



The Use of Gentani Approach for Benchmarking Resource Efficiency in Manufacturing Industries

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Abstract. The majority of today's manufacturing processes are based on well-developed and well-established procedures that are characteristics of mature technologies. The manufacturing industries have not evolved significantly over time because of recent economic, environmental, and societal advances at an unprecedented rate. As a result, there are numerous challenges and opportunities available, especially regarding resource efficiency. The majority of industrial processes consume far more energy than the theoretical minimal process energy requirements. This paper aims to develop a theoretical framework utilising the Gentani approach whilst targeting the minimum resources needed to carry out a process for use by manufacturing industries. The resource efficiency (exergy) metric has also been discussed that can be used as a tool to evaluate the efficiency of industry, depicting a more holistic level of energy and material consumption. The framework will help manufacturing industries in lowering costs and remain competitive by improving resource efficiency, aimed at reducing resource use and providing value delivery. The study will also assist in transforming these industries into resource-efficient modern manufactories in line with the Net-Zero 2050 agenda.

Keywords: Manufacturing · Net Zero · Gentani · Resource Efficiency · Exergy

1 Introduction

Manufacturing is a major embodiment of a country's national economy and overall national strength, as well as a cornerstone industry for building human wealth. The manufacturing industry plays a critical role in the generation of value for its customers; however, this value generation involves processes that are material and energy-intensive. This produces a lot of waste and has a negative impact on the environment [1]. According to the International Energy Agency (IEA) statistics, the industrial sector accounted for about 26% of global CO₂ emissions and 38% of global energy use in 2020 [2]. Environmental pollution and resource scarcity push the energy and resource-intensive industries towards the future targets of the net-zero 2050 agenda which is to transform these industries into resource-efficient and non-polluting manufactories.

Most industrial processes consume much more energy than the theoretical minimal process energy requirements. For instance, steel production from iron requires the theoretical energy of 6.7 GJ/ton, plus an extra 1.2 GJ/t for melting [3], whereas globally an

average of 22.6 GJ energy is used for 1 ton of material [4]. Cement processing requires only 1.8 GJ/t, but the average industrial value is 4.6 GJ/t. For flat glass production 3 GJ/t energy is required, this is significantly less than the present energy consumption of 7 GJ/t, resulting in 43% energy efficiency [5]. This shows that there are opportunities available to explore the resource efficiency of processes involved in the manufacturing industries.

Conventionally material efficiency and energy intensity metrics are used to measure the resource efficiency of the industry. However, since these metrics require different units that cannot be integrated (e.g., kg with kJ), a thorough analysis of industry efficiency is not permissible. This limitation has been addressed by exergy which can be used as a metric to measure both material and energy utilisation in a single integrated metric [6]. The exergy of a production process involves its both physical and chemical exergy. Physical exergy is the maximum useful work a particular flow can do until it reaches thermomechanical equilibrium with the atmospheric conditions [7]. Whereas chemical exergy denotes the ability of a material to do work due to its chemical composition difference in relation to the (surrounding) environment [8]. Exergy analysis can be employed to measure the interaction and trade-off between material and energy flow. It is stated that exergy provides a meaningful value to resource efficiency since it specifies the quality of a commodity, allowing the practitioners to distinguish the desired product from waste or by-products [9]. The automobile industry has also begun to employ resource efficiency throughout its production chain by creating components that consume significantly less fuel [10]. Toyota has successfully reduced the energy usage of its vehicle production focusing on the real minimum resource required for any process, the adopted approach is known as Gentani [11].

The word “Gentani” is a Japanese phrase that originated from the term called “Kousuu”, which refers to an approach based on resource consumption that enables users to determine the minimum resources used in an activity. In the later version, it is referred to as Gentani. In Japan, Gentani is extensively used in the manufacturing sectors to highlight resource consumption and devise new approaches and work support services to improve the utilization of resources and meet the set targets [12, 13].

