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Comparative Analysis of Specific Energy Consumption and Energy Consumption Benchmarking in Galvanising Plants

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Abstract

The inadequacy of sustainable energy is endlessly posing major challenges globally. The issue of energy optimisation is indispensable for manufacturing sector, particularly for a hot-dip galvanising process where galvanising furnaces are the significant energy users. This study is aimed at comparative analysis of specific energy consumption and energy consumption benchmarking in four galvanising plants with the view to necessitate the identification of best practices. Energy baselines were used as quantitative reference points to compare energy performance indicators and quantify fluctuations in energy performance during the baseline and reporting periods. A quantitative analysis was also conducted to benchmark four galvanising facilities on factors that included the electricity/zinc ratio, electricity /dips ratio and product tonnage/zinc used ratio. The results revealed improved performance for plant 4 over time relative to the baseline consumption when compared to plants 1, 2 and 3. Plant 4 also outperformed other facilities after the energy efficiency interventions in terms of electricity/zinc ratio and electricity/ product tonnage ratio. Given the disparity between the results of specific energy consumption (SEC) for the four plants, it was concluded that SEC alone should not be used as an energy performance indicator.

Keywords
Energy performance indicator; Energy efficiency.

1. Introduction
Manufacturing plants are currently regarded as significant contributors to overall carbon gas emissions due to high-energy usage (Sibanda and Ndlela, 2020). By definition, the carbon footprint is a measure of the environmental impact of human lifestyles and processes (Pandey, Agrawal and Pandey, 2011). Quantitatively, it is a metric measurement indicative of the amount of carbon dioxide and other gases that are emitted to the environment. The accumulative effect of carbon dioxide results in the "greenhouse effect", which is the capacity of all these gases to heat insulate the earth's surface thus resulting in the latter's temperatures gradually rising (Kweku et al., 2017). It is noted that promoting energy efficiencies in manufacturing industries will generally reduce both the carbon footprint as well as operational costs. Hot-dip galvanising is a process of coating steel products through immersion into a bath of molten zinc (Bordignon and Eynde, 2007). When considering components and fabrications that should be used with zero or minimum maintenance for extended periods, hot-dip galvanising becomes an adequate cost-effective protection system (Hornsby, 1995). The issue of energy optimisation is indispensable for manufacturing sector, particularly for a hot-dip galvanising process. Galvanising steel or iron is the product for about half of the zinc produced worldwide (Blake and Beck, 2004). The cited galvanising sector was found to be devoid of methodologies for the establishment and documentation of energy baselines for improving their energy performance for hot-dip galvanising process, which adversely impinges on tractability in the analysis of energy consumption. The outlying challenge faced in computing the energy consumption benchmark for the galvanising plants lied in the fact that even plants that are processing the same raw materials have variable equipment sizes and throughputs. Hence, the aim of the study was to develop energy performance indicators for galvanising plants.

2. Literature Review
It is vital to comprehend that energy performance indicators are critical for provision of the pertinent information on energy performance, which is a key enabler for development of energy-saving initiatives by a galvaniser. This section focuses on the literature survey on energy consumption baselines, energy performance indicators, specific energy consumption, and energy consumption benchmarking.

Many industries are facing challenges regarding the issue of developing methodologies for the establishment and documentation of energy baselines, which is crucial for energy performance improvements (Solutions, 2013). The process encompasses defining system boundaries, identifying energy sources, defining baseline timeframe, relevant variable definition, followed by determination and calculation of energy performance indicators, and finally addressing baseline adjustments. The energy consumption baseline establishes the "before" energy scenario through the capture of the total energy that is used by a system before implementing energy efficiency initiatives (Reichl and Kollmann, 2011).

The International Performance Measurement and Verification Protocol (IPMVP) is an international reference for measurement and verification (M&V) of energy savings that are derived from energy efficiency projects and energy cost reduction highlights the determination of baseline consumption as a crucial factor measurement and verification of savings (Cowan, 2002). Valencia-Ochoa, Ramos and Meriño (2017) conducted a study on the application of energy planning to reduce the consumption of gas for a hot-dip galvanising process basing on ISO 50001 standards. Gas consumption, level of production, and time were the three variables that were considered from real data to obtain energy performance indicators that included baseline and goal line, consumption ratio concerning production level, and cumulative sum. The implementation of this method realised energy saving potentials, reduced greenhouse gas emissions as well as reduced operational costs for the plant.

An energy baseline, according to ISO 50001:2011, is a quantifiable energy consumption reference that can be exploited for comparing energy performance indicators and quantifying variations in energy performance (da Silva Gonçalves and dos Santos, 2019). Artificial neural networks can be deployed to determine baseline consumption and post-retrofit energy consumption and production system can be recreated to reflect the configuration prior to energy-efficiency initiatives (Rossi and Velázquez, 2014). Energy Performance Indicators (EnPIs) are quantifiable measures of a facility's energy performance that are utilised in the determination of improvements in energy consumption, energy usage, and energy efficiency, and thus would reveal the effectiveness of management efforts in energy efficiency (da Silva Gonçalves and dos Santos, 2019). The main types of EnPIs comprise measured energy value, cumulative sum and ratio. Annualised consumption is an example of measured energy value, however it is characterised by misleading results, does not measure energy efficiency, and relevant drivers or variables are not captured. On the other hand, the ratio EnPIs such as SEC do not take non-linear effects and baseload into account and are characterised by misleading results as well (Valencia-Ochoa et al. 2017).
SEC is a measure of the quantity of primary energy that is expended to produce a single unit of product (Ang and Zhang, 2000). The magnitude of energy-consuming equipment, average energy consumed, and the production quantity for a facility are used for the calculation of SEC (Palamutçu, 2015). As a ratio EnPI in energy consumption benchmarking, SEC can be used as an indicator for energy efficiency improvements in processes. The monitoring of specific energy consumption for a galvanising process is important, given the increasing environmental concerns and intense global market competition that characterise the sector (Moors et al., 2005). Considering the growing importance of monitoring the improvements in industrial energy efficiency and the mounting popularity of SEC as a key performance indicator for energy monitoring, there has been a upward interest in conducting research to comprehend the benefits and limitations of using SEC (Lawrence et al. 2019).
Energy consumption benchmarking a technique of collecting and analysing the data on energy performance of analogous entities, and then evaluate and compare the performance between the entities (Saygin et al. 2011). It is an energy consumption indicator that is dependent on the nature of the raw materials, process and output (Worrell and Price 2006). Energy consumption benchmarking can be used to compare the energy performance of several facilities within the same industrial sector, comparison of the fluctuating energy performance of one plant at different periods, striving to enhance energy performance (Ke et al. 2013). Saygin et al. (2011) posited that improved energy efficiency is one of the key measures that is used to abate CO_2 emissions in the industry. Energy benchmark curves were plotted for individual plants to offer a basis for estimating sectoral energy efficiency improvement potentials compared to current global best practice technology. Best practice technology data was compared with current energy use to estimate the energy efficiency improvement potentials. The results demonstrated that best practice technology offers improvement potentials worldwide.

