduce global CO_2 emissions. In this context, the commitment of large, small and medium-sized companies is essential. Obstacles to developing energy efficiency in small and medium enterprises are several: many do not have the capacity to assign energy monitoring tasks to a worker of the company; they lack knowledge about energy efficiency financing; monitoring of energy consumption is non-existent and there are no energy audits in place. If these barriers can be overcome, it has been shown that improving energy efficiency reduces a company's cost of products and goods and therefore increases competitiveness and productivity.

It is important to note that industries can belong to two different groups according to their energy consumption. Thus, industrial enterprises are classified as either energy-intensive or non-energy intensive (Paramonova and Thollander, 2016). In non-intensive industries, the energy cost is around 1-3% of the total costs, while intensive industries have an energy cost of 5% or more (Rohdin and Thollander, 2006). Breweries are classified as energy-intensive. The consumption of a small company such as a micro-brewery has to be taken into account, not because it has a special weight in the total energy consumption of a country, but because due to a large number of small and medium-sized companies, they constitute a significant part of the national energy usage. In Sweden, the industrial sector uses 35-40% of the country's energy and the energy-intensive industry represents approximately two-thirds of total industrial energy use (Paramonova and Thollander, 2016).

The European Union is promoting efficiency in the use of energy and resources in industrial production. For small-scale companies, in particular, it is interesting to do energy and economic study, not only because it would improve efficiency and reduce energy abuse, but also because it would allow them to compete more effectively with other small-scale companies, without compromising the quality of beer.

1.2. Aims and limitations

The main objective of this work was originally going to be to carry out an energy audit on a small-scale brewery in Sweden. It was intended to take various measurements in the brewing systems and suggest different energy efficiency measures, with the aim to reduce energy use and environmental impact.

The specific company was the microbrewery Bollnäs Bryggeri & Bränneri AB, located in Bollnäs in the mid-Sweden. Due to a lack of demand for beer and high bills to pay due to the Covid-19 pandemic, the company have been forced to close down, making it impossible to carry out the energy study.

In fact, in this section of the project I wanted to dedicate a paragraph to the pandemic and the socio-economic problems it has caused. The brewing industry, and manufacturing companies in general, have suffered huge economic blows, as "working from home" is not viable in this type of industry. Many companies have carried out a large number of redundancies resulting in job losses and huge economic losses. In addition, the reduced number of workers has led to the disruption of supply chains (Nicola et al., 2020).

There are also cases of collaborations between those working in the manufacturing sector. Some breweries have used their facilities to make hand sanitiser, a product widely used during the pandemic, or have sold or donated beer that was not going to be bottled to hand sanitiser manufacturers. This has been the case with Bollnäs Bryggeri & Bränneri AB, where production of short time hand sanitiser was carried out (Norris et al., 2021).

In spite of the problems encountered in carrying out this thesis, it has been decided to make a literature study on energy audits in small-scale breweries, with the aim of summarising the different suggestions for energy efficiency that are currently being carried out in small-scale companies nowadays.

1.3. The brewing process

In brewing beer, processes such as mashing, boiling, cooling, fermentation, filtration, bottling and labelling must be carried out, all of which require the use of specialized machinery that uses energy (Funk, 2008). Two main stages are differentiated: firstly, a stage consisting of the production or brewing of the product itself, the beer; secondly, the beer packaging process. However, as the focus of this project is on the energy aspect, in this section the process will be described mainly on this topic, without going into detail on other aspects. In general terms, the process can be summarized in the following stages (Funk, 2008):

1. Malting, milling and mashing
2. Boiling
3. Fermentation and maturation
4. Filtration and carbonation
5. Packaging or bottling

Regarding the layout of the brewery, two production areas can be delimited. On one hand, the hot block, where all the operations with high thermal energy demand linked to the brewing process takes place. The term hot block is due to the saturated steam used for carrying the heat to boilers and other machinery. On the other hand, the cold block, where the fermentation, maturation, filtration, carbonation and packaging processes are carried out. In this second area, it is essential to keep the tanks cooled normally by means of the glycol solution and the tank control system. Thus, the energy usage in this block is related to refrigeration and hence the name of the cold block. *Figure 1* below summarizes the different brewing stages.

