The Improvement of Energy Utilisation in African Breweries' Production Processes to Reduce CO_2 Emissions

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Abstract

The increasing global warming temperature has caused pressure on all manufacturing companies to reduce their production emissions. Carbon dioxide (CO_2) remains the highest greenhouse gas that is emitted daily. The beer industry is among companies that utilise fossil fuels to generate energy for production. This study explores the energy efficiency improvement opportunities that exist in African breweries to reduce CO_2 emissions caused by beer production processes. To be able to identify improvement opportunities, the research determined the causes of high heat energy usage in the beer manufacturing process. Quantitative and qualitative secondary data and records from 10 African breweries of Company X were used to analyse the relationship that exists between heat energy utilisation and CO_2 emissions from breweries. High heat energy utilisation is caused by poor practices that exist in the breweries. The findings showed that when steam production has high boiler efficiency the total heat energy used will be reduced. The total steam usage by brewery processes and heat energy utilisation had a positive relationship. Statistical analysis showed a strong correlation between both boiler efficiency and steam usage with CO_2 emissions for most of the breweries. The findings highlighted the importance of breweries being able to identify sources of heat energy inefficiencies. For sustainable improvements, capital investment into energy-saving technologies can be explored when energy wasters are eliminated.

Keywords

Energy efficiency, Beer production, Coal-fired boiler, CO_2 emissions and Regression models.

1. Introduction

Africa reported its third warmest average temperature year in 2021 with a temperature of 1.33°C above average (NOAA National Centers for Environmental Information, 2022). Climate change poses a higher risk to disadvantaged communities that contribute minimally to its cause and do not have means of protection. Global warming has caused increased natural disasters such as floods and disruptive storms, leaving many human beings without shelter (World Health Organisation, 2021). The 2020 Emissions Gap Report stated that 65% of the total greenhouse gases are from CO_2 emissions caused by fossil fuels (United Nations Environment Programme, 2020). In 2021, global CO_2 emissions increased by 2.58 parts per million, making the year the 5th highest increase in 63 years (Lindsey, 2022).

The African beer industry is continuing to grow year after year with a total of 141 million hectolitres of beer produced in 2021. In the year 2021, South Africa was the highest producer of beer at 31 million hectolitres followed by Nigeria at 19.4 million hectolitres (Conway, 2022). This growing demand for alcoholic beverages is creating a need for green sustainability in the beer industry. Breweries utilise steam for brewing, packaging, and cleaning purposes. This steam is generated mainly from the coal-fired boilers that release CO_2 emissions because of the carbon content in coal. The study will focus on the heat energy inefficiencies that are caused by African breweries during the production of beer and how this has an impact on CO_2 emissions.

Company X has committed to reducing CO_2 emissions in the production of its beverages by 25% in 2025. Company X has managed to reduce greenhouse gases by only 13.58% in 2021 when using 2017 as the baseline. Heat energy usage is one of the ten KPIs used in the continuous improvement management system used by Company X. For a brewery to be rated world-class for heat energy usage, it had to achieve a 2021 target of 55 MJ/hectolitres of beer packaged. Using the 2021 year-end results, none of the breweries of Company X achieved world-class status, resulting in an average of 98.4 MJ/HL heat energy usage for the entire company. The high heat energy usage by production facilities in Africa poses a threat to the 2025 sustainability goal. Company X, therefore, needs to identify opportunities to improve its energy efficiency to ensure that the 2025 emission goal is achieved.

1.1. Objectives

The objectives of the research were as follows:

1. To analyse the relationship between these high heat energy usage instances and CO2 emissions.
2. To identify energy efficiency improvement opportunities to improve CO2 emissions.

2. Literature Review

The purpose of this literature review is to give an overview of previous work that has been completed on heat energy utilisation in the brewing industry and how this has impacted the emissions of CO_2 to the environment. The beer production process was outlined followed by heat energy production, losses, and optimization technologies.

2.1. Beer production

Beer is an alcoholic beverage that is produced from malted cereals, water, hops, yeast, and adjuncts. The common type of cereal used to make beer is malted barley which is complemented by other cereals such as wheat, rice, oats, and rye (Tapville Social, 2018). Figure 1 below, shows the beer manufacturing process with raw materials highlighted.

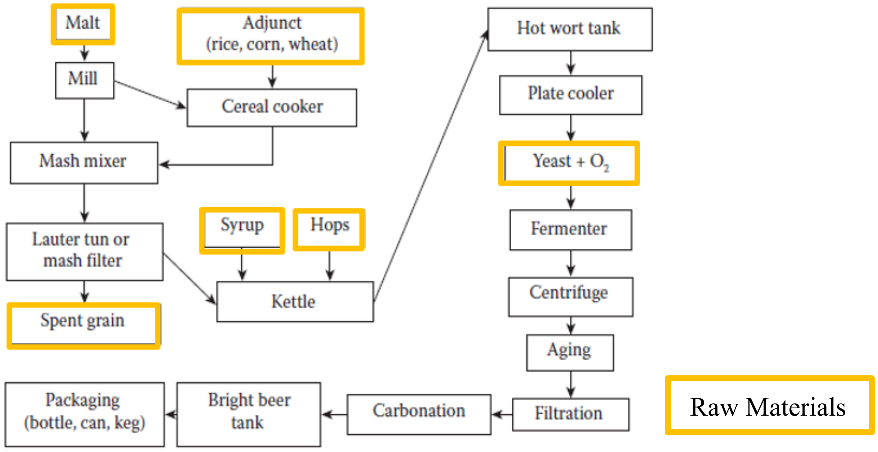

Figure 1 Beer manufacturing process (Eaton, 2017)