3. Methodology
The research approach embraced determining and calculating energy performance indicators and SEC was adopted. The first step embraced collection of electricity consumption data and production data on product tonnage, the amount of zinc used and number of dips per month were collected from the companies' databases. Energy baselines were used as quantitative reference points to compare energy performance indicators and quantify fluctuations in

energy performance during the baseline and reporting periods. A quantitative analysis was also conducted to benchmark four galvanising facilities on factors that included the electricity/zinc ratio, electricity /dips ratio and product tonnage/zinc used ratio. The second step in the development process for energy performance indicators was establishing whether baseline adjustments should be done. Many organisations are characterised by changes such as operational change, energy source changes, business change, or energy management system change. It was established that there was no need for baseline adjustments. However, regardless of whether there were changes to the operation, it was imperative that the galvanisers define intervals at which they would review the main aspects of their operations that influence energy performance.

4. Results

The specific energy consumption EnPI was vital for ensuring that pertinent information on energy performance was provided so that the galvanisers would be able to appreciate their energy performance and develop interventions to save energy. Energy consumption benchmarking was also done as analyses energy performance data of comparable activities to evaluate and compare performance between the four galvanising plants.

4.1 Specific Energy Consumption

4.1.1 Specific energy Consumption for Plant 1

Figure 1 shows a comparative schematic for specific energy consumption per tonne of zinc used for the baseline and reporting periods. Concerning the baseline period, the galvaniser failed to realise a target of 5 kWh per tonne for the first 10 months, but it achieved in November and December.

It was established that the level of production affects the specific energy consumption. The addition of production data to the SEC chart would therefore aid to explain the trends on the SEC chart. For instance, a very low SEC would be anticipated if the level of production is low as a result of baseload or fixed energy consumption (energy consumption that happens regardless of production levels). Figure 1 depicts the relationship between SEC and the amount of zinc used (Production).

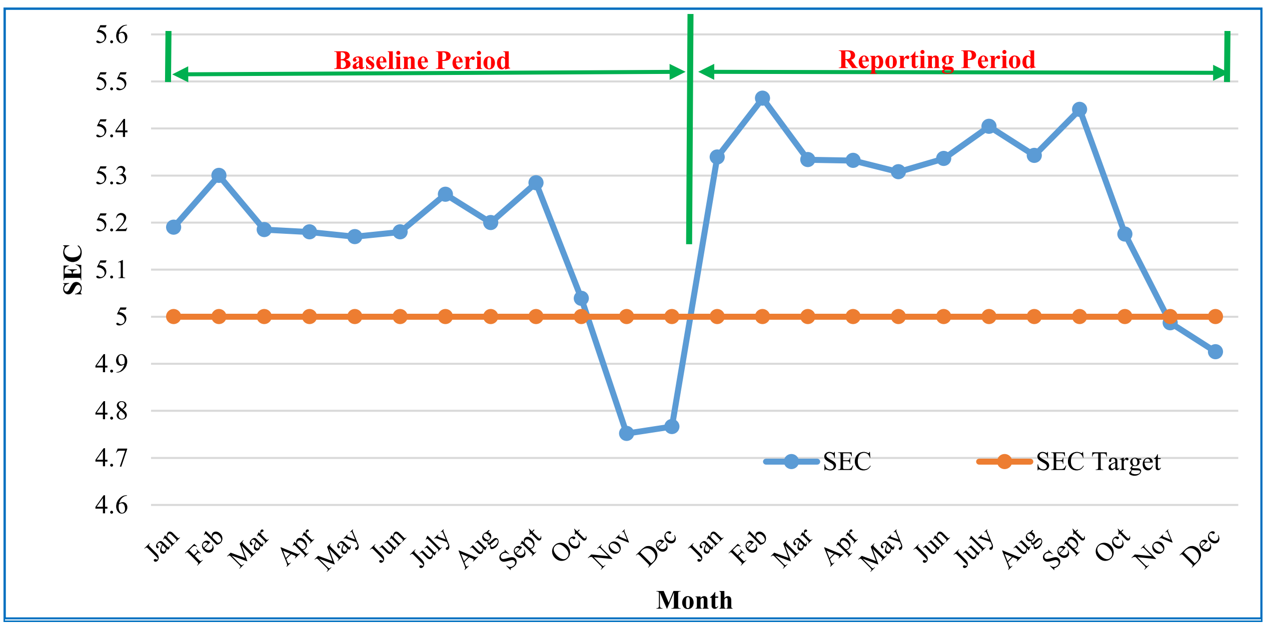

Figure 1. Monthly SEC per tonne of zinc used for Plant 1

Figure 2 reveals that the specific energy consumption per tonne of zinc used for the reporting period has generally increased when compared to the SEC for the baseline period. There was generally no substantial increase in the amount of zinc used between the baseline and reporting period. Since the data fit between SEC and the amount of zinc used is poor, yet there should be a relationship, the scenario of Plant 1 indicates a poor level of control and hence greater potential for energy savings.

