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Energy Benchmarking of Manufacturing Processes in Foundation Industries

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Abstract

Benchmarking energy consumption and utilisation has become a crucial tool for the manufacturing sector in the drive towards sustainability. However, incorporating industrial perspectives into benchmarking efforts is necessary to identify effective and relevant metrics. This study aims to evaluate the metrics for benchmarking energy utilisation within the foundation industries by deploying two surveys while incorporating the views of industry and subject matter experts. The study also involved conducting interviews with metal foundries to investigate the energy consumption of their processes and their metrics utilisation. The findings indicate the need for an accurate and reliable method to extract values for energy benchmarking of manufacturing processes. Proper procedures must be in place to ensure the data is collected consistently and uniformly across different processes and organisations. The deployment of effective and relevant metrics through industrial prospection will help ensure the benchmarking process is meaningful, actionable and supports the goal of a more sustainable future.

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1. Introduction

Severe environmental pollution is the outcome of significant energy use and emissions. Manufacturing processes have come under increasing scrutiny as the industry seeks ways to reduce its environmental impacts. Energy consumption is a crucial area of focus, as the manufacturing sector accounts for 38% of global energy consumption [1]. Thereby, it is responsible for up to 25% of global CO₂ emissions, with much of it coming from process energy and electricity consumption [2]. To reduce these emissions, it is crucial to reduce energy consumption in manufacturing. One way to achieve this is through the use of more energy-efficient equipment and processes [3,4]. Another approach is to use renewable energy to power manufacturing processes [5]. These energy sources have a lower carbon footprint and their energy generation process do not produce greenhouse gas emissions. However, it is not always clear which areas to tackle first and which change will have the most effect.

Benchmarking energy consumption is a crucial step in identifying areas for improvement in manufacturing processes [6]. Through the process of comparing energy utilisation data to industry standards or to similar operations, manufacturers can gain a comprehensive understanding of their energy consumption and determine areas that require optimization. The utilisation of both external and internal benchmarking methods is essential in this endeavour [7]. External benchmarking entails comparing a company's energy consumption to that of other companies within the same sector, utilizing publicly available data from reputable organizations. This allows for the identification of areas for improvement through the provision of a valuable external perspective on a company's energy consumption [8]. Internal benchmarking, on the other hand, involves comparing a company's energy consumption across different operations within the same facility or between different departments. This approach enables manufacturers to identify variations in energy

consumption and target areas of the facility where the greatest improvements can be made [9].

Regular monitoring and benchmarking of energy consumption can aid manufacturers in identifying areas for improvement in energy efficiency, reducing costs, and decreasing their environmental impacts [10]. Furthermore, it allows manufacturers to track the success of their energy-saving initiatives over time and make necessary adjustments to continue to improve.

Benchmarking is the process of determining the highest standards of excellence for processes, goods, or services - often referred to as "best practices" - and then implementing the necessary improvements to meet those standards [11]. Although benchmarking is a useful tool, it has some limitations such as a "best practice" cannot simply be adopted and implemented into one's own organisation. Before adapting a process, one must consider how things are currently done, the culture in place, the human resources being used, etc. Majority of the companies employ benchmarking as an information tool to promote continuous improvement and acquire a competitive edge. There are some questions that should be answered before implementing benchmarking i.e., what will be assessed or compared and who the organisation should use as a standard or reference point for comparison [12].

In recent years, there has been an increasing number of initiatives that companies have focused on tracking the performance of their operations with respect to energy consumption and utilization. This tracking is typically achieved through the collection of Key Performance Indicators (KPIs), indicators, or metrics, referred to collectively as "metrics" in this article. Despite the wide array of metrics available for tracking energy consumption and utilization, many organizations struggle to select a meaningful and effective set of metrics for their operations. This is in part due to the lack of consideration given to the impact that the choice of metrics can have on decision-making processes [13].

As a result, manufacturing companies have faced challenges in determining which metrics to use for evaluating their processes and how to interpret these metrics in order to drive improvements in energy efficiency and utilization [14]. Given the complexity of the field and the profusion of metrics available, it is imperative that a systematic approach should be taken to ensure that the most relevant and useful metrics are selected. This will enable organizations to make informed decisions and drive progress towards a sustainable future.