Figure 1: Brewing process diagram (Cocinista, 2010)

Beer production requires various raw materials such as malt, hops, water, etc. and energy in the form of electricity and heat. Usually, the electricity is supplied from the electricity grid and the process heat is generated in a natural gas boiler on site. Approximately 3% to 8% of a brewery's total budget is spent on energy costs, depending on the size of the brewery and many other details (Olajire, 2020). The different processes use energy, both electricity and thermal energy. The latter is used to produce steam in the boilers, which will be used to boil the wort and heat the water for the different steps of the process. Regarding electricity, it is mostly used for the cooling system, although it is also used in the bottling system and other processes. Olajire (2020) reported that *"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."*

Sorrel (2020) highlighted in a study the energy use of the different stages in beer production. It is true that the size and the different systems that are present in a large multinational compared to a microbrewery may vary, but the ranges of consumption presented in the study fit quite well with both cases. It can be seen in *Figure 2*, as stated before, that thermal energy is mainly used in the brewhouse, to carry out wort boiling and other processes. On the other hand, electricity consumption is led by the cooling system, followed by the bottling system.

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%

Figure 2: Consumptions of the different processes of a brewery (Sorrel, 2020).

Kubule et al. *(2016)* showed the simplified regime of a brewing process where a case study was carried out to suggest improvements for the energy efficiency of a microbrewery. The scheme in *Figure 3* below shows the brewing process, the raw material used and the type of energy used in each step together. This diagram summarises in a very clear way the process of beer production, combining the raw materials that are used, the different stages of the process, indicates the type of energy that is needed in each stage to produce the beer and it also shows the generated solid byproducts and wastewaters.

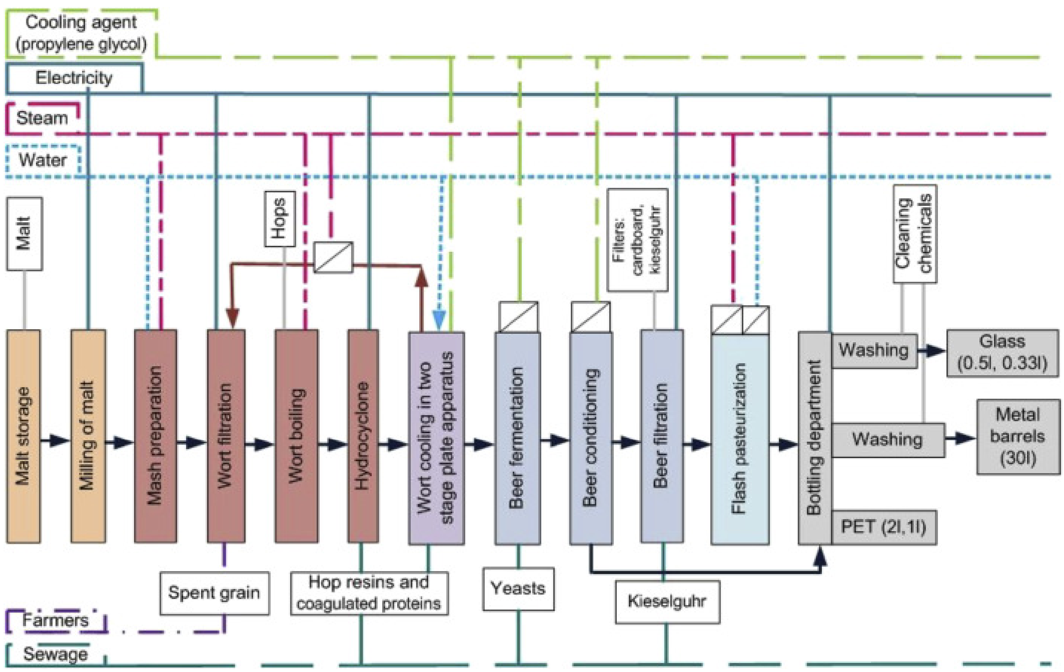

Figure 3: Simplified diagram of a microbrewery (Kubule et al. 2016)

The brewing process is divided into the following steps: the malt is compressed between the mill rolls, which run on electricity, to achieve the finest possible flour. The next process will be responsible for extracting the malt, one of the most important stages of the brewing process, which will give it a different touch depending on the type of beer, by means of natural enzymatic and biochemical processes. This phase of beer production is carried out in the mash kettle, where the ground malt is mixed with water at a temperature of 60-70°C to promote the extraction and enzymatic hydrolysis processes. The mashing usually lasts between one and two hours and the result at the end of this process is a sweetened wort. The water is heated and kept warm by the steam provided by a steam boiler *(Kubule et al. 2016)*.