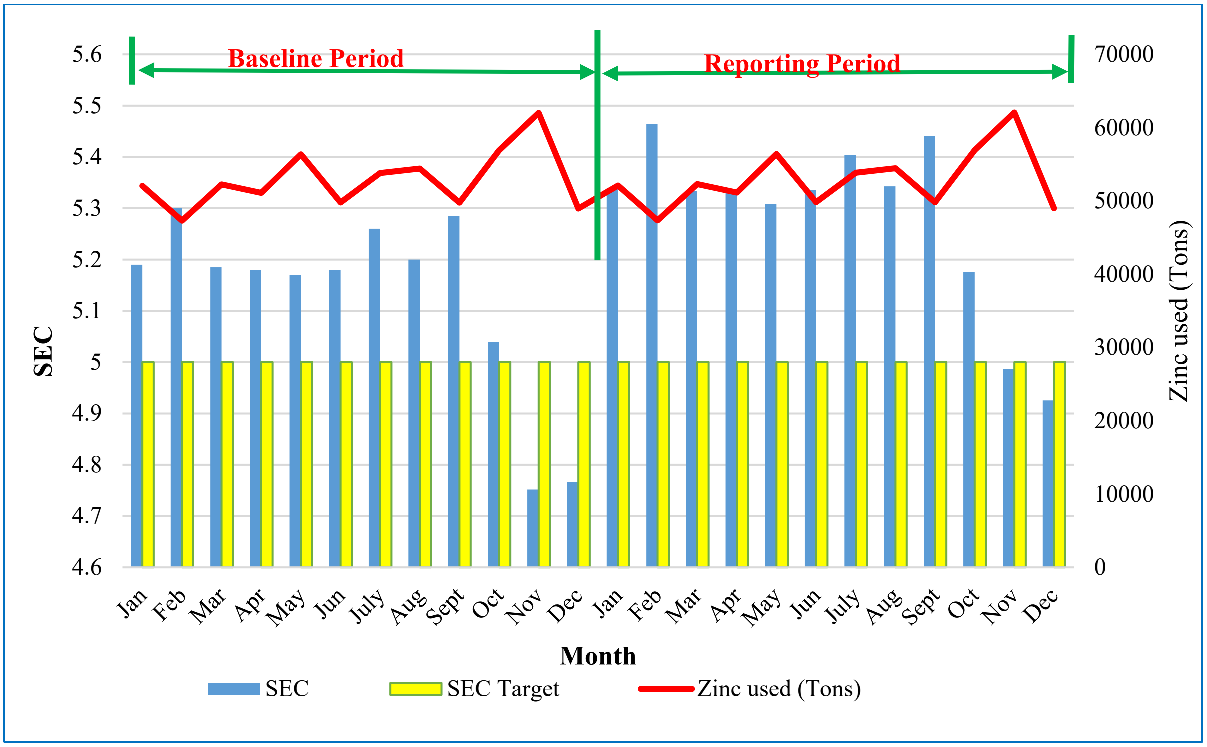

Figure 2. SEC with Production (Zinc used) for Plant 1

4.1.2 Specific Energy Consumption for Plant 2

Figure 3 shows a comparative schematic for specific energy consumption per tonne of zinc used for the baseline and reporting periods for Plant 2. The baseline and reporting periods were benchmarked against a set target of 5 kWh. The galvaniser failed to achieve the target for the months from January to October during the baseline period, but it achieved in November and December. On the other hand, the galvaniser failed to achieve the target for the months from January to August during the reporting period but achieved from September to December.

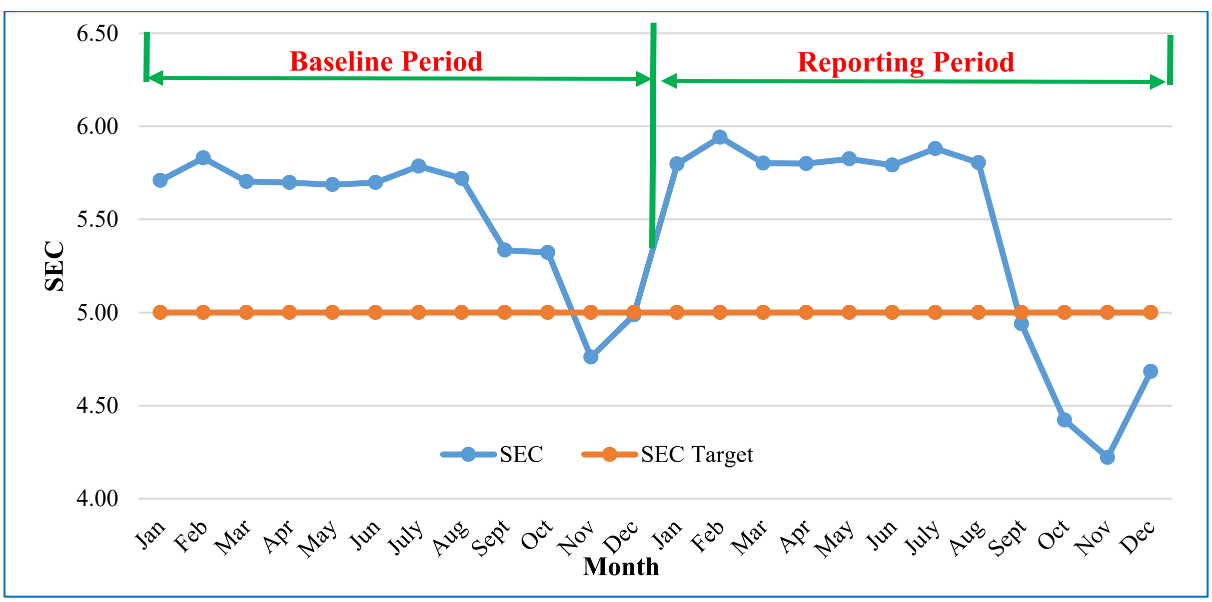

Figure 3. Monthly SEC per tonne of zinc used for Plant 2

Figure 4 also reveals that the specific energy consumption per to.nne of zinc used for the reporting period has generally increased when compared to the SEC for the baseline period. This is attributed to a poor level of control such as attending to reworks on cracks, damaged areas, and dross removal which is conducted on a timed basis, yet drossing frequency should be dependent upon tonnage galvanized.