This work is a part of the TransFIRE project that aims to transform the foundation industries in line with the net-zero agenda. Applying Gentani is one of the important research objectives of this project i.e., to identify the minimum resource required to perform a particular process. This paper is focused on developing a theoretical framework based on the Gentani approach highlighting the bare minimum of resources required to complete a process for application in manufacturing industries.

2 Theoretical Framework Based on Gentani Approach

This study proposed a theoretical framework based on the Gentani approach, following the four steps provided below.

2.1 Develop Process Models

The primary step of this framework involves the development of process models that account for materials, energy, water, and non-product flows like emissions, compressed

and blown air, by-products, process and cooling water and waste materials. Figure 1 provides a visual picture of an overall process model for a generic production system. This model can be further decomposed into detailed process models to provide a comprehensive overview of all the input resources and outputs associated with each manufacturing/sub-process.

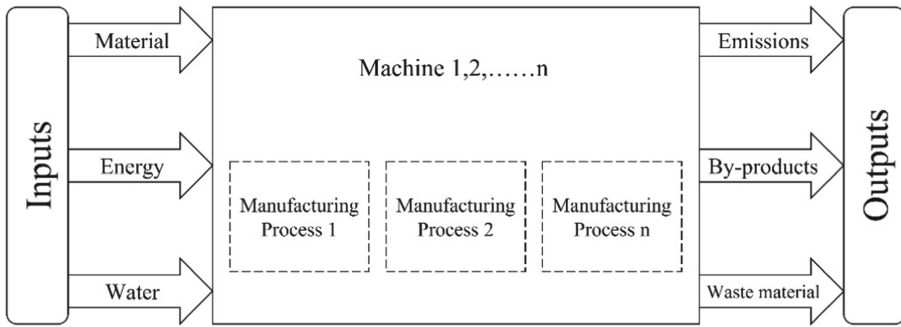


Fig. 1. Graphical picture of a generic process model

2.2 Develop and Evaluate Targets

The second step is to develop and evaluate targets for the most efficient use of resources for each manufacturing process and use these to benchmark processes in the manufacturing industries. Additionally, determine how distant the manufacturing sector is from meeting these targets.

There are several processes involved in the manufacturing industries such as heat exchange, comminution, cooling, material handling and transportation, etc. All of these processes require a lot of energy and resources. Based on the theoretical calculations the absolute minimum resource required to accomplish these processes can be estimated and the optimal resource efficiency for these processes is benchmarked. Comparing the difference between present and benchmark values provide an idea of how far the manufacturing sector is from its ideal target values.

2.3 Determine Best Practices

Identification of best practices for obtaining the maximum resource utilisation in the manufacturing sector/industry is performed in the third step. One of the examples of best practices is to reincorporate by-products into the production process which can help improve the resource efficiency of a sector by up to 4% [9] (see Fig. 2). The other examples may include the capture of waste heat/energy and reutilising it. These practices can help manufacturing industries to get closer to the best feasible resource efficiencies.



Fig. 2. Introduction of by-products as an input material [5]

2.4 Integrate Knowledge

Lastly, approaches to attain the targets in Sect. 2.2 are identified and knowledge is transferred into the manufacturing sector to help overcome any encountered barriers.

An overall outline of the proposed framework is shown in Fig. 3. Mapping of resource consumption is important to identify the inputs and outputs involved in the process. This will also help to determine the hotspots (highest resource consumption) in the production. The optimum resource efficiency of the process can be benchmarked by calculating the theoretical minimum resource consumption value and comparing it with the industrial resource consumption data. To achieve optimum resource efficiency, it is necessary to identify and implement the best practices.

3 Resource Efficiency Metric

Resource efficiency is an important feature of sustainable policies and practices, especially in industries that use a lot of energy. The industry employs resource efficiency as a strategy to produce more suitable outputs with the minimum possible inputs [14]. It is used by industry leaders and governments to set priorities based on a product's added value and to identify areas where a process can be improved. Resource efficiency is a well-established metric for determining the total energy performance of the manufacturing industry.

