Eco-Efficiency of Metallurgical Value Added Process Facilities for Sustainable Production

A. Ayyakkannu, P.S. Kumar*, P.C. Naganoor, Basavaraj Hatti

Department of Mineral Processing, VSKU PG Centre, Nandihalli-Sandur, Karnataka-583119, India

*Corresponding author: sharathkumar@vskub.ac.in

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Abstract  This study aims to analyze the practices of iron ore pelletizing and Pig iron manufacturing units; considered as major value-added process facilities of iron and steel manufacturing plants. To achieve the concepts of cleaner production and sustainability demands, estimation of eco-efficiency of value-added process facility (VAPF). The technical procedure adopted was the case study; the data collection was done through direct observation and literature review. The main results were obtained from the analysis of company reports available to the public. The study concludes that the eco-efficiency of value-added process facilities increases when the VAPF adopts the utilization policy to make the ancillary products of higher market value. The existing value-added process facility shows the 74% eco-efficiency whereas the VAPF 4 shows 85% Eco-efficiency.

Keywords: sustainability, value added, efficiency, pelletization, economic variables

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1. Introduction

The concept of sustainable development is attained major importance after the Earth Summit, held in 1992 in Rio de Janeiro. Formation of a sustainable economy in the industry of acquiring mineral resources, and the creation of new methodologies for the development of conditional values, which can be used as a tool for the measure of the sustainability of standalone port-based pellet plants of India. Maximize the profit by maximizing production and minimizing the cost of production is a general concept of every industry [1,2,3]. Nearly 70-80% of the total cost of pig iron and steel products manufacturing units invites raw materials which are higher than the cumulative amount for Men, Machines, and other expenses [4]. Studies reveal that adding the social and economic dimensions one needs to recognize that, minerals and metals are currently indispensable for availing global society of the goods and services that make up our modern lifestyle. The industry appears now solidly focused on maximizing the contribution of mining and minerals to the sustainable development of society at large and in particular the communities in which it operates. Mineral's beneficiation activities involve basic operations like crushing, milling, and beneficiation of the mined ore, and extractive metallurgy involves the use of the high-temperature source to produce elemental metal. The continuous demand fluctuations in the Steel market have increased the difficulty for the steel manufacturer to match the raw materials requirements in terms of the right quantity, right time without compromising the quality at the cheapest price [5]. The standalone pellet and pig iron plants of India are facing scenario problems with their capital assets. Most of the standalone pellet and pig iron manufacturing facility location facilities of India are not having captive mines and need to depend on high-grade iron ore resources [6]. Mines and beneficiation facilities were located in the Western Ghats in India, which subsequently ceased and metallurgical capital assets are located at a major port on the west coast of the Karnataka region [7]. To augment the present assets outsourcing of primary high-value resources like iron ore, lump-fine, and coke and secondary resources like power, water, furnace oil, and fluxes. Both the high value primary and secondary resources are transported by Land and Waterway Modes of Raw Materials Transportation Facilities (LWMRMTF). Figure 1 shows the general flow of operations in the pellet and pig iron plants.

The Literatures review highlights various tools and methodologies used to incorporate sustainability considerations for mineral processing operations [8]. The wide range of tools and methodologies are without a consistent, integrated approach to support the mineral industry in incorporating a greater level of sustainability in the design process [9]. Such shortcomings can be resolved by eco-efficiency. Eco-efficiency is used for sustainable manufacturing [10].

The eco-efficiency indicates how the inputs are used by the system. As per geo - metallurgy, mining, and mineral processing can be considered as the methodologies to prepare input resources and metallurgy as output manufacturing. Therefore, the eco-efficiency is considered as the equilibrium between input resources and output products.
This paper deals with iron ore pellet making and the production of pig iron, as these, require large amounts of energy and raw materials, produce a large volume of semi-finished products. Eco-efficiency (EE) of pellet making and pig iron production can have a positive impact on the value addition methods and the pellet and pig iron enterprise sustainability and is therefore relevant from the perspective of mine closure, site location, and rehabilitation. However, to achieve satisfactory closure with minimal ongoing management requirements, EE in the pellet making needs to be complemented with planned approaches to mine closure, storage of large volume raw material, and reduction of operating cost. This paper aims to demonstrate that despite its roots being in manufacturing and trade, EE is applicable to value addition enterprises like standalone pellet making and pig iron manufacturing units. Section 2 briefly takes stock of value addition methods and geo-metallurgical operations. Section 3 summarizes the value addition processes. The following discussion focuses on the eco-efficiency framework and implication for technology development. The final section provides the concluding remarks.

2. Value Addition Processes (VAP)

Modern mining and mineral industries are facing new challenges that are not common from several decades ago. Minerals are used as raw material for their value addition by removing wastes; such processes are referred to as Value addition processes. If the minerals of different qualities are used without removing wastes, such operations are called a transformation or conversion process. In both cases, Mineral processing functions are involved. Similarly, when the iron ore is directly transformed into final products with the help of thermal energy, such operations shall be treated as iron/steel making functions. If the iron ores of different grades are used for making semi-finished products, such as pellet and pig iron are referred to as intermediate process functions. Declining ore grade, increased variability within the ore body, and highly fluctuating commodity prices have made a high impact on the profitability of value addition facilities and thus, require more accurate short and long term planning strategies to meet the circular economy. The geo-metallurgy has proved to bring significant improvement in the predictability of the feed quality and processing performances which involves geology, mining, mineral processing, and metallurgy. Pelletization and pig iron making is considered as value addition processes. Different routes of pellet and pig iron making operations are shown in the Figure 2 & Figure 3 includes resources, conversion systems, and products. Resources and conversion systems as input variables and products are referred to as output variables that are fixed as per the location-allocation logistics matrix. The resources, conversion systems, and products are responsible for efficiency.