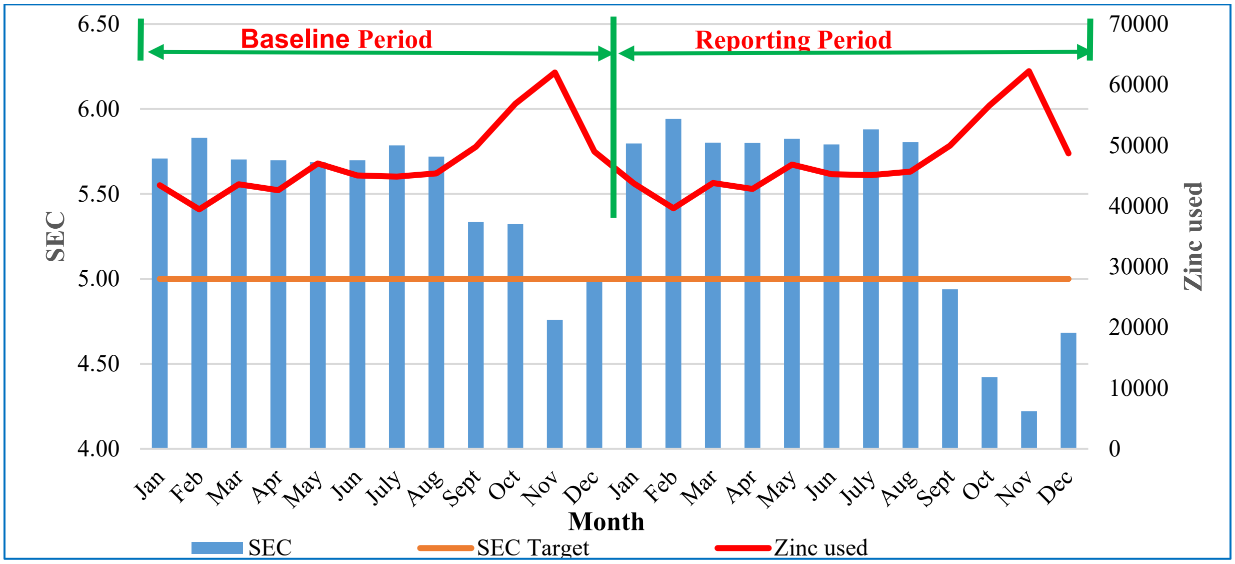

Figure 4. SEC with Production (Zinc used) for Plant 2

The addition of production data to the SEC chart would aid to explain the trends on the graph since it was established that the level of production affects the specific energy consumption. It was revealed from Figure 4 that as the level of production increased the SEC generally decreased, as noted especially in November for both the baseline and reporting periods for Plant 2.

4.1.3 Specific Energy Consumption for Plant 3

Figure 5 shows a comparative schematic for specific energy consumption per tonne of zinc used for the baseline and reporting periods.

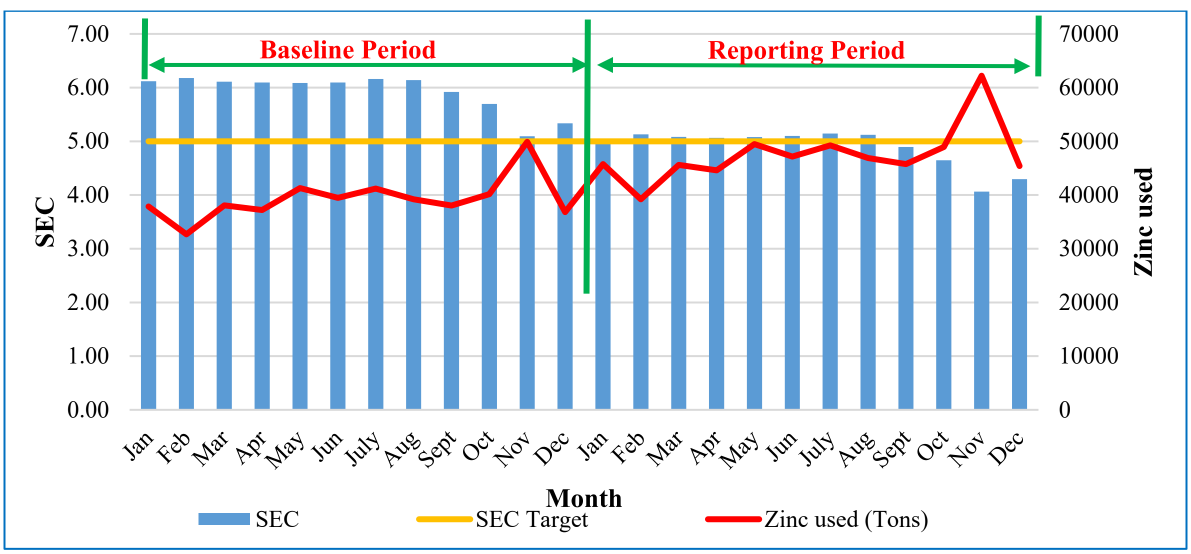

Figure 5. SEC with Production (Zinc used) for Plant 3

4.1.4 Specific Energy Consumption for Plant 4

It was established that galvanising tanks are the largest SEU followed by degreasing and pickling tanks, while the flux tanks consume slightly less energy followed by the cranes which are the fifth SEUs for Plant 4. Figure 6 shows a comparative schematic for specific energy consumption per tonne of zinc used for the baseline and reporting periods. The baseline and reporting periods were benchmarked against a set target of 5 kWh. Similar to Plant 3, the galvaniser failed to achieve the target for all the months during the baseline period. On the other hand, due to energy efficiency interventions during the reporting period, the galvaniser's energy performance improved it managed to achieve the target from May to December of the reporting period.