Having already dissolved the soluble matter in the malt and transformed the starch into sugars during the previous step, it is necessary to separate the wort from the insoluble part of the malt called bagasse, using a mash kettle which also runs on electricity. Bagasse is a product rich in fibre, protein and minerals, so it is used as animal feed, reducing the generation of solid waste *(Kubule et al. 2016)*.

The wort obtained is boiled again in the mash kettle. During the boiling process, hops are added to the wort. Depending on the amount and variety of hops used, the beer will have more or less hop bitterness, flavour and aroma. This process normally takes between one and a half and two hours *(Kubule et al. 2016)*.

The next step in the brewing process is the so-called clarification, which is carried out by imparting a centrifugal movement to the wort inside the mash kettle, which runs on electricity. After allowing these particles to settle at the bottom of the unit, they are extracted by means of the valve located in the centre of the bottom of the unit. After the wort has been boiled and the solid particles have been separated, it is hot (around 95ºC), so before fermentation, it must be cooled and prepared so that it has the right temperature for the yeasts to work well. This cooling is done in a double effect heat exchanger. The hot wort is sent to the heat exchanger, where the wort is cooled in a first phase, from the initial 95ºC to 25-30ºC, by means of water circulating countercurrent, while it is heated by the heat exchange effect between the wort and the water. This hot water will be recovered in the hot water tank for use during bagasse exhaustion, or for cleaning equipment, becoming a good option to reduce the plant's energy and water consumption. In the second phase, the wort will be cooled from the 25-30ºC of the first phase to the 10-22ºC, necessary for the yeasts to work optimally during the fermentation of the different types of beer *(Kubule et al. 2016)*.

The next step is the fermentation phase, which along with mashing, is the most important in the brewing process. The wort, cooled in the heat exchanger, is sent to one of the fermentation tanks. In order for the yeast to work under optimal conditions, it needs a suitable temperature, which varies between 10 and 22°C, depending on the type of beer. This temperature is kept constant by means of the circulation of glycol water through the cooling chamber that the fermenters have for this purpose since during the fermentation process, heat is emitted and it must be eliminated so does not to alter the flavours and characteristics of the beer to be brewed. At the end of fermentation, the yeasts are deposited at the bottom of the fermenter and are removed from it by means of the bottom valve so that their decomposition does not alter the flavour of the beer. The fermentation process lasts between 5 and 20 days, depending on the type of beer *(Kubule et al. 2016)*.

After fermentation, the beer is filtered and conditioned for about two weeks, allowing it to cool to about 2ºC. Finally, the beer is bottled and stored in a temperature-controlled room. Once the storage time has elapsed, the bottles are labelled, placed in boxes and dispatched *(Kubule et al. 2016)*

2 Method

In order to carry out this literature review, several internet databases were used to search for peer-reviewed articles related to energy auditing in the brewing industry. This study will be based on previous research studies and other similar scientific articles and theses, where they will be described and discussed, drawing various conclusions at the end.

Thus, in order to search for articles related to the subject of this project, the databases of the Högskolan I Gävle University, the database of the University of the Basque Country (UPV-EHU), Science Direct and Google Scholar have been used. The search was restricted with respect to dates, from 2010 to 2022, with some minor exceptions, as the date was not relevant to the information being collected. In addition, the following search words were used separately and in combination with each other: brewing industry, energy audit, energy efficiency, environmental impact, sustainability and energy recovery.

In order to obtain a complete perspective, the following criteria were used: the articles had to be peer-reviewed and published in English, Spanish or Basque, and be related to energy issues. The data material was processed, analysed and reflected upon, reading the material to get an overall impression of the content, and highlighting the topics most related to the general theme of this project for each section of the thesis work.

3 Results and discussion

There are several factors that influence the pattern of energy usage in a brewery. Among many other examples, local climatic conditions, production technology, product mix, use of different bottling technologies, production capacity, etc. can be highlighted. At the same time, it can be stated that the biggest barriers to applying energy efficiency measures for the small scale industries are the lack of capital and capacity, the imperfect know-how and the inability to collect all kinds of data and information (Muster-Slawitsch et al., 2011).