![Figure 1. Overview of Steps Involved In Pellet Industries](image1)

![Figure 2. Pelletizing value addition process](image2)
3. Metallurgical Value Addition Process Facility

Value addition process facility; represent the in-house facility of the enterprise and their optimum utilization. Optimization of semi-finished products (Pellet and Pig iron) manufacturing enterprises is strongly recommended for the identification of an uncertain environment for the development of sustainable methodologies. The existing facilities at the value addition process are shown in Table 1. VAPF-1 is the only available value addition process at the existing pellet and pig iron plant facility and the required value addition process facilities for the existing standalone pellet and pig iron plant are named VAPF-2, VAPF-3, and VAPF-4. The Pareto sets are developed by considering the iron ore and other raw materials used by outsourcing, transformation processes, uncertainty, and constraints. The output quantities are divided as products. The number of products for each VAPF is shown in Table 1.

4. Eco-efficiency Framework

The term eco-efficiency is used as a maxim eco-efficiency which refers to the reduction of environmental impacts. The term eco-efficiency is also used to describe the ratio of created value per environmental impact added. According to the second notion, we use eco-efficiency as a ratio, i.e. as.

\[
\text{Eco-efficiency} = \frac{\text{Value Added}}{\text{Environmental Impact Added}}
\]

(1)

Eco-efficiency describes the degree to which an enterprise uses environmental resources relative to its economic activity. Proponents of eco-efficiency claim that improvements in eco-efficiency enhance corporate contributions to sustainability. When looking at the relationship between sustainability and eco-efficiency one can distinguish between weak and strong improvements of eco-efficiency. Strong improvements in eco-efficiency comprise both an improved economic and environmental performance whereas weak improvements of the ratio only require one dimension to be improved. In the present study, eco-efficiency is expressed as.

\[
\text{Eco-efficiency} = \frac{P_{sv}}{P_{cv}} > 1
\]

(2)

Where; Psv - Sale value of Products, Pcv - Cost value of Products Therefore, the eco-efficiency is considered as the equilibrium between input resources and output products. The Input-output variables of the value-added process facility are shown in Figure 4. Process variables are a, b, c, P, and economic variables are r, m, p. The differences between process variables and economic variables are the accountability of standard loss (\(\rho\)).
Table 1. Pareto sets of Value Added Process Facility Conditions

| FACILITY CONDITIONS | Input | Process adopted                  | Products                                | Remarks                                      |
|---------------------|-------|----------------------------------|-----------------------------------------|----------------------------------------------|
| VAPF 1              | Coal / Coke And others           | Pelletization and pig iron            | Pellets, Pig iron, Slag                   | 03 Outsourcing of raw material               |
| VAPF 2              | Coal / Coke And others           | Pelletization, Pig iron, steel        | Pellets, Pig Iron, finished steel Slag    | 04 Outsourcing of raw material and steel capacity less than inverse $\pi$ value. |
| VAPF 3              | Coal / Coke And others           | Pelletization, Pig iron, sintering, Steel Making | Pellets, Pig iron, Slag, sinter, Finished Steel, cogeneration of power, | 06 Outsourcing of raw material and steel capacity equivalent to $\pi$ value. |
| VAPF 4              | Coal / Coke And others           | Pelletization, Pig iron, Sintering, Steel making, clinkering | Pellets, Sinter, Pig iron, Slag, Finished Steel, Cogeneration of power Cement | 07 Outsource and captive resource of Iron ore and coal/Coke Outsourcing |

The economic variables for each value-added process facilities are calculated using the arc-length method and shown in Table 1. Table 2 shows the economic variables such as resources ($r$) standard loss ($\rho$) and value addition methods ($m$).

Table 2. Values of economic variables

| VAPF | Arc length | Degree Sequencing | $r$  | $\rho$  | $m$  |
|-----|------------|-------------------|------|---------|------|
| 1   | 6.82       | 52.78°            | 1.993| 1.993   | 2.816|
| 2   | 10.220     | 35.22°            | 2.993| 2.993   | 4.216|
| 3   | 13.63      | 26.41°            | 3.987| 3.987   | 5.632|
| 4   | 17.034     | 21.13°            | 4.990| 4.990   | 7.047|

The eco-efficiency of the value-added process facilities (VAPF 1-4) is determined by using economic variables as shown in Table 1 by incorporating in logarithm function as shown in equation 1

$$Eco-efficiency = \log_m r.$$  \hspace{1cm} (3)

Equation 3 can be written as

$$Eco-efficiency = \frac{\log_{10} m}{\log_{10} r} = \frac{\ln m}{\ln r}.$$  \hspace{1cm} (4)

Eco efficiency of VAPF 1-4 is shown in Figure 5 using the equation 4.

5. Conclusion

The term efficiency is used to analyze the performance of a unit or the process. Concerning the context of the study, the term eco-efficiency is used to build the relationship between the input quantities and its cost. The effectiveness is used to the economic value realization by the given resources. Efficiency and effectiveness are expressed by eco-efficiency. Eco-efficiency is one of the main tools to promote a transformation from unsustainable development to one of the sustainable development. It is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution (WBCSD-2018). Iron ore pelletization and Pig Iron value addition process facilities are carefully analyzed and eco efficiency of such units increases upon production of diversified products.

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