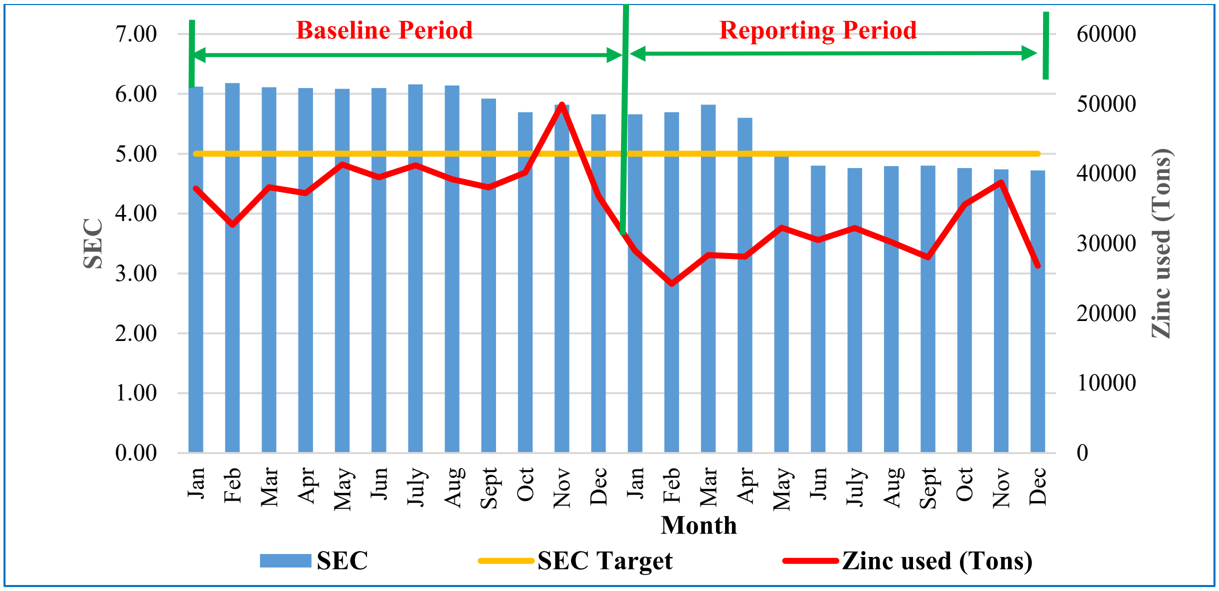

Figure 6. SEC with Production (Zinc used) for Plant 4

Production data was added to the SEC chart to establish the effect of the level of production on the specific energy consumption. The results from Figure 6 show that the level of production during the reporting period is lower than the production level during the baseline period, and the SEC also decreased during the reporting period.

4.2 Energy Consumption Benchmarking

Energy consumption benchmarking was also done as analyses energy performance data of comparable activities to evaluate and compare performance between the four galvanising plants. The essence of energy consumption benchmarking was to increase general awareness of energy efficiency among the galvanisers and necessitate the identification of best practices. The following measures were used to compare the four galvanising facilities prior to any energy efficiency interventions:

- Electricity/zinc ratio
- Electricity /dips ratio
- Product tonnage/zinc used ratio

Box-and-whisker plots were used as an exploratory graphic to exhibit the distribution of electricity to zinc ratio, electricity to dips ratio and product tonnage to zinc used ratio, explicitly showing the centre, spread and overall range of the distributions.

4.2.1 Electricity - Zinc Ratios

Figure 7 shows a box and whiskers plot for electricity/zinc ratios for the four plants before energy efficiency interventions. The results for all four plants demonstrate that the median is closer to the top of the box, revealing that the distribution is negatively skewed (skewed left). Some outliers were noted for Plant 1 and Plant 3.