The brewing process starts with a milling process to expose the starch contained inside the husk of the malted barley (Rogers, 2022). Next, the grits are mixed with hot water at a temperature between 60-72°C to convert the starch into fermentable sugars, called mashing. The temperatures used during this process are important in activating the enzymes used to convert malt starch into fermentable sugars (Palmer, 2017).

The next step, wort separation, involves separating the liquid sugars from the solids. The wort is then boiled in a kettle, which normally takes 60-90 minutes at temperatures between 96°C to above 100°C. Hops and refined sugars (adjuncts) are added during this process. The boiled wort is transferred to a clarification process where the spent hops and coagulated solids are removed. The clarified wort is then cooled down from 96-99°C down to 5-18 °C. The cooled wort is aerated with oxygen or air and transferred to a fermentation vessel (Galitsky, et al., 2003).

The fermentation process converts sugar into alcohol and carbon dioxide, with yeast and other wanted and unwanted flavours as by-productsDuring the fermentation process, normally from day 3, the produced carbon dioxide is collected to be purified for other brewing processes. At the end of fermentation, yeast is collected from the bottom of the vessel to be discarded or stored for subsequent fermentations (Eaton, 2017). Beer is then transferred to the conditioning, ageing, or maturation vessel where it is stored at a temperature below 0°C for a minimum of 4 days (Paroha, 2020).

The matured beer is later filtered to remove any remaining yeast and coagulated proteins and the beer is kept in a bright beer tank and ready for packaging (Aroh, 2018).

Packaging is the final step in the beer manufacturing process. In the packaging process, the beer that is produced is put into containers which can be kegs, cans, or bottles. . The filled bottles are conveyed to the pasteuriser to expose the beer to heat for a certain period to remove microbial spoilage such as yeast and other bacteria (Sharma, 2020). The beer in a can or bottle is slowly passed through a stainless steel tunnel and it is sprayed with hot water at a temperature between 60-65°C for approximately 30 minutes (Kline, 2020). Filled containers are fed into a labeller for identification. In the final stage, the bottles or cans are packaged into boxes and palletised for transportation.

2.2. Heat energy

Heat energy remains the highest user of total brewery energy at 70% (Brewers Association, n.d.). (De Villiers, 1992), however, stated that heating accounts for almost 80% of the total heat energy in the brewery. Heat energy in breweries is generated by using boilers in the form of steam or hot water at very high temperatures. The heat produced is used for mashing, wort separation, wort boiling, bottle washing, pasteurisation, and cleaning brewery equipment (Brewers Association, n.d.).

Steam or high-temperature hot water used in breweries is produced from boilers, with large breweries being equipped with more than one boiler to be able to meet peak demands. Most boilers are equipped with a series of tubes that act as heat transfer surfaces between water and the combustion products.

The fossil fuels that are used to generate heat energy in the boiler are gas such as liquefied petroleum gas (LPG) and natural gas, oil such as heavy fuel oil (HFO), and coal. For energy-intensive industries, the total emissions in metric tons of carbon (MtC) by fossil fuel type are coal at 18 MtC, oil at 6.1 MtC and gas at 29.6 MtC. These fossil fuels are burnt in the boiler and the produced fuel gas transfers the heat to the water resulting in the production of steam or high-temperature hot water. Boiler efficiency which is the percentage of steam produced from the fuel that is supplied is impacted by the type of fuel used, coal fired boiler efficiency ranges between 81% and 85%, 78% to 81% for oil boilers, and 76% to 81% for the gas fired boiler (Einstein, et al., 2001).

CO_2 contributes the highest to greenhouse gas emissions at 55%. Fuel combustion is responsible for 98% of total CO_2 emissions with coal at 30-40% (Demirbas, 2008).. During the combustion process, the fuel hydrocarbons are oxidised to form CO_2, and water and heat are released (Green, 2014). The increase in the amount of coal used to fire the boiler is directly proportional to the amount of CO_2 emissions that the boiler produces (Othman, et al., 2008). The efficiency of the boiler is an indication of how much heat is lost during the operation. Heat losses during the generation of steam or hot water can be caused by many reasons. Combustion efficiency is defined as the ability of the boiler to use all available fuel and not generate carbon monoxide and unburnt hydrocarbons (Bhatia, n.d.). This efficiency is impacted by the amount of air that is supplied to the boiler. Inadequate air results in incomplete combustion and too much air results in heat losses due to more heat being required to heat the increased air. The key number that will impact the combustion efficiency is fuel to air ratio. Most boilers operate with air that is 15% or less than the stoichiometric fuel-to-air ratio (Einstein, et al., 2001). The additional excess air is dependent on the fuel type used, but a 10-15% excess air for oxygen of between 2 to 4% is recommended (Bhatia, n.d.).