In order to find energy efficiency in industries, energy auditing is the first step. Different types of investigations in energy auditing have been made before in small-scale companies, focusing on some ideas that the researchers considered a matter of study. In general terms, the aim of an energy audit is to find out and evaluate the energy usage in a company and, consequently, to discover energy-saving opportunities and suggest energy efficiency improvements. To achieve this objective, all energy-using systems, processes and machinery must be evaluated and measured and inefficiencies in the process must be identified.

Following this thread and according to literature, the industrial processes can be divided into two main categories: production processes, which are engaged in producing the product and support processes, those needed to support the production (Paramonova and Thollander, 2016). In brewing beer, for example, some production processes could be malting, boiling, fermentation and bottling, while some support processes are lightning, heating system or ventilation. Typically, energy audits focus on energy savings in production processes, as these are the most energy-intensive. However, Paramonova and Thollander (2016) studied energy savings in support processes, discovering that good energy-efficient savings could also be achieved, particularly because they are much easier to apply for small-scale companies.

In fact, one of the main problems faced by small businesses is the lack of budget to carry out an audit and especially to carry out energy efficiency improvements. One study found that of the 14,000 small businesses that underwent a free energy audit from 1976 to 2008 in the United States, only 50% implemented changes to their processes (Muthulingam et al., 2008). In Sweden, that rate was even lower when a similar program was offered to small companies, reaching implementation rates between 22% and 40% (Thollander et al., 2007). The program showed that the majority of the suggestions for energy improvements were proposed for support processes, as the support processes have a higher aggregate energy use than the production processes for small-scale companies (Thollander et al., 2015). At the same time, the implementation of these new technologies in order to save energy is usually cheaper, becoming one of the first options for these businesses, such as the implementation of thermal panels to heat the water or the implementation of LED lights, which require low investment.

Several types of energy audits exist, but they are all closely related. A well-known energy audit is based on the EINSTEIN methodology, published by Brunner et al. (2010). It is a methodology and software that allows to carrying out high-quality thermal energy audits in the industry. It is divided into 4 phases, which will be described below:

1. The first phase or preliminary or pre-audit phase consists of a quick preparation of the company and the auditor before facing the actual audit.
2. The second phase is divided into two steps: first, the company is visited and the necessary inspections and measurements are made on the equipment, followed by the use of the software to carry out the necessary calculations.
3. The third phase is in charge of suggesting different energy efficiency alternatives and taking into account energy performances, energy and cost savings, environmental and economic impact, etc. different alternatives can be studied.
4. In the fourth and last phase, the report is presented with all the results obtained, and various suggestions are carried out if they are feasible and accepted by the company.

In the following sections, energy improving options will be summarized, differentiating the possibilities of implementing new efficient technologies, the treatment of waste generated in the production of beer with the aim of reusing it to recover part of the energy and finally, the environmental impact.

3.1 Energy improving options

As stated before in the Introduction section, the brewing industry is energy-intensive and uses big volumes of water, not just for the beer production itself but also for cleaning, washing and sterilising units. Olajire *(2020)* observed that the main heat consuming processes in a brewery are mashing and wort boiling, both located in the brewhouse. As a result of this research study, it was proven that it was possible to reduce the energy use by reducing the heat energy expended in the brewhouse, using an internal boiler to slowly boil the wort, decreasing the unwanted volatiles.

In the same study, several interesting data on the consumption rates in a brewery were reported. It can be seen in *Figure 4* that the highest consumption is centred on pumps, compressors, motors and cooling systems.

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

Figure 4: Uses of energy in the brewing process (Olajire, 2020).

Willaert and Baron (2004) studied the possibility of applying sustainable technology in a brewery to try to save primary energy. Bearing in mind that wort boiling is the most energy-intensive process when brewing beer, they focused on saving energy in this stage. By using water vapour condensers, the energy of the steam coming from the boilers was recovered and it could be used afterwards for heating the water of the mash, among other utilities. In addition, they discovered that the implementation of heat exchangers in the processes of wort cooling could be translated into the recovery of big amounts of energy. Heat exchangers are usually a good solution in order to decrease heat and energy losses, making it more efficient the systems and reducing the economic and environmental impact of every industrial process.

