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*Full Length Research Paper*

# Assessment of Energy Efficiency in Beverage Industry

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## ABSTRACT

**The brewery industry has a significant contribution to the national income. However, it is also associated with energy-intensive processes and pollution. In this work, the energy efficiency assessment of the largest brewery in Tanzania i.e., Tanzania Breweries Limited has been conducted. Energy consumption analysis was conducted according to IEEE SA 739-1995. Important parameters used to assess brewery energy efficiency were boiler efficiency and losses, equipment energy productivity as well as load factor. It was found that the main energy consumers are packaging (54.63%), brewing (29.30%) and utilities (15.17%). More importantly, it was found that about 68% of the brewery energy demand is thermal energy which is supplied by the boiler whose efficiency (62%) is significantly lower than the expected value of 94-95%. Load factor analysis showed that the equipment of both brewing and packaging line 4 are significantly oversized. Furthermore, energy productivity of 45.5 kWh/L of beer is significantly higher than the industry minimum of 23.6 kWh/L.**

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## INTRODUCTION

Brewery industries are one of the most economically important sectors in the world with sustained expansions over the years due to increase in consumption (Olajire, 2012, Ortiz et al., 2019). According to the World bank data, alcohol consumption in Tanzania has been increasing since 2002 as shown in Figure 1 below (World-Bank, 2021).

However, the main challenges facing the industry are high energy and water consumption, large waste generation as well as emissions of $CO_2$ to the atmosphere (Scheller et al., 2008). The food and beverage industry is the biggest consumer of energy and causes 67% of the greenhouse gas emissions (Millán et al., 2020). It has been reported that, the major consumers of electricity in breweries are refrigeration (44%), packaging (20%), and compressed air (10%) (Scheller et al., 2008).

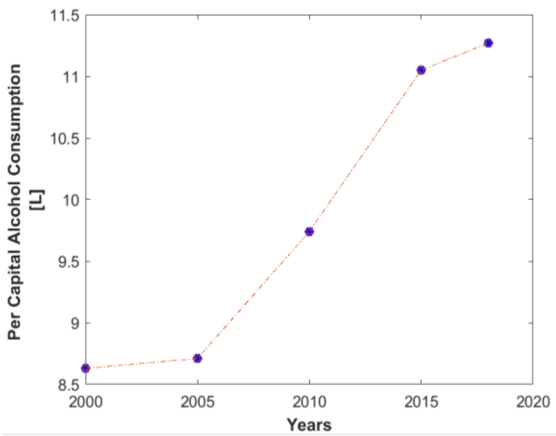


**Figure 1: Per capital Alcohol Consumption in Tanzania (15+ years of age)**

A number of studies have been done to improve energy efficiencies of brewery industry (Stewart, 2006, Muster-Slawitsch et al., 2011). For instance, it has been suggested that a savings of up to 4.7 kWh/hL energy consumption in the Brewhouse can be achieved with proper installation procedures (Scheller et al., 2008).

Potential areas for energy efficiency improvements opportunities for breweries have been identified and well-studied elsewhere (Worrell et al., 2002). There include: Boilers and Steam distribution, Motors and Systems Using Motors, Refrigeration and cooling, Mashing and Lauter Tun, Wort boiling and cooling, Fermentation, Processing, Packaging and other supporting utilities like water treatment and air compressors.

There are limited studies on the energy efficiencies of brewery industry in Tanzania. More importantly little is known about the specific energy demand per production, an important measure of energy productivity. This paper reports on the analysis of energy efficiency opportunities for Tanzania Breweries Limited, which is among the largest brewery in the Eastern African region.

## MATERIALS AND METHODS

### Data Collection

This study used data from Tanzania Breweries Limited in Dar es Salaam. The Information extracted were monthly data of electricity consumption in *kWh*, Diesel and Heavy Fuel Oil usage in *litres*, Natural gas consumption in $kg/m^3$ as well as production volumes in *hectoliters* (hL).

### Data Analysis

For effective identification of energy consumption, loss, saving opportunities and determination of appropriate energy saving measures, this research adopted the following approach;

(i) Process flow identification and analysis of factory energy inflows and outflows

(ii) Assessment of energy consumption patterns by using energy meters' records for each production section.

(iii) Assessment of current employed energy saving measures in each production section of the brewery.