Stack losses are the heat losses from the boiler through the flue gas and they are the highest type of losses at between 10-30% (Saidur, 2011). The temperature, fuel composition and firing conditions of the flue gas determine the loss experienced. The two types of stack losses are dry flue gas loss which is the sensible energy due to flue gas temperature and wet flue gas which is latent heat energy from water produced from hydrogen combustion reaction (Canada.ca, 2018).

Radiation and convection heat losses from the boiler are a result of a temperature difference between the boiler shell's external surface and its surroundings (A. Bhatia, 2012). Unburnt carbons in the form of soot build up on boiler tubes and result in the reduction of heat transfer efficiency which increases the fuel consumption by 2.5%. When the stack temperature increases by 20°C above the temperature of a clean boiler, that is an indication that the soot deposits should be removed (Kumar, 2012). "[A]soot layer just 0.8 mm thick reduces heat transfer by 9.5% and a 4.5 mm layer by 69%" (A. Bhatia, 2012). Beer production heat energy losses.

The wort production process uses the highest energy, around 45% while wort boiling consumes the highest amount of energy. A brewery using a conventional wort kettle boils wort for 90 minutes at temperatures between 105-107°C and around 8-12% of energy is lost due to evaporation (Githuka, 2012) - around 14 kWh for each 1 HL of wort, which is equivalent to 50.4 MJ (Tomescu & Csatlos, 2012).

During the wort cooling process, chilled water is used to cool down the wort to temperatures desired for the fermentation process. Wort at a temperature of between 96-98°C is cooled down to 5-18°C using water at 3-6°C (Goldammer, 2008). When the flowrate of chilled water and hot wort is not at a ratio of 1:1, energy is lost across the heat exchanger. A plate heat exchanger with scaling reduces heat transfer efficiency. Energy can also be lost when the steam and hot water distribution lines have poor insulation that is not maintained, which results in losses to the environment before reaching the source (International Finance Corporation World Bank Group, 2007).

2.3. Brewer energy-saving systems

The 2020 Emissions Gap Report states that 65% of the total greenhouse gases are from fossil carbon dioxide emissions (United Nations Environment Programme, 2020) thus breweries need to invest in technologies and best practices that are aimed at saving energy. Below are some of the systems that can be adopted:

2.3.1. Wort boiling energy efficiency technologies

It is estimated that the reduction of the evaporation rate from 12% to 6% can save 6.8 MJ per brew, thus it is important to ensure that the type of kettle used has a minimal evaporation rate (Githuka, 2012).

To save energy from a boiling system, it is important to recover the energy lost during the evaporation of wort. Vapour condensation is a technology that installs a vapour condenser on a chimney of a wort kettle. Nowadays the type of condenser used is made up of a single-layer plate heat exchanger where cold water passes through and is heated with the vapour recovered. According to (Tomescu & Csatlos, 2012), 1 hl of evaporated wort can generate 0.8 hl of hot water at 80 degrees Celsius. Another study showed that 1kg of the extracted vapour can generate 1kg of water at 100 degrees which has a total energy of 2260 kJ. The generated water from the vapour condensation system can be used to pre-heat the wort from the wort separation process from around 76 to 92 degrees Celsius before the wort boiler (Willaert & Baron, 2016). If 1000 hl of wort is boiled from 92 degrees to 100 degrees, the energy saving is 6.8 MJ/hl of wort, a 68% reduction (Hancock, 2018).

Vapour compression is another method that can be used to recover energy from wort evaporation. The vapour produced during a conventional wort boiling can be compressed using a mechanical or heat compressor. The mechanical compressor utilises a turbo, screw or rotating piston, and vapour from the kettle chimney is compressed to 0.3 to 0.4 bar. The wort kettle still uses fresh live steam produced from the brewery boiler, however, once the wort reaches a temperature of 102 to 106 degrees Celcius, the vapour produced from the compressor is supplied to the kettle to maintain the boiling (Willaert & Baron, 2016). In a Thermo compressor, the steam from the boiler is passed through a steam jet pump that has the evaporated vapour. The steam used is at a pressure of between 8 and 18 bar and it passes the jet pump at a high velocity that causes kinetic energy to be produced resulting in the recovered vapour compression to 0.1-0.4 bar (Tomescu & Csatlos, 2012).

Another technology, low-pressure boiling was introduced in 1979 with the intent of reducing energy costs in breweries. In this system, the pressure of the wort is kept constant at 1.08 to 1.21 bar throughout the boiling. This technology was further developed into a new system called dynamic low-pressure boiling which has a series of phases. The pre-boiling phase allows pressure to build up to 1.17 bar at a temperature of 104 degrees Celsius for 3 minutes. The next phase is the pressure reduction phase where pressure is released to 1.05 bar at 101 degrees Celsius. This phase ensures the wort boils vigorously and this rapid boiling allows the stripping of unwanted volatiles. The last phase is the post-boiling for 5 minutes at 100 degrees Celsius. The overall evaporation rate of this system is between 4.4 to 4.5% (Willaert & Baron, 2016). The dynamic process of pressure build-up and release occurs 6 times in an hour (Craft Beer & Brewing, 2021).