Currently, energy intensity and material yield are the typical forms of metrics that are used to evaluate plant efficiency in terms of resource usage. However, these metrics are focused on a particular resource. The calculation of resource efficiency necessitates the use of a single objective unit for all resources [15]. Exergy is one approach to do this that accounts for both material and energy usage. It presents the maximum useful work that a system can perform [16].

Hernandez et al., [17] proposed the resource efficiency metric as a tool (measured in exergy) to holistically measure industry efficiency considering both material and energy consumption. This metric allows the integration of four major possibilities for improving resource efficiency, that are usually considered separately: reducing fuel and material inputs along with recovering energy and material by-products. In another work,

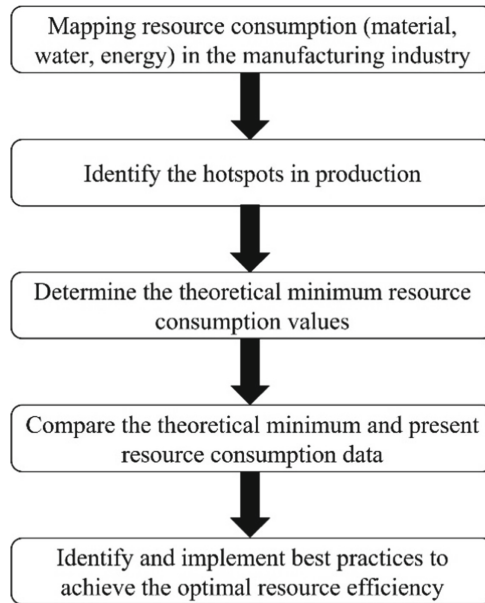


Fig. 3. Outline of the conceptual framework

Hernandez and Cullen [6] found exergy as an effective metric for measuring the resource efficiency of the industry. This reveals the exergy metric as the best approach to evaluate the industry resource efficiency.

4 Conclusions

The manufacturing sector consumes a huge amount of energy compared to other end-use sectors and therefore has a huge potential for improvement in terms of lowering energy usage and emissions. In this paper, the use of the Gentani approach has been introduced to benchmark resource efficiency in the manufacturing sector. A theoretical framework has been presented that can help resource-intensive manufacturing industries to identify theoretical and actual resource consumption limits (water, energy and materials). This novel approach will uncover many opportunities for the manufacturing sector in terms of performance enhancement.

Resource efficiency can be measured with different metrics such as energy efficiency, energy intensity and material efficiency that are limited to a specific resource. The exergy-based metric is a comprehensive measure of resource efficiency that can be used to examine, analyse, and optimise industrial processes as a measure of both material and energy quality. Exergy analysis is a more realistic way to justify the system's performance than material and/or energy analysis.

5 Future Directions

Using the Gentani approach this study aims to develop a theoretical framework to benchmark and identify best practices in the manufacturing sector in terms of resource efficiency (energy, water, material etc.). However, the work is limited to a high-level framework. This is an ongoing project and will be explored further towards an advanced level of the framework by involving industrial experts. Moreover, some case studies will be performed to evaluate the framework with the industrial partners of TransFIRE.

Further research is in progress to identify and benchmark the resource efficiency of the common processes across the foundation industries. Detailed level process models will also be developed looking at the whole aspect of manufacturing.

Acknowledgement. The authors would like to acknowledge the Transforming Foundation Industries Research and Innovation hub (TransFIRE) for the support of this work. TransFIRE (EP/V054627/1) is funded by UKRI.

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2023-04-26

Springer

https://doi.org/10.1007/978-3-031-28839-5_51

Sarfraz S, Jolly M, Salonitis K. (2023) The use of Gentani approach for benchmarking resource efficiency in manufacturing industries. In: 18th Global Conference on Sustainable Manufacturing (GCSM 2022), Manufacturing Driving Circular Economy, 5-7 October 2022, Berlin, Germany. Lecture Notes in Mechanical Engineering, pp. 457-463