Energy metrics found in literature could be broad such as energy efficiency [15,16], energy or fuel consumption [17] or it could be limited to sustainability such as the ones suggested by Mahmood et al. [18] including renewable energy use.

Metrics provide a systematic way of measuring and evaluating the performance of energy utilization in the foundation industries. While there are numerous metrics available in the literature for industry use, it is important to note that their implementation and utilization may not always be optimal. It is often that industries either do not use these metrics or do not use them to their full potential [19]. Furthermore, existing research has not thoroughly investigated the industries' actions in utilizing these metrics, which can provide valuable insights into the most effective metrics and associated

information gathering practices. By incorporating the views of industry and subject matter experts, this study aims to provide a comprehensive and objective evaluation of the available metrics, and ultimately recommend the most effective metric for benchmarking energy utilization. Kibira et al. [20] highlighted that having a set of selection criteria to guide the selection of metrics ensures that the metrics chosen effectively reflect the operation or parameter being evaluated. Therefore, selection criteria (defined by ISO 22400 [21]) have been used to evaluate suitable metrics for energy benchmarking while incorporating the views from industry and subject matter experts.

In the next section, the research methodology adopted in this study is presented. Section 3 describes the obtained results and discusses their implications. Finally, section 4 concludes the paper.

2. Methodology

The selection of metrics for benchmarking energy use in foundation industries is crucial for identifying areas for improvement and determining the effectiveness of the manufacturing processes. The methodology adopted in this study started with a literature review which helped to identify and explore the metrics and benchmarking approaches presented in published research. Next, two surveys were launched aiming to filter down the selection criteria and evaluate the metrics utilised by the industry. In the final stage, interviews were conducted to ascertain the perspective of industries regarding the benchmarking metrics to be used.

2.1. Criteria filtration survey (Survey 1)

Survey 1 was designed to filter the selection criteria by assessing their importance and relevance in determining the most effective metrics to use in benchmarking energy use. The selection criteria were obtained from ISO 22400 [21] and included parameters such as accuracy, automation, cost-effectiveness, standardization etc. A full list is available in Appendix A (Table A.1.). The survey consisted of a 4-point Likert scale ranging from "not important at all" to "extremely important", where participants were asked to rate the importance of each selection criterion. It was circulated among a sample of academics and industry experts, who were considered to have the relevant knowledge and expertise to provide meaningful responses. The responses were collected and analysed to determine the most important criteria that should be considered when selecting metrics for benchmarking energy use.

The survey was conducted to gather insight from experts in the field and provide a comprehensive understanding of the importance of different selection criteria in benchmarking energy consumption and utilisation. It ensured that the selection of metrics for benchmarking was based on expert opinion and relevant industry standards. By prioritizing the most important selection criteria, the study aims to provide a comprehensive procedure for the selection of metrics for benchmarking energy use in foundation industries.

2.2. Metrics evaluation survey (Survey 2)

In order to gather insights from industry experts on the practical implementation of energy consumption and utilisation metrics in their organisations, survey 2 was conducted. This survey aimed to explore the current state of energy benchmarking practices in industry and to identify the challenges and opportunities for improvement. In particular, various energy metrics were presented in which participants selected which criteria satisfies the metrics that is/has been used to monitor processes in their organization. If no criteria is selected, then an assumption is made that the metric has not been used by the organisation.

The methodology used for evaluating metrics is adapted from Sherif et al. [19] who created a database to collect metrics that represent manufacturing operations ranging from organisational level down to process level. The energy related metrics at the process level which have been extracted are:

- Energy consumption
- Fuel consumption
- Electricity consumption
- Energy efficiency
- Energy intensity
- Waste energy
- Renewable energy
- Renewable electricity

2.3. Data collection Interviews

After conducting the surveys, interviews were organised with industries to provide a more comprehensive understanding of the usage of the identified metrics within the context of the organizations. These interviews aimed to gather actual data on the metrics from the industries, in order to analyse the real-world application of the metrics. The collected data helped to shed light on how the metrics were being used by the organizations and to what extent they were effective in measuring the desired outcomes. The interviews proved to be a valuable complement to the research, providing a more in-depth understanding of the metrics and their implementation in the manufacturing industry.