Sterile filtration also known as cold stabilisation is an alternative method of pasteurising beer without using heat. This process uses different methods that have a pore size of up to 0.45µm to reduce microbial spoilage in beer down to 1 cell/100 ml of beer (Andrew, 2021). Flash pasteurization uses less energy compared to tunnel pasteurisation because it heats the beer rapidly on an in-line heat exchanger. The estimated optimum heat recovery is around 94-96% (Xhagolli & Marku, 2014).

2.3.2. Boiler energy-saving best practices

The amount of energy leaving the steam or hot water generation boiler through the flue gas can be recovered and used in an installed economiser. An economiser is finned tube equipment that captures heat from flue gas and transfers it into the incoming boiler feed water. A boiler with a flue gas temperature of 260°C can raise the feedwater temperature to 15°C (Kumar, 2012). For every 10°C rise in the temperature of incoming feedwater, there is a 1% reduction in fuel cost (Ryker, 2019). The heat from a flue gas can also be used to preheat the combustion air which will improve the efficiency by 1% for a 20°C increase (Kumar, 2012).

2.3.3. Pinch technology for energy saving

Pinch technology is a thermodynamic-based system that focuses on energy saving in a process and the entire plant. The methodology begins with getting data for the process of interest to be able to do a material and energy balance for the cold and hot streams of the process. The energy target is then set up using the composite curves for the cold and hot streams. The hot stream composite curve shows the heat that is available in the process and the cold composite curve shows the heat demand in the process. The minimum energy target is determined by overlapping the two composite curves and separating them with a minimum temperature difference. This temperature is indicated as a pinch point of the composite curves (Linnhoff March, 1998). A grand composite curve can also be developed using the cold and hot composite curves. This curve is achieved by moving down the hot composite curve by half of the minimum temperature difference and moving up the cold curve also by half of the minimum temperature difference. Once the two curves are moved, the new minimum temperature difference becomes zero. The heat exchanger network diagram is developed using different stream types, temperatures, enthalpies, and heat transfers in a straight line (Viktor, 2018).

3. Methods

A quantitative research method was used to better understand the research question (Guetterman, 2020). For this method, secondary energy data from January to December of 2021 was collected from Company X spreadsheets and it was analysed using Microsoft excel and Minitab software statistical tools.

4. Data Collection

The company that was used for research has over 20 operational breweries, however, this research used secondary data from only the 10 breweries from 7 African countries, named Brewery A to Brewery J in alphabetic order. The company currently has breweries that utilise coal, natural gas, biogas, and light-fuel oil to produce steam for brewery processes. The research's focus was to study the impact that the heat energy from coal-fired boilers has on CO_2 emissions, thus only the breweries that utilise coal-fired boilers were chosen for the study. The collected data was from the 2021 financial year (January to December 2021). All the KPIs that are linked to energy efficiency were collected from all breweries' digital reporting systems and they are packaged beer, heat energy usage, steam usage, coal usage, boiler efficiency, CO_2 emissions.

Heat energy which is the energy content contained in coal is calculated using the below equation referenced from:

$$\text{Thermal Energy} = \text{Coal} \times \text{Calorific value of coal} \qquad \text{(Unit Juggler, 2013)}$$

Where units of measure are:
Heat energy: Mega Joules (MJ)
Coal: kilograms (kg)
Calorific value: Mega Joules per kilogram (MJ/kg)

The calorific value of coal is the total amount of energy produced as heat when coal is completely combusted with oxygen. For the collected data, the breweries utilise an amount of 25.9 MJ/kg. The coal received by the breweries is stored in silos that have weight load cells for measuring the kilograms of coal remaining in the silo. When coal is transferred to the boiler through a conveyor belt, the weight before and after the transfer is used to calculate the amount of coal used.

The research was aiming at determining factors that can assist in reducing the current CO_2 emissions from the 10 breweries. CO_2 data collected are calculated values that are determined using the below equation:

$$\mathrm{CO_2\ emitted\ (kg) = Coal(kg) \times 0.6 \times 3.67} \qquad \text{(360 Energy, 2020)}$$

The breweries all utilise coal that contains 60% of carbon and using the molar mass of CO_2 (12 for carbon and 16 x 2 for oxygen), a factor of 3.67 was used to convert the coal mass to CO_2 mass.

5. Analysis and Results

5.1. Breweries' control charts

Control charts were used to analyse the stability of the process data collected from the 10 breweries. The variables that are calculated from coal usage, which are heat energy and CO_2 emissions were not tested for stability because they are directly proportional to coal results. Coal usage, boiler efficiency, and steam usage control charts were created using Minitab.

Figure 2 shows the control chart for the coal usage average for all 10 breweries on monthly a basis.