Energy consumption analysis was conducted according to IEEE SA 739-1995 standard (Recommended Practice for Energy Management in Industrial and Commercial Facilities) (IEEE, 1995).

The total energy for each facility was computed by using equation (1), where; thermal energy $E_{th} = C_f W$ is given by calorific value of fuel $C_f$ and Quantity of fuel $W$.

$$E_{tot} = E_{th} + E_{el} \tag{1}$$

The losses due to boiler flue gases was computed by using equation (2), where $m$ is the weight of flue gas in *kg*/*kg* of fuel, $C_p$ is the specific heat of flue gas in *kJ*/*kg*, $T_f$, is the flue gas temperature in $K$, $T_a$ is the ambient temperature in $^oC$ and $GCV$ Gross calorific value of the fuel used in boilers in *kJ*/*kg*.

$$L_f = \frac{mC_p(T_f - T_a)}{GCV} \times 100 \tag{2}$$

The radiation and convection losses from the boiler were estimated from equation (3), where; $V_m$ is the wind speed in m/s,

$$L_r = 0.548\left\{\left(\frac{T_s}{55.55}\right)^4 - \left(\frac{T_a}{55.55}\right)^4\right\} + \\ +1.957(T_s - T_a)^{1.25}\sqrt{\left(\frac{196.85V_m + 68.9}{68.9}\right)} \tag{3}$$

Boiler efficiency was then calculated according to equation (4) (Vakkilainen, 2017), where $Q_{abs}$ is the useful heat absorbed (heat transferred to steam), $Q_{in}$ is the heat and energy input into the boiler, $Q$ is the quantity of steam generated in *kg*, $q$ is the quantity of fuel used in *kg* and $H$ and $h$ are the enthalpies of steam and boiler feed water in *kJ*/*kg*.

$$\eta = \frac{Q_{abs}}{Q_{in}} = \frac{Q \times (H - h)}{q \times GCV} \times 100 \tag{4}$$

Thermal and electrical energy consumption of all other sections of the brewery were estimated from the steam supply data (i.e., mass flow rate, Temperature and pressure) and electricity meter data.

Load factor is the useful indicator for establishing whether the high energy consumption is associated with equipment oversizing. Load factor for all main electrical equipment in the factory was determined using equation (5) below (Hasanbeigi and Price, 2010, Ullah et al., 2021).

$$L.f. = \frac{kWh \text{ used in a period}}{Peak\ kW \times 24\ hrs \times \text{Number of days in a period}} \times 100 \quad (5)$$

## RESULTS AND DISCUSSION

### Energy Consumption

Figure 2 below shows the annual average energy consumption from all sources used by the plant. Note that all values have been converted to *MJ* for convenience of presentation. The respective equivalent values in original units are shown at the top of each bar chat.