3. Results and discussion

3.1. Survey 1 results

The results of the survey were based on a statistical measure known as a 95% confidence interval, which provides a range of values that are likely to contain the true population value with 95% probability [22]. This indicates that the results of the survey are highly reliable and trustworthy. The survey aimed at determining the most suitable criteria for evaluating the performance of energy-related metrics in the manufacturing sector where 7 out of 18 criteria were selected which are presented in Table 1.

Table 1. Filtered criteria – results based on survey 1

Criteria	Definition [21]
Quantifiable	The value of the metric can be numerically specified; if uncertainty is present, it should also be quantified.
Relevant	The metric enables performance improvement in the target operation, demonstrates real-time performance, allows the accurate prediction of future events, and reveals a record of past performance valuable for analysis and feedback control.
Understandable	The meaning of the metric is comprehended by team members, management, and customers, particularly with respect to corporate goals.
Accurate	The measured value of the metric is close to the true value, where a departure from the true value can be affected by poor data quality, poor accessibility to the measurement location, or the presence of substandard measurement devices and methods.
Comparable	Means are defined to reference supporting measurements over a period of time, and a normalizing factor to express the indicator in absolute terms with appropriate units of measure.
Documented	The instructions for the implementation of a metric are up-to-date, correct, complete, and unambiguous, including instructions on how to compute the metric, what measurements are necessary for its computation, and what actions to take for different metric values.
Trackable	The appropriate steps to take to fix a problem are known, documented, and accessible, where the particular problem is indicated by particular values or temporal trends of the metric.

3.2. Survey 2 results

A full selection of criteria for a metric indicated a high degree of effectiveness, while the absence of a selection indicated that the metric was not in use or under consideration. As seen from Fig. 1, the results showed that the metric of "energy consumption" was most widely utilised based on the total number of responses and all criteria were selected for it followed by other consumption metrics for electricity and fuel. However, this does not necessarily indicate them as the most effective as all criteria were also selected for other metrics. The only metric that did not have all criteria selected was "energy waste". Notably, the criterion of "quantifiability" was the most selected for all metrics.

For the purpose of further examination of the discrepancies within and across the sectors, the results of 2 foundries, 2 chemicals industries and 2 glass industries were compared. Fig. 2. portrays the responses in which the number of bars represent the number of metrics used by the industries and the height of the bar signifies the quality of the metric based on the number of criteria selected for that metric. It can be seen that there is a high variance of responses within as well as across the sectors. For instance, foundry A is prevailing in tracking their energy consumption and utilisation as they employ a larger number of metrics with higher quality compared to foundry B. On the other hand, while chemicals A utilises metrics with higher

quality, chemicals B tracks a larger number of metrics in which they also track their renewable energy consumption.

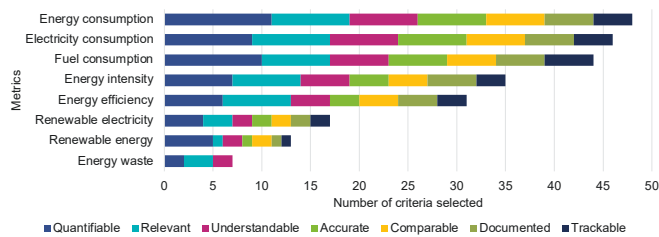


Fig. 1. Results of the second survey: energy metrics usage and effectiveness

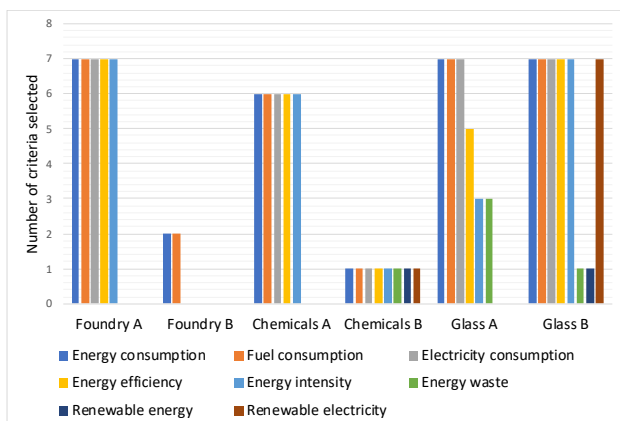


Fig. 2. Metrics evaluation by industry: quality vs. quantity

3.3. Interviews results

The final phase involved conducting interviews with two metal foundries (denoted as company A and B) to investigate the energy consumption of their processes and their metrics utilisation. Company A measured their energy consumption by reading electricity meters on-site and using invoices from the energy company which provided data on their total consumption. Then they calculated the consumption per process based on theoretical percentages, although this method of measuring the energy consumption is not entirely accurate. Nevertheless, the procedure was well-defined, and it was performed regularly, usually on a monthly basis.