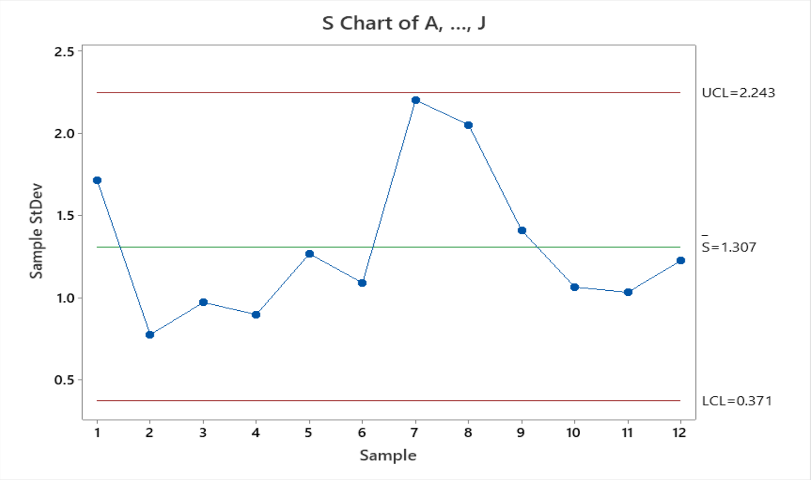

Figure 2. Coal usages control chart for 10 breweries

From Figure 2, high values of coal usage standard deviations are experienced in January, July, August, and September with low values seen in early and towards the end of the year.

Figure 3 shows the control chart for the average boiler efficiencies for all 10 breweries over 12 months.

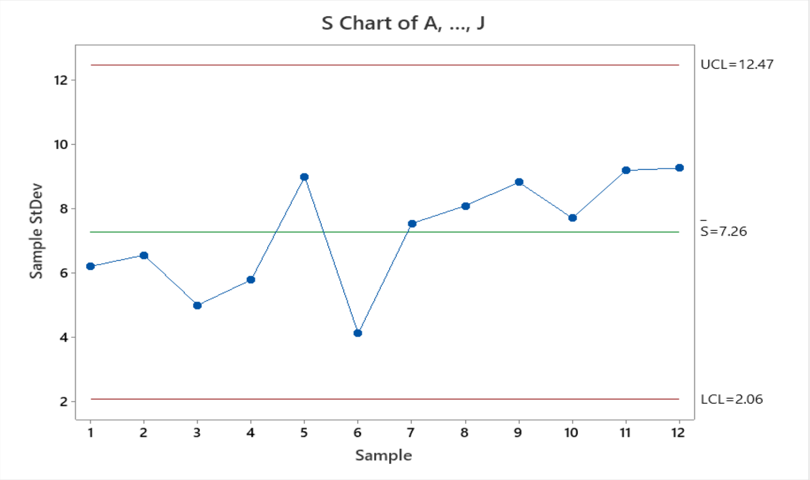

Figure 3 Boiler efficiency control chart for 10 breweries

The boiler efficiency control chart shown in Figure 3 shows no patterns. The boiler efficiency subgroup standard deviations vary around the mean standard deviation.

Figure 4 shows the control chart for the average steam usage for all 10 breweries over 12 months.

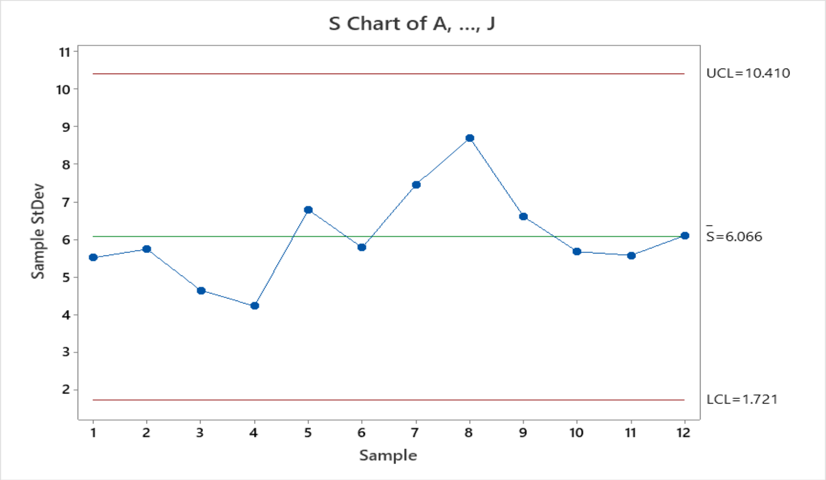

Figure 4. Steam usage control charts for 10 breweries

Control chart results for steam usage had all values within control limits as shown in Figure 4. The data points vary around the standard deviation with no visible trends observed.

5.2. CO_2 emissions root cause identification

One of the objectives of the research was to determine the causes of high energy in breweries and how these causes affect CO_2 emissions.

5.2.1. Regression models

Regressions models were conducted using Minitab software for variables that were not calculated using coal usage. The boiler efficiency and the steam usage by the 10 breweries were compared with CO_2 emissions and the results were analysed as follows:

- Determine if the alternative hypothesis is true ($p\text{-value}<0.05$): this hypothesis states that there is a statistically significant relationship between the x and y values.
- Determine how well the regression fitted line fits the data points: the R^2 value will be used.

Table 1 shows regression model results with all the p-values and R^2 percentage values for the regression models of boiler efficiency and steam usage compared with CO_2 emissions for all the breweries.