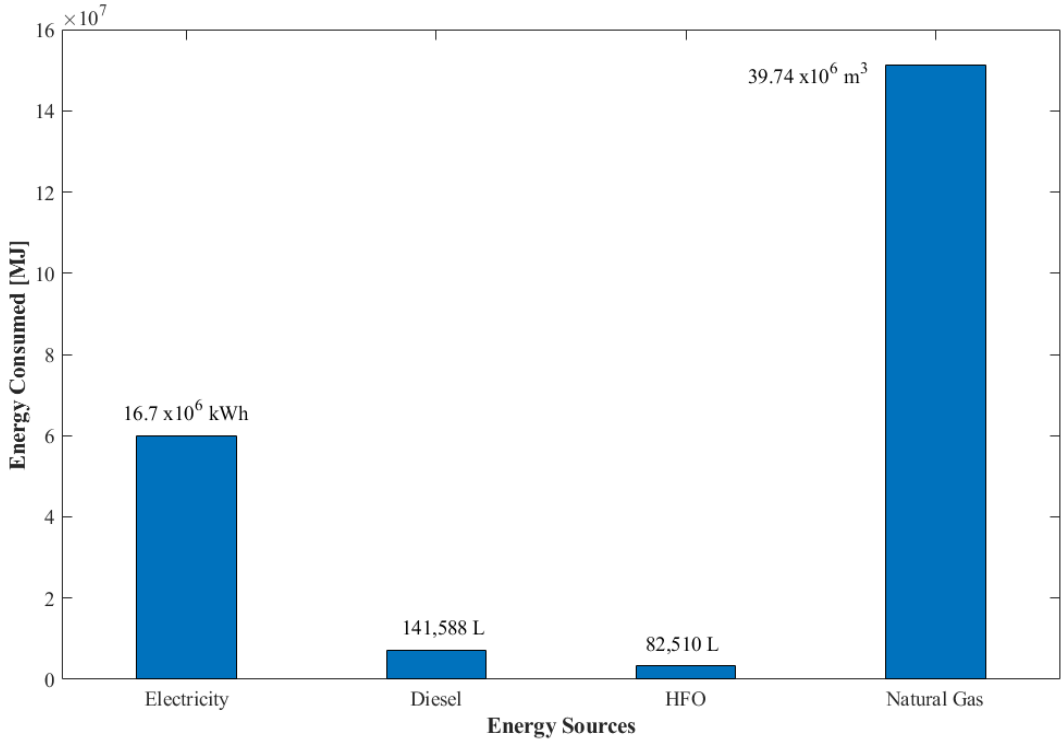


**Figure 2: Annual Average Energy Consumption at TBL Dar es Salaam brewery.**

It can be seen that heavy fuel oil energy expended was found to be the lowest at 1.5 % for the five years period of study. This was followed by diesel at about 3.2 % and electricity from TANESCO at 27.1%. At 68.2% of the total source of energy consumed, natural gas was found to account for more than half of the energy supply as it was used as the main fuel for steam boilers. The total annual average energy consumption from all sources was found to be 221.6 x $10^6$ MJ.

### Energy Flows in the Brewery

The energy consumption across all the sections of the brewery as well as energy losses at the boiler were calculated using the methodology presented in materials and methods section above.

Table **1** below shows the amount of both electrical and thermal energy consumed annually by each section of the brewery. The main sections are responsible for about 99 % of the total energy consumption, of which Packaging section account for 54.63 %, followed by Brewing (29.3 %) and utilities (15%).

**Table 1:** Annual Electricity and Thermal Energy Consumption at TBL Dar es Salaam brewery

| | Electrical Energy $\times 10^6$ (MJ) | Thermal Energy $\times 10^6$ (MJ) | Section Total Energy $\times 10^6$ (MJ) | Consumption (%) |
|---|---|---|---|---|
| **Main Sections** | | | | |
| Brewing | 18.14 | 37 | 55 | 29.30 |
| Packaging | 12.17 | 91 | 103 | 54.63 |
| Utilities | 29.66 | - | 30 | 15.70 |
| **Other Sections** | | | | |
| Yeast Drying | - | 0.07 | 0.07 | 0.04 |
| Workshop | 0.13 | - | 0.13 | 0.07 |
| Canteen and Offices | - | 0.51 | 0.51 | 0.27 |
| **Total Energy** | **60.61** | **128** | **188.97** | **100.00** |

The breakdown of energy consumption of both Packaging and Utilities sections are shown in **Error! Reference source not found.** and Table 3 below respectively. It can be seen that the refrigeration utility unit account for more than half (58.27 %) of the annual utility electricity consumption. The least energy consuming categories are office and plant lights as well as air conditioning, which in total they account for less than 5% of the brewery electricity consumption. Based on the energy flow analysis and the plant layout, the energy flow diagram of the brewery was finally developed as shown in **Error! Reference source not found.** below. It was notes that, the brewery has better performance in sections with major electricity consumption. The refrigeration, packaging and compressed air sections account for 28.5, 20 and 5.8% of electricity consumption respectively. These values are better than the global industry averages of 44% for refrigeration, 20% for packaging and 10% for compressed air (Scheller et al., 2008).

**Table 2:** Annual Electricity and Thermal Energy Consumption of Packaging Section

| Subsection | Electrical Energy x $10^6$ (MJ) | Thermal Energy x $10^6$ (MJ) | Subsection Total Energy x $10^6$ (MJ) |
|---|---|---|---|
| Packaging L4 | 6.95 | 52.01 | 58.95 |
| Packaging L5 | 3.53 | 26.45 | 29.99 |
| Packaging L6 | 0.43 | 3.25 | 3.68 |
| Packaging L7 | 1.25 | 9.36 | 10.61 |
| **Total Energy** | **12.17** | **91.06** | **103.23** |