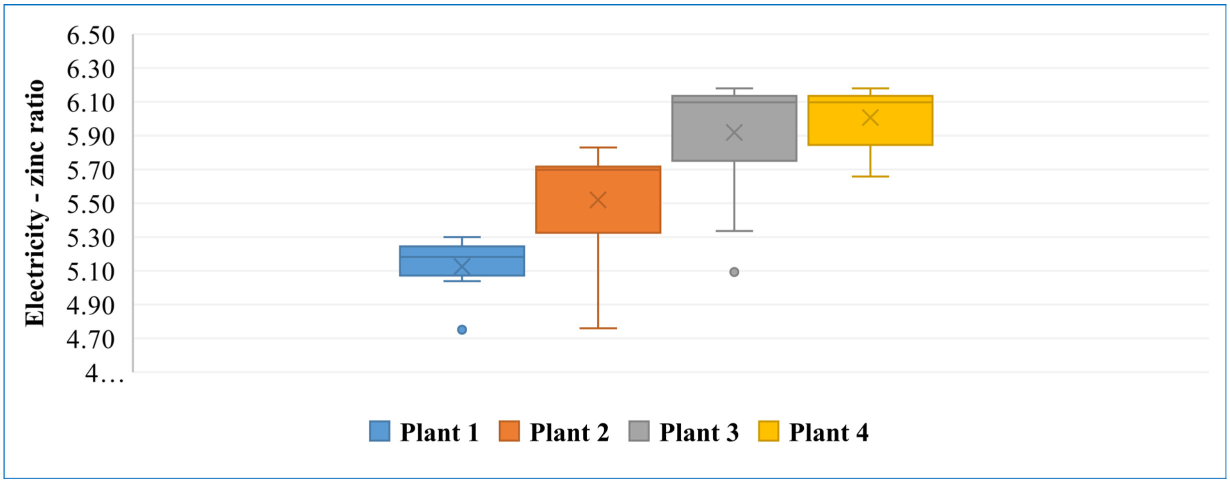

Figure 7. Box and whiskers for electricity/zinc ratio before interventions

The comparison of the respective medians of box plots revealed that the median line of a box plot for Plant 1 lies outside of the box of a comparison box plot for Plant 2, an indication that there is likely to be a difference between the two groups. Significant differences were also noted between Plant 2 and Plant 3. However, the comparison of the respective medians of box plots revealed that the median line of a box plot for Plant 3 lies inside of the box of a comparison box plot for Plant 4, an indication that there is likely to be no difference between the two groups. Comparison of the interquartile ranges and whiskers of box plots (box lengths) was also done to examine how the data is dispersed between each plant sample data. The results from Figure 7 shows longer boxes for Plant 2 and 3, an indication that the data is more dispersed. The data for Plant 1 revealed less dispersion, while the dispersion for Plant 3 was medium.
Figure 8 shows the box and whiskers plot for the electricity/zinc ratio after the energy efficiency interventions. The results demonstrate a major improvement in energy performance by Plant 3, a marginal increase for Plant 4, and no improvement for Plant 1 and Plant 2.

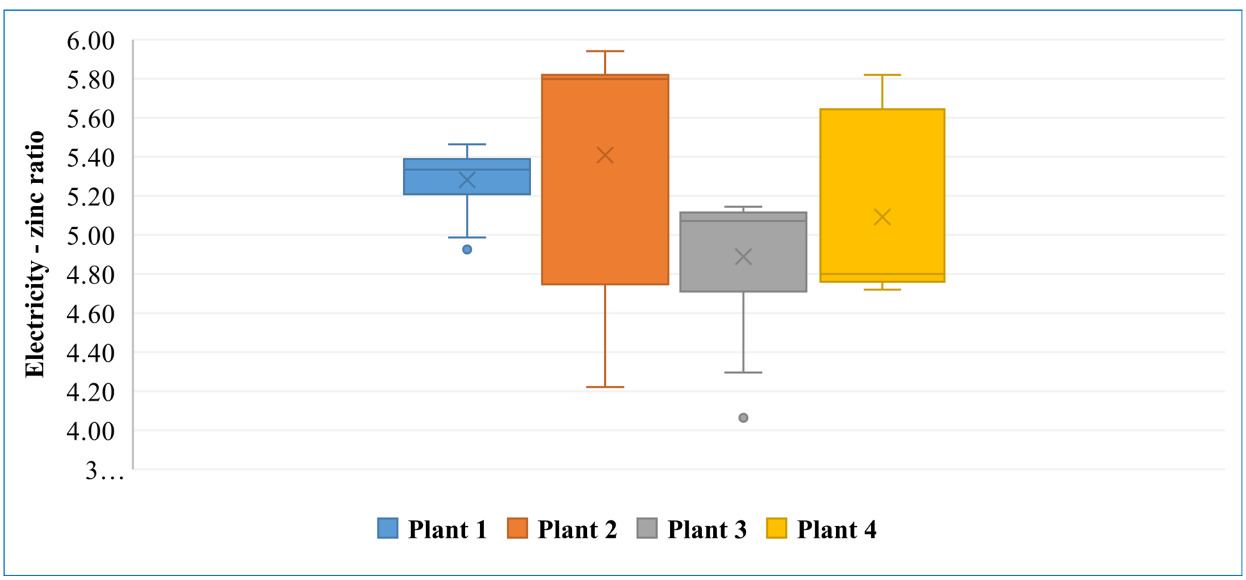

Figure 8. Box and whiskers plot for electricity/zinc ratio after interventions

4.2.2 Electricity - Dips ratio

It was also vital to investigate the relationship between the amount of electricity used and the number of dips for each of the plants since the number of dips would generally influence the frequency of covering and uncovering the process tanks to abate heat loss. Figure 9 shows a box and whiskers plot for electricity/dips ratios for the four plants before energy efficiency interventions. The results for Plant 1 and Plant 4 demonstrate that the median is closer to the centre of the box, revealing that the distribution is symmetrical, while the median for Plant 2 and Plant 3 is closer to the bottom of the box, an indication that the distribution is positively skewed. Some outliers were noted for Plant 2 and Plant 3.