Table 1. Regression models result for boiler efficiency and steam usage compared with CO_2 emissions

	Boiler efficiency		**Steam usage**	
Brewery	**p-value**	**R^2 (%)**	**p-value**	**R^2 (%)**
A	0.7980	0.70	0.0040	58.60
B	0.4690	5.40	0.0000	95.10
C	0.1800	17.20	0.0020	62.70
D	0.4160	6.70	0.8000	0.70
E	0.0460	34.20	0.0000	81.40
F	0.0010	71.40	0.0000	77.50
G	0.0000	72.10	0.0000	89.00
H	0.0100	50.40	0.0000	85.30

I	0.0130	47.80	0.0000	92.20
J	0.0420	35.30	0.2530	12.80

For brewery A, there was no correlation between boiler efficiency and CO_2 emissions since the p-value is 0.798. The R^2 value is 0.7%, which indicated that 99.3% of CO_2 emissions variations cannot be explained by the boiler efficiency values. Steam usage and CO_2 emissions p-value is 0.004, which is below 0.05, thus there was a significant relationship between the two variables. The 58.6% of the CO_2 emissions can be explained by the model. The CO_2 emissions for brewery B are not statistically caused by boiler efficiency, the p-value is higher than 0.05 at 0.469. The regression model could only explain 5.4% of the emissions. Steam usage for brewery B had a significant relationship with CO_2 emissions with a value of 0.000. The model explained 95.1% of the emissions. Brewery C CO_2 emissions did not have a significant relationship with boiler efficiency, the p-value is 0.180. Only 17.2% of the emissions were explained by the regression model. The steam usage for brewery C is significantly related to the CO_2 emissions with a p-value of 0.002 and the regression model could explain 62.7% of the emissions. The CO_2 emissions and boiler efficiency for brewery D did not have significant relation, a p-value is greater than 0.05 at 0.416 with only 6.7% of emissions explained by the model. Brewery D steam usage did not significantly correlate to CO_2 emissions since the p-value is 0.8, greater than 0.05 and the regression model could explain 0.7% of the emissions. The p-value for brewery E boiler efficiency and CO_2 emissions is 0.046 which is below 0.05, thus the relationship between the two variables was significant. The R^2 for the model is 34.2%, a percentage of emissions that could be explained by the model. Steam usage and CO_2 emissions showed a significant relationship with a p-value of 0.000 and 81.4% of the emissions are explained by the regression model. The boiler efficiency for brewery F had a significant relationship with the CO_2 emissions with a p-value of 0.001. The regression model explained 71.4% of the CO_2 emissions. Steam usage and CO_2 emissions for brewery F had a significant relationship with a p-value of 0.000 and 77.5% of the emissions could be explained by the regression model. The brewery G boiler efficiency and CO_2 emissions regression model had a p-value of 0.000, which indicated a significant relationship. The R^2 value showed that 72.1% of the emissions could be explained by the regression model. There is a significant relationship between brewery G steam usage and CO_2 emissions with a p-value of 0.000 and 89% of the emissions could be explained by the model. The relationship between boiler efficiency and CO_2 emissions for brewery H is significant with a p-value of 0.010 and 50.4% of the emissions are explained by the model. The p-value for brewery H steam usage and CO_2 emissions is 0.000, which showed a significant relationship between the two variables. The regression model could explain 85.3% of the emissions. Brewery I boiler efficiency and CO_2 emissions had a significant relationship with a p-value of 0.013, and 47.8% of the emissions could be explained by the model. A significant relationship between brewery I steam usage and CO_2 emissions existed with a p-value of 0.000 and the model could explain 92.2% of the emissions. The boiler efficiency and CO_2 emissions for brewery J had a significant relationship at a p-value of 0.042. The regression model could only explain 35.3% of the emissions. Brewery J steam usage and CO_2 emissions had no significant relation, the p-value is greater than 0.05 at 0.253. The model could only explain 12.8% of the emissions.

6. Discussion

This section of the report discusses the analysed results from chapter 5 to answer the two research objectives stated in chapter 1.

6.1. Impact of inefficient heat energy on CO_2 emissions

The regression models were generated for all 10 breweries to determine the relationship between both the boiler efficiency and steam usage with CO_2 emissions. The alternative and null hypotheses were used to answer whether the relationship exists or does not exist. The results showed that 60% of the breweries (6 out of 10 breweries) have a strong relationship between boiler efficiency and CO_2 emissions. An inefficient boiler is a boiler that utilises a high amount of fuel to produce low to medium steam. This boiler causes an increase in the amount of coal burnt and thus increases the CO_2 emissions released (Demirbas, 2008). From the regression models, 80% (8 out of 10 breweries) of the breweries showed a strong correlation between steam usage and CO_2 emissions. The breweries with high amounts of steam usage produced the highest CO_2 emissions.