**Table 3:** Annual Electricity and Thermal Energy Consumption of Utilities Section

| Utility | Electrical Energy x $10^6$ (MJ) | Consumption (%) |
|---|---|---|
| CO2 plant | 1.05 | 3.55 |
| Effluent treatment | 2.23 | 7.51 |

| | | |
|---|---|---|
| Air compressors | 3.55 | 11.97 |
| Refrigeration | 17.29 | 58.27 |
| Water treatment | 3.56 | 12.01 |
| Steam Boiler | 0.80 | 2.69 |
| Lighting | 0.62 | 2.09 |
| Air Conditioners | 0.57 | 1.91 |
| **Total Energy** | **29.66** | **100** |

## Boiler Energy Consumption

From the energy flow diagram in **Error! Reference source not found.** above, boiler consumes about 154.4 MJ (69%) of the total primary energy supply. This makes the boiler a significant priority equipment inters of energy efficiency improvement. The available data suggests while the monthly maximum value of efficiency recorded was 81 % in May 2012 (**Error! Reference source not found.**), is value relatively lower than the expected efficiency values of industrial natural gas fired boilers of 94-95 % (Vakkilainen, 2017). Moreover, the annual mean efficiency is about 62% as shown in Figure 4. This indicates that boiler efficiency has been decreasing over the years.

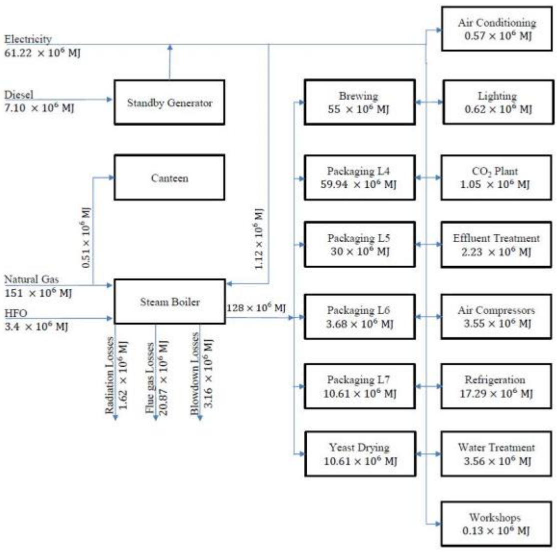


**Figure 3: Energy flow diagram**

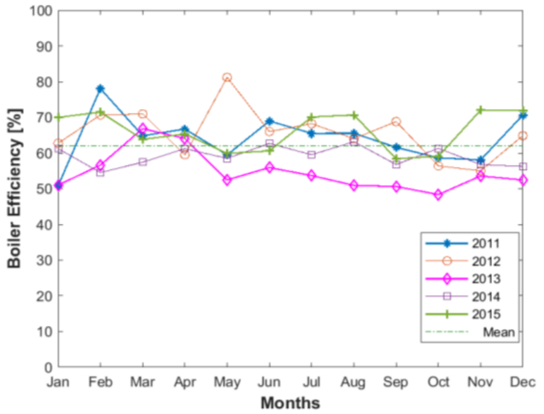


**Figure 3: Monthly Variation of Boiler Efficiency.**

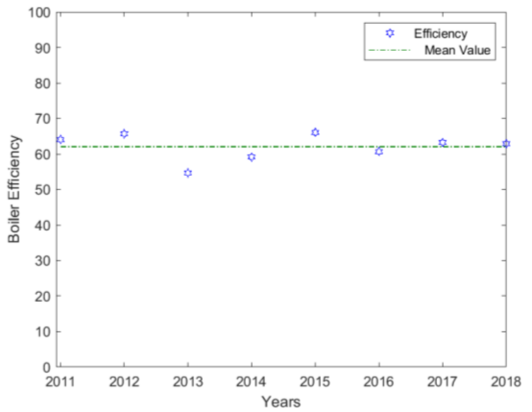


**Figure 4: Annual Variation of Boiler Efficiency.**

## Energy Productivity of Production Sections

In order to understand the effectiveness and productivity of the brewery from the energy point view it is important to establish the level of energy productivity. This indicator has significant implication in both energy use and profitability as it measures the energy consumption per unit of production output. Figure 5 below shows the energy productivity of the brewery and the main three production sections, namely Brewing, Packaging and Utilities. Utilities section is least performing as it has the highest energy productivity 6 kWh/hL, followed by the brewing section at 3.7 kWh/hL and the best performing is the packaging section at 2.5 kWh/hL. When the entire brewery is considered, production of 1 hectoliter of beer requires approximately 45.5kWh/hL (163.74MJ/hL), which is significantly higher than the expected industry minimum value of 23.6 – 33.3 kWh/hL (85 – 120 MJ/hL) (Conduah et al., 2019, Kubule et al., 2016). These observations suggest that there is still opportunity for energy efficiency improvement of the brewery.