In any case, nowadays many large breweries have already implemented numerous changes in their production system, achieving a reduction in the use of energy and raw materials, such as water. Small scale breweries can also implement various improvements, but always taking into account their economic capacity. Although there are several technologies that are already available to improve energy efficiency and have already been adopted by some larger companies, there is still a lot of potential in the small industry. One of the main problems faced by these companies is batch production and non-continuous operation, which results in inefficient energy use and losses in thermal energy distribution (Thollander and Ottosson, 2010).

Sturm et al. (2013) deduced that the production capacity, the different types or variety of beer produced or brewed and the type of packaging (bottling or canning) are the details that most directly influence the variable energy usage of small-scale breweries. Indeed, the keyword here is “variety”. A microbrewery cannot only brew one type of beer, as it will lose a lot of customers and could be very risky to be competitive in the market. As it needs to produce this variety, it cannot afford to have a production system for each type of beer, having to work in batches and stopping the system to change the type of beer to be produced. This is where the biggest difference with the big multinational breweries is noticeable, where they can afford to have fully efficient systems for each type of beer. Therefore, it can be concluded that a microbrewery will always have higher energy costs than an efficient production system of a multinational brewery, but this does not imply that energy efficiency measures cannot be taken.

Indeed, the packaging materials have varied during the last decades. In the early 2000s, numerous investments were made to try to reduce the environmental impact of bottled beer and soft drinks in general, with the aim of finding more sustainable materials, recycling and finding lighter weight materials to make them easier to transport. As an example, the company Coors reduced the diameter of the cans from 206 to 202, drastically reducing the tons of aluminium needed at the end of the year (EnvironmentArticleBBPA, 2006). In the last decades, more glass bottles and beers had been produced, even if the most efficient way of packaging beers is using beer kegs. In fact, bottling beer in bottles uses almost three times more fuel and electricity per hectolitre than using kegs or barrels (Sturm et al., 2013).

It should be noted that small-scale breweries mostly use bottles and/or cans to store their beer because as a small company, they need differentiation in the market, which is achieved by attractive designs of this packaging and the variety of different types of beer. The use of kegs is more common in large industries, as this allows to transport beer more easily and cheaply to bars, restaurants and other establishments. This is another small barrier faced by small-scale breweries, as kegs are, among other advantages, easier to recycle or reuse than bottles or cans. At the same time, they do not need any design or labelling, they are more resistant and can be knocked over and, as has been found in various articles, require less energy in the packaging process.

Further research differentiates between two options for improving energy efficiency. The first one directly influences the production process and has a direct impact on energy savings, which is to implement an internal boiler for dynamic boiling of the wort, as in previous articles that have been studied. The second option, with a more indirect impact, would be energy balance, process optimisation, heat integration and integration of renewable energies by applying simulation software, pinch analyses and other procedures. This impact will directly be translated into energy efficiency and the reduction of waste. In addition, the involvement and awareness of the company's employees play a key role, as they are responsible for, for example, using the right amount of water when cleaning, turning off lights when they are not needed or using machinery efficiently. Therefore, for a small brewery, it is key to enact behavioural changes in its employees, in order to save energy and gain more profits *(Bär and Voigt, 2019)*.

Another option for microbreweries to improve efficiency is to reduce production when energy is more expensive during working hours. Adapting and coordinating production schedules is key in this regard. With the help of energy audits, analysis and forecasting software, microbreweries can make key decisions to reduce the economic costs of energy usage in their production (Gahm et al., 2016).

In addition to the suggestions of these previous studies, the implementation of renewable energies, such as the installation of solar panels, is certainly an option to consider. One of the biggest problems for small-scale businesses when it comes to improving or making their production more efficient after carrying out an energy study is undoubtedly the budget allocated to this field. A solar panel is an economical option that a small-scale brewery could afford. Mekhilef et al. (2011) reviewed the possibility of adding thermal and photovoltaic solar systems to small scale industries. The research revealed that these systems reduce primary energy needs and that thermal panels could be used, for example, to heat the water needed in CIP systems[1] in the breweries.

3.2 Generated waste recovery

As it has already been mentioned during this literature review, the brewing industry generates a large number of waste by-products, both in the form of solids, liquids and gases. Some of these by-products are, among others, spent grains, spent hops, yeast, wastewater and CO_2. On the one hand, it is interesting to highlight that many of these solid wastes are highly energetic raw materials that have good properties for biotechnological research, as well as for farm feed or incineration. On the other hand, wastewater must be treated before it is returned to the environment or reused in the process. Some of these possibilities will be studied and discussed in the following section.