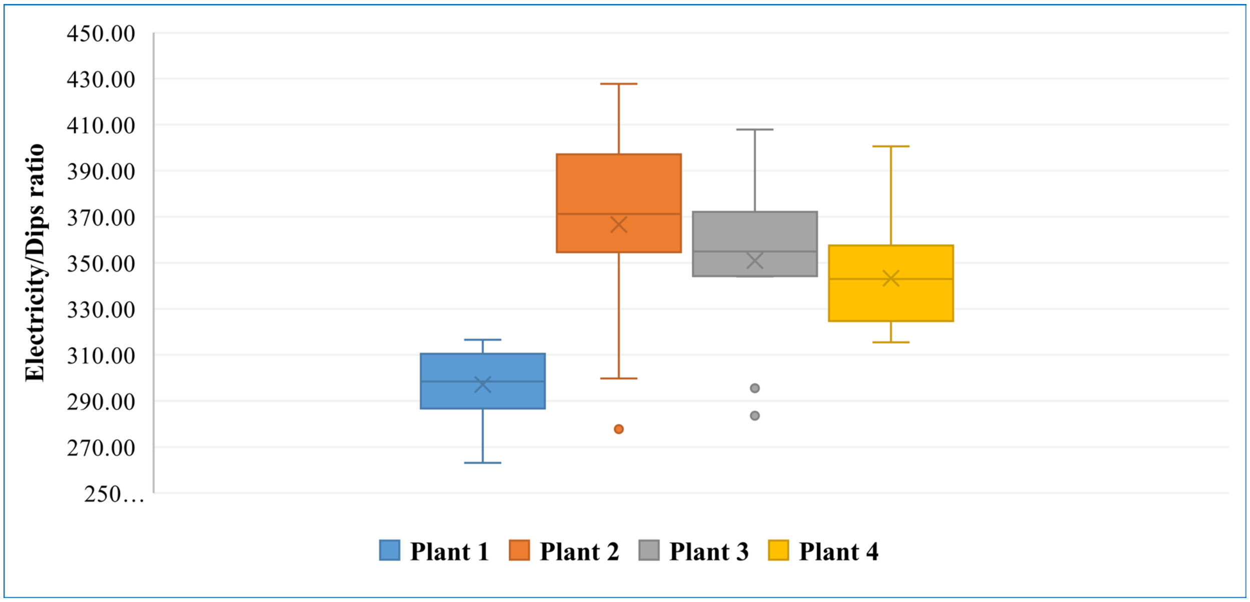

Figure 9. Box and Whiskers plot for Electricity/Dips ratio

The comparison of the respective medians of box plots revealed that the median line of a box plot for Plant 1 lies outside of the box of a comparison box plot for Plant 2, an indication that there is likely to be a difference between the two groups. Significant differences were also noted between Plant 2 and Plant 3 and between Plant 3 and Plant 4. Comparison of the interquartile ranges and whiskers of box plots was also done to examine how the data is dispersed between each plant sample data. The results from Figure 9 shows longer boxes for Plant 2 and 4, an indication that the data is more dispersed. The data for Plant 1 revealed less dispersion, while the dispersion for Plant 3 was medium.

4.2.3 Electricity - Product Tonnage Ratio

It was also vital to investigate the relationship between the amount of electricity used and the product tonnage for each of the plants since it is long-standing galvanising industry practice to charge hot-dip galvanised products based on 'white weight', which is the weight of the steel after it has been galvanised. The material in hot-dip galvanising is moved throughout the facility by overhead cranes and lowered into the surface preparation and galvanising baths. Considering the case-in-point galvanisers, hot-dip galvanised products are usually priced in rands per tonne of galvanized steel.

Figure 10 shows a box and whiskers plot for electricity/product tonnage ratios (kWh/tonne) for the four plants before energy efficiency interventions. The results for Plant 3 and Plant 4 demonstrate that the median is closer to the centre of the box, revealing that the distribution is symmetrical, while the median for Plant 1 is closer to the bottom of the box, an indication that the distribution is positively skewed. The median for Plant 3 is closer to the top of the box, an indication that the distribution is negatively skewed. Some outliers were noted for Plant 2, Plant 3 and Plant 4. The comparison of the respective medians of box plots revealed that the median line of a box plot for Plant 1 lies outside of the box of a comparison box plot for Plant 2, an indication that there is likely to be a difference between the two groups.

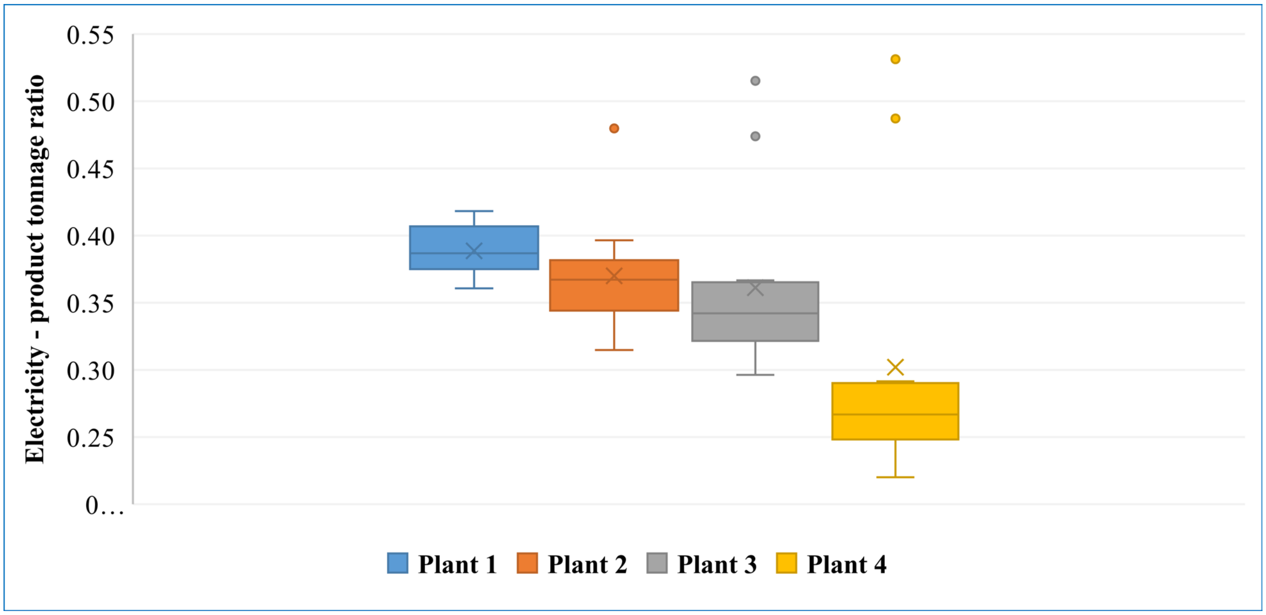

Figure 10. Box and Whiskers plot for Electricity - Product tonnage ratio

Significant differences were also noted between Plant 2 and Plant 3 and between Plant 3 and Plant 4 (Figure 11). Comparison of the interquartile ranges and whiskers of box plots was also done to examine how the data is dispersed between each plant sample data. The results from Figure 10 show boxes of medium length for Plant 2, Plant 3 and Plant 4, an indication that the data is moderately dispersed, while the data for Plant 1 revealed less dispersion. Some outliers were noted for Plant 2, Plant 3 and Plant 4. A clustered column chart can display more than one data series in clustered vertical columns, allowing direct comparison of multiple data series per category and can also show change over time.