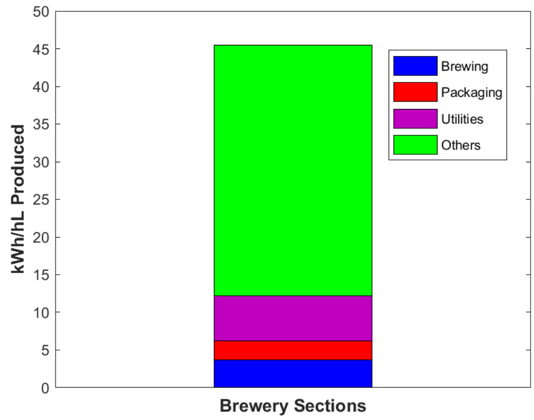


**Figure 5: Energy Productivity of the Brewery.**

### Equipment loading factor

Load factor is the useful indicator for establishing whether the high energy consumption is associated with equipment oversizing.

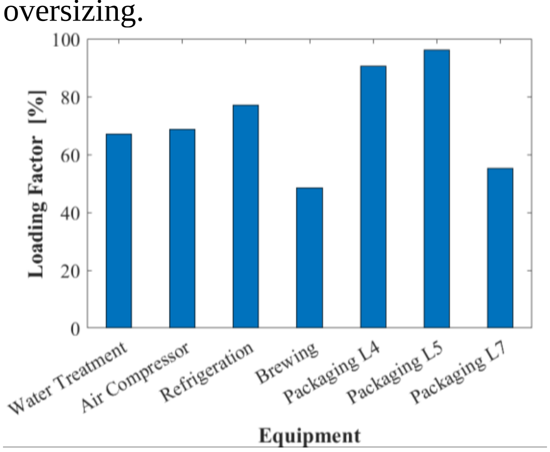


Figure *6* shows the loading factors for the main equipment of the brewery. The calculated loading factors are in the range of 48-96 %. Since values above 70 % are considered to be acceptable (Sen, 2010), the refrigeration, line L4 as well as line 5 equipment with values of 77 % and 90 % and 96 % respectively are considered have acceptable loading values. On the other hand, the equipment of both brewing and packaging line 4 are significantly oversized. These observations might be indication of inefficiency in energy consumption.

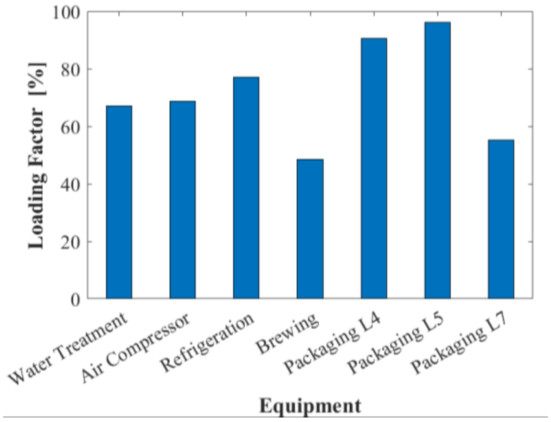


**Figure 6: Loading Factors of the Brewery Main Equipment.**

## CONCLUSION

In this study energy analysis of a brewery industry has been conducted. As expected, it has been established that, the production sections are the main consumers accounting for about 99 % of energy consumed. Of which, 54.63 % is only by packaging due to high thermal energy demands. The second consumer in the production section is Brewing, also due to high thermal energy demands. Since the main source of thermal energy is the steam boiler, further analysis revealed that the boiler operated below the rated efficiency and thus steam generation offers the opportunity for energy efficiency improvement. It has also been established that most of the electricity is consumed by the utility section, of which the refrigeration section accounts for more than half of the total consumption. This observation was consistent with the reports from the literature. Lighting was found to have less significant contribution to total energy consumption mainly because of the recently induced efficient lights throughout the brewery. Furthermore, energy efficiency can be improved by optimizing the load factors of brewing and packaging sections.

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