A lot of research has been carried out to investigate the possibility of using the residues of the brewing process in a sustainable way, with the aim of recovering part of the energy to reuse it in a new process and at the same time minimizing the amount of generated undesirable byproduct. In a beer production process, three main waste products can be found: yeast, CO_2 and grain husks, the latter representing 85% of the total amount of waste. The findings of this research show that, by gasifying the grain, is possible to achieve a net economic saving of around 22%, while the generated amount of waste by-products is significantly minimized. In other words, the application of thermal valorisation to the grain will be directly translated into energetic efficiency. In any case, the report states that due to the small amount of grain waste generated in small-scale breweries (compared to a big industry), the energetic and economic savings are almost non-existent, but at least the generated solid wastes are reduced considerably *(Ortiz et al., 2019)*.

Various technologies have been used to carry out this valorisation of biogas, such as anaerobic digestion, combustion, incineration or gasification. To begin with, anaerobic digestion requires know-how, economic capacity and time that microbreweries may not possess. Regarding combustion, although it is true that the generated grain waste in the beer production process has a high calorific value, it generates emissions of gases and particles containing nitrogen and sulphur dioxide, so in case this possibility is taken as an option, appropriate

[1] CIP systems: "Clean-In-Place systems are automated systems used to clean the interior surfaces of food and beverage process machinery, without disassembling the process."

precautions should be taken to reduce these emissions. In the case of gasification, it demonstrates a lower environmental impact than incineration and high electrical efficiency. With this last technique, by applying a previous granulation and drying to the grain waste, it is possible to produce biogas fuel, to be used in the brewery itself or to be sold for other purposes, producing energy. In any case, as it was studied in the previous article, this energy recovery is a good option for big industries, while smaller breweries will only retain the advantage of reducing waste (Pérez et al., n.d.).

It is important to emphasize that the energy recovered in the brewing process should be reused in the same or other brewing stages in a sensible way. Most of this waste is used in agriculture, more specifically as animal feed. However, more research has been carried out in recent years to try to recover energy in other ways, remarking that this would require closer collaboration between brewers and researchers. Energetically speaking, anaerobic digestion of the sludge is being studied to recover part of the energy from the process. It is also possible to burn the spent grains to produce energy. Other studies focus on biotechnology and its possibilities, such as the production of biogas from anaerobic fermentation of wastewater (Thomas, n.d.).

A parallel study found that bioreactors are another good solution when dealing with wastewater products. The options are diverse: membrane filtration bioreactors and fluidized bed bioreactors, which make it possible to reuse the water again in the process; the anaerobic membrane bioreactors, which produce biomass that could be used to generate electricity. In any case, the research states that due to the cost of these technologies and the lack of environmental and health policy frameworks, this still remains an option for the near future for the breweries *(Werkneh et al., 2019)*.

An interesting point to note from the above study is the production of biomass. To achieve sustainable and economical biomass production, Mathuriya and Sharma (2010) suggested using wastewater from the brewing process as raw material. One of the key feedstocks of the biomass formation process is microalgae, which are found in this wastewater. These microalgae are capable of producing large amounts of biomass in a short time. Nevertheless, this option requires a lot of knowledge, capital investment and time, things that small industries do not possess. An option could be, for example, selling this wastewater to a company engaged in water treatment or biomass production.

Anyway, in a brewing process, there are not only liquid and gaseous emissions but also solid ones. A large amount of agro-industrial solid waste is produced annually, which has to be treated in order to try to reuse it in other areas and thus reduce its environmental impact. For instance, the brewing industry includes processing and fermentation stages for barley, hops and other vegetable raw materials. In a study on the treatment of these solid wastes, new processes were reviewed that could generate less waste or treat them to add more value to the waste. It was observed that most of the residues shared high protein properties and this is why nowadays the most widespread use of these treated residues is still in the field of animal feed and human nutrition (Thiago et al., 2014).