6.2. Energy improvement opportunities

The last objective of the research was to identify energy efficiency improvement opportunities to improve CO_2 emissions. The first recommendation is for the breweries to utilise the pinch technology identified in the literature to identify energy efficiency opportunities. The first step will be to do a heat energy balance to identify the processes or equipment with the highest energy usage. Equipment are designed with specified energy requirements, the energy balance findings should be compared with these specifications to identify waste points. The current breweries studied do not have energy-saving technologies installed. When waste is eliminated, it is also recommended that breweries invest capital in installing energy recovery systems to have energy savings (Gross, 2020). The current 10 breweries utilised coal-fired boilers, and coal has been identified as the fossil fuel with the highest CO_2 emissions. It is recommended that breweries explore the modification of the current boiler to start using natural gas for steam production. Breweries should install an air monitoring system that will measure the air supplied to the boilers. This will ensure that sufficient air is supplied to improve combustion efficiency. Production teams need to do regular plant walkabouts to identify steam leaks in their areas of work. When all breweries across Africa move towards greener beer production, the journey toward the 2050 goal of Net Zero Emissions will be accelerated.

7. Conclusion and Recommendations

7.1. Conclusion of the study

The purpose of this study was to understand how the causes of high heat energy usage impact the amount of CO_2 emitted to the environment. The study did not only look at the production of steam by the boiler but also considered the usage of the produced steam by the beer processes. From the statistical analysis, the study was able to identify that boiler efficiency and steam usage have a strong correlation with the amount of CO_2 released by the boiler during steam production. When breweries utilise a high amount of steam for beer production processes, that increases the kilograms of CO_2 emitted. The global warming crisis increases the risk of human and animal deaths and natural disasters. It is the responsibility of all industries to implement technologies that will reduce the amount of CO_2 they release. The study highlighted opportunities that exist in the beer industry that can be used to assist the current global warming crisis.

7.2. Recommendations for further research

This research focused on the coal-fired boiler that produces steam, future research could study the heat energy usage for fuel types such as natural gas, biogas, and light-fuel oil to understand their impact on CO_2 emissions. Breweries can utilise steam or hot water at very high temperatures for production and cleaning purposes, it is recommended that the two products be compared to understand how they can impact boiler efficiency, coal usage, and CO_2 emissions. Breweries with implemented energy-saving technologies should be studied to further understand how technologies improve the total amount of CO_2 that is emitted. The supply chain network for breweries also includes the transportation of raw materials and finished products. The amount of CO_2 emitted by the mode of transport should be studied to understand the severity of its impact on carbon emissions. The research revealed a strong relationship between both boiler efficiency and steam usage to CO_2 emissions. The causes of low boiler efficiency and high steam usage should be studied to identify solutions that can further improve heat energy utilisation.

References

360 Energy, *How Does Using Energy Create Carbon Emissions?.2020* [Online] Available at: https://360energy.net/how-does-using-energy-create-carbon-emissions/ [Accessed 8 August 2023].

A. Bhatia, B., *Improving Energy Efficiency of Boiler Systems,* Fairfax, Virginia: PDH Online, PDH Center. 2012.

Andrew, F., *Beer and Brewing.* [2021. Online] Available at: https://beerandbrewing.com/dictionary/dbmo7NxF7k/ [Accessed 17 April 2022].

Aroh, K., *Review: Beer Production,* Owerri: Federal University of Technology Owerri. 2018.

Bhatia, A., *Improving Energy Efficiency of Boiler Systems,* Woodcliff Lake: Continuing Education and Development Engineering. n.d.

Brewers Association, *Energy Usage, GHG Reduction, Efficiency and Load Management Manual,* Colorado: Antea Group. n.d.

Conway, J., *Statista.* 2022. [Online] Available at: https://www.statista.com/statistics/202411/beer-production-in-different-african-countries-in-2010/ [Accessed 21 February 2023].

Craft Beer & Brewing, *The Oxford Companion to Beer definition of Boiling,* California: Unfiltered Media Group. 2021.

De Villiers, M. G., *Energy management in idustry: A Case Study on the Brewing Industry,* Cape Town: University of Cape Town (UCT). 1992.

Demirbas, A., Carbon Dioxide Emissions and Carbonation Sensors Turkey. *Energy Sources,* Part A(30), pp. 70-78. 2008.

Eaton, B., Handbook of Brewing. In: I. R. A. A. Graham G. Stewart, ed. *An Overview of Brewing.* 3rd ed. London: CRC Press, pp. 53-66. 2017.

Einstein, D., Worrell, E. & Khrushch, M., *Steam systems in industry: Energy use and energy efficiency improvement potentials,* California: Lawrence Berkeley National Laboratory. 2001.

Galitsky, C., Martin, N., Worrell, E. & Lehman, B., *Energy Efficiency Improvement and Cost Saving Opportunities for Breweries,* Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory. 2003.

Gendre, I.,. *What are Scopes 1, 2 and 3 Emissions?,* s.l.: Greenly Institute. 2023

Githuka, C. M.,. *A Study of Thermal Energy use at brewing plant with emphasis on wort boiling process,* Nairobi: University of Nairobi. 2012

Goldammer, T., *Wort Cooling and Aeration: A Complete Book to Brewing Beer.* 2nd ed. USA: Apex. 2008.

Goldammer, T., *The Brewer's handbook: The Complete Book to Brewing Beer.* 3rd ed. Virginia: Apex Publishers. 2022.