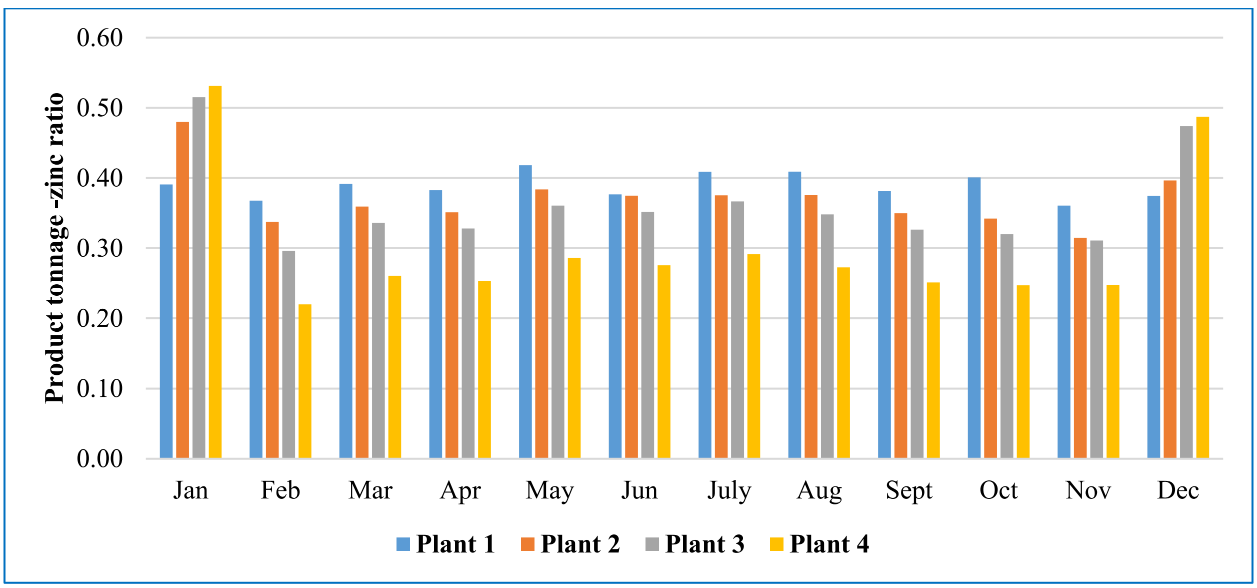

Figure 11. Clustered chart for electricity - product tonnage ratio

Figure 11 shows a clustered chart for the electricity/product tonnage (kWh/tonne) ratio for the four plants before energy efficiency interventions. The results show an increase in the electricity/product tonnage ratio from Plant 1 to Plant 4 for January and December. A decrease in electricity/product tonnage ratio from Plant 1 to Plant 4 was noted from February to November during the baseline period. The variation was noted as a result of the product demand and organisational shutdown policies during the festive season.

5. Discussion

Energy is consumed during the galvanising even when the process is idling where no parts are produced since it is imperative that the zinc is kept in a molten state. Therefore, the SEC depends on the production rate of the galvaniser and thus, SEC is not constant. Previous work by Blake and Beck (2004) had also revealed the production-dependent nature of SEC, outlining that at low levels of production, the energy losses from the walls and surface of the furnace during the galvanising process become more influential. The evidence from work measurement revealed that the exposed surface of molten zinc spent more time without insulative covers when compared to the time which the furnace expended in production.

There was generally no substantial amount of zinc used between the baseline and reporting period, hence the scenario of Plant 1 indicates a poor level of control and hence greater potential for energy savings. On the other hand, for Plant 2, it was revealed that as the level of production increased the SEC generally decreased. The level of production during the reporting period was found to be higher than the production level during the baseline period, while on the other hand, SEC decreased during the reporting period for Plant 3. On the other hand, for Plant 4, the level of production during the reporting period was found to be lower than the production level during the baseline period, and the SEC also decreased during the reporting period. Hence, given the disparity between the results of SEC for the four plants, it was noted that SEC alone cannot be used as an EnPC since it is not influenced by production only but affected by other variables such as material handling efficiency.

The essence of energy consumption benchmarking was to increase general awareness of energy efficiency among the galvanisers which in turn may influence a behaviour change provides objective, reliable information on energy use and the benefits of improvements. A box and whiskers plot for electricity/zinc ratios for the four plants before energy efficiency interventions indicated that there is likely to be a difference between Plant 1 and Plant 2. Significant differences were also noted between Plant 2 and Plant 3. However, no significant differences were noted between Plant 3 and Plant 4.

A box and whiskers plot for electricity/dips ratios for the four plants before energy efficiency interventions indicated that there is likely to be a difference between Plant 1 and Plant 2. Significant differences were also noted between Plant 2 and Plant 3 and between Plant 3 and Plant 4. A box and whiskers plot for electricity/product tonnage ratios (kWh/tonne) for the four plants before energy efficiency interventions revealed a difference between Plant 1 and Plant 2. Significant differences were also noted between Plant 2 and Plant 3 and between Plant 3 and Plant 4.

6. Conclusion

Bottom-up energy efficiency and saving calculations can be used to derive the energy savings that could be achieved by the galvaniser after the implementation of energy efficiency measures. Best practices were identified in Plant 4; covering of process tanks with insulating material prevented heat loss and led to improved energy performance. It was concluded that SEC alone should not be used as an energy performance indicator since it is not influenced by production only but affected by other variables such as material handling efficiency. Energy consumption benchmarking can be focused on poorly performing Plant 4 and necessitates the identification of best practices from Plant 4 that can be replicated across other Plants 1, 2 and 3.

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Biography

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