3.3 Environmental impact

Regarding the environmental impact, it was observed that the main concern of the breweries was the production of non-treated wastewater, noise, odour and dust. These last two are the most important air emissions coming from breweries, besides CO_2. The odour comes from the wort boiling process, while the dust comes from different sources such as barley, sugar and malt storage. In any case, these impacts are in the second line and it is underlined that the main issue to solve in beer production processes is the treatment of wastewater above all *(Olajire, 2020*).

A general overview of the water and energy spent in the brewing process is shown below, together with the generated waste by-products that directly affect the environmental impact. The values in *Figure 5* were calculated in a sustainability report by Unicer SA, all of them in relation to the cost of producing 1m^3 of beer. It is important to clarify that solid wastes involve all types of broken glass, plastic, labelling paper, simple industrial residues, etc. while yeast and spent grains are categorized as sub-products. Regarding the air emissions, the implementation of renewable energies in order to leave aside fossil fuels will be translated into a reduction of CO_2 emissions, mainly formed in the combustion of these fuels.

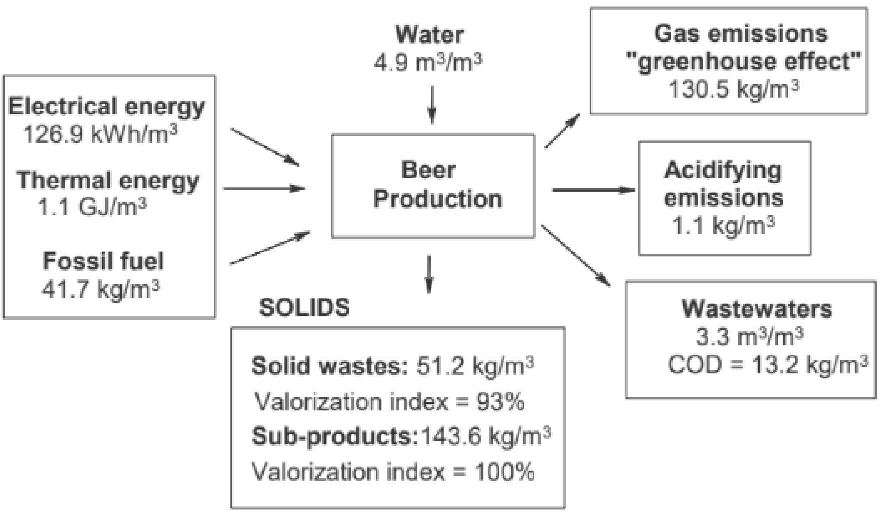

Figure 5: Inputs and outputs with specific values for the production of 1m^3 of beer (Olajire, 2020).

Another important issue in energy efficiency and environmental impact for a small-scale brewery is the choice of packaging the beer in bottles or cans. In most cases, the type of bottling will affect the quality of the beer and this will be perceived by the customer, affecting the final decision to buy one brand or a competing brand. Apart from personal preferences that a customer can have related to the design or touch of a glass bottle or an aluminium can, this study revealed that both materials hide a slight difference when it comes to the formation of volatile components. It was found that storage time was an important variable and that both glass bottles and aluminium cans retained these compounds very acceptably, compared to the plastic PET bottle which retains them less well, showing changes in the concentration of compounds already in the first month. In the end, everything comes down to the recycling of the materials, the economic costs and the preferences of each brewery, because the environmental impact is similar *(Gagula et al., 2020)*.

In any case, the most frequent barrier for microbreweries to implement energy improvements and allocate part of the annual budget to reduce environmental impact is the priority given to this issue. Several small-scale breweries were surveyed by Cagno et al.(2013) for similar factors and all agreed that the main problems to invest in these energy efficiency measures are the lack of financial resources and attitude toward energy efficiency. The priority in the budget is usually given to quality raw materials and other resources, as the cost of energy in the overall budget is not so high (Cagno et al., 2013).

In conclusion, several studies have been carried out on improving efficiency and trying to decrease the environmental impact of small-scale breweries. The biggest challenge is to make energy consumption more efficient and decrease the formation of wastewater in the brewing process. Both problems could be solved at the same time, either by using an internal boiler that would generate less waste or by putting this waste to new use by treating it in bioreactors, a field that still needs to be studied and that looks a more suitable option for big industries than for the small ones. The choice of packaging material is also key in terms of energy, economy and the environment for a brewery, being influenced by customer preferences and material recycling, being glass bottles and aluminium cans the most popular choices for bottling beer.