Grand Canyon University, *Doctoral Journey.* 2022. [Online]
Available at: https://www.gcu.edu/blog/doctoral-journey/most-efficient-qualitative-data-collection-methods
[Accessed 13 March 2023].

Green, W., *Combustion Chemistry,* Cambridge: MIT Department of Chemical Engineering. 2014.

Gross, S., *Brookings.* 2020. [Online]
Available at: https://www.brookings.edu/policy2020/bigideas/the-united-states-can-take-climate-change-seriously-while-leading-the-world-in-oil-and-gas-production/#:~:text=Minimizing%20methane%20releases%20is%20one,fuels%20like%20coal%20or%20oil.
[Accessed 4 March 2023].

Guetterman, T. C., *An introduction to mixed methods study design.* University of Michigan, Stellenbosch University,, Primafamed Conference. 2020.

Hancock, J., *Energy minimization, recovery and re-use within the brewhouse.* Midlands, Briggs of Burton. 2018.

IEA,. *Global Energy Review: CO2 Emissions in 2021,* Paris: s.n. 2022

International Finance Corporation World Bank Group, *Environmental, Health, and Safety Guidelines for Breweries,* s.l.: World Bank Group. 2007.

Kline, B., *Beer Filtration and Packaging,* s.l.: The Beer Thrillers. 2020.

Kumar, J.,. An Approach towards Efficient Operation of Boilers. *International Journal of Scientific & Engineering Research,* June, 3(6), pp. 1-11. 2012

Lindsey, R., *Climate Change: Atmospheric Carbon Dioxide.* 2022. [Online]
Available at: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide#:~:text=Without%20carbon%20dioxide%2C%20Earth's%20natural,causing%20global%20temperature%20to%20rise.
[Accessed 18 February 2023].

Linnhoff March,. *Introduction to Pinch Technology,* Northwich, Cheshire: Linnhoff March. 1998

Minitab 20 Support, *Methods and formulas for the S chart in Xbar-S Chart.* [Online] 2021.
Available at: https://support.minitab.com/en-us/minitab/20/help-and-how-to/quality-and-process-improvement/control-charts/how-to/variables-charts-for-subgroups/xbar-s-chart/methods-and-formulas/s-chart/
[Accessed 18 March 2023].

Minitab, *Minitab Blog: Common Assumptions about Data Part 3: Stability and Measurement Systems.* 2016. [Online]
Available at: https://blog.minitab.com/en/quality-business/common-assumptions-about-data-part-3-stability-and-measurement-systems
[Accessed 23 March 2023].

paNOAA National Centers for Environmental Information, *Monthly Global Climate Report for Annual 2021.* [Online]
Available at: https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202113
[Accessed 23 February 2023].

Othman, M., Zakaria, R. & Fernando, W., *CO2 emission and carbon capture for coal fired power plants in Malaysia and Indonesia,* Malaysia: School of Chemical Engineering, Universiti Sains Malaysia. 2008.

Palmer, J., How the Mash works: Mashing defined. In: *How to Brew: Everything You Need to Know to Brew Great Beer Every Time.* Colorado: Brewers Publications A division of of the Brewers Association. 2017.

Paroha, D. S., *Notes on Production of Beer,* Kanpur: National Sugar Institute. 2020.

Rogers, K., *Britannica.* [Online] 2022.
Available at: https://www.britannica.com/topic/beer/Yeast
[Accessed 4 April 2022].

Ryker, C., *Boiler basics 101: Economizers for increased efficiency,* Fremont, California: Nationwide Boiler Incorporated. 2019.

Saidur, R., Energy Savings and Emission Reductions in Industrial Boilers. *Thermal Science,* 15(3), pp. 705-719. 2011.

Sharma, B., 2020. *Liquor Thing.* [Online]
Available at: https://theliquorthing.blogspot.com/2020/05/a-review-on-beer-pasteurization-the-process-and-its-effect-on-quality-of-beer.html
[Accessed 13 April 2022].

Tapville Social, *What four primary ingredients are used to make beer?.* 2018. [Online]
Available at: https://www.tapvillesocial.com/craftbrewu/2018/6/19/what-four-primary-ingredients-are-used-to-make-beer [Accessed 4 April 2022].

Tomescu, M. & Csatlos, C., *Energy saving wort boiling system in brewery factory,* Romania: Henri Coanda Air Force Academy. 2012.

Unit Juggler, *Unit Juggler: Convert everything with ease.* 2013. [Online]
Available at: https://www.unitjuggler.com/convert-energy-from-kgSKE-to-MJ.html [Accessed 3 March 2023].

United Nations Environment Programme, *Emissions Gap Report-Executive Summary,* Nairobi: United Nations Environment Programme (UNEP) and UNEP DTU Partnership (UDP). 2020.

Viktor, D., *Stream Identification in Pinch Analysis: Fixed and Flexible flows,* Sweden: MITTUNIVERSITET, 2018..

Willaert, R. & Baron, G., *Wort Boiling Today – Boiling Systems with Low Thermal Stress in Combination with Volatile Stripping,* Belgium: Hogeschool Gen, Vrije Universiteit Brussel. 2016.

World Health Organisation, 2021. [Online]
Available at: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health [Accessed 11 February 2023].

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