On the other hand, company B had their equipment embedded with a system that provided more accurate real-time energy consumption values. These results provide insight into the different methods used by foundry industries to measure and track their energy consumption and the factors they prioritize. The findings may be useful for developing benchmarking methodologies and enhancing energy efficiency in the foundry industry.

Both companies indicated that they track their energy consumption for the purpose of identifying areas of improvement to maintain their competitiveness and reduce the cost of their operations. Table 2 presents the energy consumption values for the melting process, a highly energy intensive process, for both companies as well as the theoretical minimum and best practice values. It can be seen that the values

greatly differ between the two companies, this could be due to a variety of factors. Mainly, the method of measuring in which company A relies on estimates which could be inflating their values. Moreover, differences in scrap geometry, material composition, shift patterns etc. could also lead to contrasting values.

The results indicate the need for an accurate and reliable method to extract values for energy benchmarking. Proper procedures must be in place to ensure the data is collected consistently and uniformly across different processes and organisations. Such procedures should be well-defined and transparent to allow for easy replication and verification.

A key factor in reducing energy consumption for the melting process is improving the efficiency of the furnace, which reduces the energy consumed per unit of metal melted. The debate between cost-saving and energy-saving presents a challenge, as using a gas-fired furnace can reduce costs but results in poor melt quality and higher hydrogen content, which requires additional degassing. However, higher quality raw materials and training furnace operators are recommended to reduce metal loss through oxidation and drossing, which lowers energy consumption. Additional energy efficiency measures can include improving air compressors, reducing metal charging frequency, and using correctly sized equipment [23]. All these key factors contribute towards energy-efficient values for the melting process.

Table 2. Energy consumption data (in kWh/t) of the interviewee companies, theoretical minimum and best values are adapted from [24]

Company A	Company B	Theoretical minimum	Best practice
1596-1824	500-740	351	538

4. Conclusion

In this study, suitable metrics for energy benchmarking of manufacturing processes have been identified based on the selection criteria (defined by ISO 22400), incorporating the views from industry and subject matter experts.

The first survey was aimed at determining the most suitable criteria (7 out of 18) for evaluating the performance of the metrics in terms of energy consumption and utilization in the manufacturing sector. The second survey identified the most used metrics (energy consumption) as well as their effectiveness based on the distinguished criteria from survey 1.

The use of metrics for benchmarking is an essential part of assessing the performance of energy utilisation within the foundation industries. Metrics allow for the quantitative evaluation of various aspects of the energy consumption and utilisation process, providing a clear and objective means of comparison. By using consistent and reliable metrics, companies can identify areas of inefficiency and develop strategies for improvement, leading to reduced energy consumption and increased cost savings.

The interviews conducted with two metal foundries revealed the different methods used by the industry to measure and track their energy consumption. Company A relied on meter readings and invoices from energy companies to estimate their consumption per process, while Company B had real-time data

from embedded systems. Both companies prioritize energy consumption values for the purpose of identifying areas of improvement and reducing operational costs. However, the values obtained differed greatly, highlighting the need for accurate and reliable methods of data collection for benchmarking purposes. In order to collect data consistently and uniformly across processes and organisations, appropriate procedures must be in place. These procedures should be clear and well-defined to enable easy replication and verification.

The findings provide valuable insight into the industry's perspective on the importance of criteria and can inform our future plan to develop effective methods for benchmarking energy consumption and utilization in the manufacturing sector.

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Appendix A.

Table A.1. Set of criteria

Accurate	Automated	Complete
Actionable	Buy-in	Documented
Aligned	Comparable	Inexpensive
Timely	Understandable	Standardized
Trackable	Valid	Unambiguous
Predictive	Quantifiable	Relevant

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