4 Conclusions

This literature review has been carried out by searching for peer-reviewed articles in different databases, which have been proven suitable tools to collect quality information in order to compile, update and gather the various options that small-scale breweries encounter when faced with an energy audit. While the objective of an energy audit is to discover and evaluate the energy usage in a company and consequently, to discover energy-saving opportunities and suggest energy efficiency improvements, the objective of the small industry receiving the audit should be to try to implement the improvements suggested in the audit, not only to reduce environmental impact and energy use but also to be able to be more competitive in the market and increase their income.

The beer industry is considered energy-intensive, meaning that energy costs are a big part of the budget company. Even if the small-scale breweries do not pay so much attention to these energy costs (Muthulingam et al., 2008), it is key to identify the potential energy efficiency improvements, which are achieved through energy audits. Cagno et al. (2013) reviewed that energy efficiency has a low status in these types of small companies, meaning that these enterprises are more focused on the quality of raw material and other resources, leaving in a second-place energy efficiency measures, becoming a big barrier for the environment and even for themselves.

While it is true that energy efficiency is achieved through technological changes and improvements in process machinery, it is also possible to take steps forward by raising awareness and changing the habits of the company's employees. Training simple small behavioural changes in workers such as using the right amounts of water, switching on lights only when a room is being used or turning on the heating system when necessary and at a comfortable and efficient temperature can make a big difference, both energetically and environmentally talking.

In conclusion, several studies have been carried out on improving efficiency and trying to decrease the environmental impact of small-scale breweries. The biggest challenge is to make energy usage more efficient and decrease the formation of wastewater in the brewing process. Both problems could be solved at the same time, either by using an internal boiler that would generate less waste or by putting this waste to new use by treating it in bioreactors, a field that still needs further research and development. The choice of packaging material is also key in terms of energy, economy and the environment for a brewery, being influenced by customer preferences and material recycling, while glass bottles and aluminium cans are the most popular choices for bottling beer. In any case, regarding the different articles studied in this project, it is evident that microbreweries will always have higher energy use and lower efficiency compared to large industries, due to batch production, idling hours and lower interest and budget to invest in energy efficiency measures. Any kind of help from institutions will be translated into greener breweries and in consequence, into a greener planet.

4.1 Outlook

Energy audits are essential on the road to a sustainable future. Planet Earth is warning us that we must find ways to use less energy and produce it in a renewable way. A possible suggestion for the future could come from governments and countries, promoting energy audits and offering information and support to the small-business sector, since as we have seen in this literature study, their preferences are focused on other aspects, such as the quality of raw materials and the quality of the final product. Perhaps, if the institutions would offer more help to these enterprises, either financially or by providing information and energy audits, the implementation rates of energy-efficient improvements in small-scale companies would increase. That first investment to implement efficient changes in the production processes or even, as seen in this project, in the support processes, would be easier to carry out with these aids. In this way, the payback would be reflected in a few years, allowing small industries to be more competitive in the market, use less energy, obtain higher profits and be more sustainable.

Regarding the new technologies being studied nowadays to improve energy efficiency, wastewater treatment, CO_2 emissions and environmental impact in general, further research is going to be fundamental for the future. Technologies such as using internal boilers to reduce the energy use in the brewhouse, implementing in the production processes water vapour condensers and heat exchangers to recover part of the energy used in the boiler, gasifying the waste grain to achieve energy valorization or the use of bioreactors to produce biogas and biomass for future production of energy are the main options nowadays. It will be vital to continue research on these technologies and to discover new and more efficient ones. Multinational breweries and big industries are already being and need to be pioneers in applying these efficient options and in the more distant future maybe also small companies will be able to apply them in their processes. Nowadays, the reality is that small-scale industries are focusing on applying efficient changes in the support processes, such as implementing LED lights or installing solar thermal panels to heat water in a sustainable and renewable way, but a little push from the institutions could be translated into less use of energy and more environmentally friendly small-scale breweries.

4.2 Perspective

Improving energy systems is going to be essential for the future of sustainability and the reduction of energy usage. Researchers are focusing on developing sustainable technologies with the aim of making more efficient the production processes that exist nowadays. The usage of fossil fuels is becoming unsustainable for the planet and renewable energy solutions are becoming better and cheaper every day. Implementing these energy-efficient technologies in the industry is going to be decisive to counter climate change.

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