The application of MFA for rural industrial symbiosis assessment

D Agustina¹, A D Wicaksono¹, C Meidiana¹
¹Department of Regional and Urban Planning, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
Jl. Mayjen Haryono 167 Malang 65145, Indonesia

Email: agus2wicaksono@yahoo.co.id

Abstract. One of proposed strategies to solve current environmental challenges includes the industrial symbiosis. However, proper evaluation methods are required to measure the potential benefits of industrial symbiosis, one of those includes the material flow analysis (MFA). MFA develops a unified database and a Step-by-Step process starting from the input, process, and output process to clarify the distribution of waste and the recycling process in the aluminum industry. The aluminum industry is regarded as an energy-intensive and high-pollution industry. The development of industrial symbiosis in the aluminum industry has significantly reduced environmental pressures and facilitated green development and green industry. Home industries that process aluminum slag raw materials require high energy thereby generating high waste during the production process. The applied method includes material flow analysis (MFA). The MFA results indicated that the production elements of the aluminum slag industry consist of 11 elements ranging from raw materials, fuel, clean water, human resources, capital, production processes, production equipment, housekeeping, products produced, waste to waste utilization. Approximately 44% of the industry sold waste to other industries, 42% of the waste was reprocessed, and 14% of the aluminum industry stockpiles production was in the form of waste in open spaces. The industrial symbiosis in the aluminum industry was an open cycle, indicating that the symbiosis produces waste, which had not been fully utilized; but in fact, the waste had potential as a source of raw materials, energy, and materials in other industrial processes.

1. Introduction

Industrial symbiosis is translated as part of industrial ecology by involving traditionally separate industries to a collective approach as a competitive advantage involving the exchange of physical, energy, water, materials, and by-products [1]. Industrial symbiosis refers to a concept in sustainable development [2][3][4]. In addition, the concept of industrial ecology provides a sustainable approach to economic development, aiming to reduce raw materials and energy inputs by utilizing waste, by-products, and energy derived from waste, thereby reducing emissions and waste generation[5]. The exchange between factories and industry players from different industries has resulted in specialized supply chain coordination. This collaboration in the supply chain improves the company's resource efficiency and environmental performance by reducing waste generation and greenhouse gas (GHG) emissions [6].

Industrial symbiosis refers to a complex system resulting from the interaction between system components and their environment. This complexity is related to system parameters such as the number...
of companies (industry) in the system, the diversity of industry types, and the distribution of industries with different sizes and interactions. This complexity requires an optimization model that facilitates assessing material and energy flows [7]. Several case studies have verified the environmental and economic benefits of industrial symbiosis. However, there are still limitations in reflecting their impact on ecosystems [6]. At this point, the decision-maker (either buyer or supplier) in the network must analyze the potential flows of by-products, waste, and energy to decide whether these flows are adequate for sustainable production. When the supplier produces the final product, the by-products and waste that arise during production employed by other buyers, leading to a closed industrial system. The level of by-products can be estimated based on the production plan; and shortages and surpluses can be reduced by stock [5].

The aluminum industry is a resource-intensive and energy-intensive industry with severe environmental problems [8]. The use of large amounts of aluminum also produces a large amount of aluminum waste [9]. The secondary industry recycles some aluminum waste into scrap, slag, foil, and dross. Aluminum can also be used as a general coagulant in wastewater and water treatment [10]. This type of aluminum processing industry is usually a home industry or small scale. Because the scale is still small, the handling of waste generated as a by-product of the aluminum industry is generally still very lacking and minimal [11]. In Jombang Regency, the aluminum industry has developed, most of which are small industries (home industry) (Industry and trade office, Jombang Regency, 2020). This industry processes recycled aluminum slag raw materials into slabs/bar products that have economic selling value. Judging from its production capacity, the type of aluminum slag recycling industry in Jombang Regency consists of medium and small industries. Based on data from the environmental service, in 2018, 136 aluminum slag smelting industries spread across two sub-districts in 20 rural areas, such as in Sumobito District (14 rural areas) and Kesamben District (6 rural areas). Based on the preliminary survey, from 136 existing industries, it has been reduced to 86 aluminum slag smelting industries. The decrease in the number of industries is caused by the COVID-19 pandemic, resulting in a scarcity of raw materials and the increasing capital spent on the production process. These 86 industries become an aluminum industrial center in Jombang Regency by producing aluminum slag waste that still disposes of waste carelessly.

The aluminum industry has several things that can be developed with the principle of industrial symbiosis, such as the presence of waste from the parent company, waste from abundant combustion residues, and labor availability. Production efficiency is obtained through the application of the industrial symbiosis concept. There is a good relationship between the parent industry (Aluminum Plate, Sheet & Foil (APRALEX, Sh&F, and the Aluminum Extrusion industry) and its derivative industries [12]. This linkage has a good impact on each industry. There is a symbiotic application industry; the activities of the aluminum industry in Jombang Regency can continue because of the great potential in the existing area.

Based on the preliminary survey, the government is still less involved in handling waste in the industrial environment in Sumobito District and Kesamben District. This is indicated by the absence of application of reducing toxicity to the environment, reducing the risk of harmful gas emissions, using environmentally friendly technology, and not increasing waste recycling. The government's role has been solely limited to planning related to the development of industrial estates and plans for developing communal wastewater treatment plant for processing industrial waste. To overcome the problem of waste generated by the aluminum slag industry in Jombang Regency, the principle of industrial symbiosis can be applied [13].

2. Method
This study used a quantitative research technique to determine the relationship between the environment and the economy and determine the dynamics in the aluminum industry's material flow (cycle), starting from input, process, output, and waste management. The analysis was carried out within the pre-defined system boundary set beforehand. The system boundary in this study is described in Figure 1.
2.1. Material Flow Analysis.

The material flow data were obtained from all aluminum industries, collected, and analyzed to determine the material flow from a production process. The production process flow and industrial symbiosis can be identified the production process starting from process input and output was identified, so that information on the total number of activities in the aluminum industry was obtained with details of each type of activity [10][14]. Waste generated from the system was the highest target in Material Flow Analysis (MFA), considering the amount of waste collected could describe an unsustainable material output cycle and indicated the need for system remediation. Material Flow Analysis (MFA) could systematically relate to the source, path, and final material disposal. The potential for a symbiosis of the aluminum industry based on the analysis of material flow and resource quality was carried out to identify opportunities for a symbiosis of the aluminum industry [8]. Figure 2 describes the material flow analysis of the Aluminum Industry in Jombang Regency.

3. Results and Discussion

3.1. Material Flow

The number of aluminum slag industries in Kesamben and Sumobito sub-districts was 86 industries. It was divided into 77 industries in Sumobito District and 9 industries in Kesamben District, all industries are located in rural areas. Industries in Kesamben and Sumobito sub-districts were independent industries with a percentage of 45.88% industries. Meanwhile, the industries under the auspices of the SMAR'S Cooperative were 28.24%, and industries under the auspices of the Kendalsari Barokah Metal Cooperative were 25.88%. The map of the distribution of the location of the aluminum industry in Kesamben and Sumobito sub-districts is illustrated in Figure 3.
Material Flow Analysis (MFA) was used on material flow in a production process system clearly defined in space and time [15]. MFA was used to quantify and describe the material flow of aluminum industrial centers in Jombang Regency. The MFA results indicated that the production elements of the aluminum slag industry consist of 11 elements ranging from raw materials, fuel, clean water, human resources, capital, production processes, production equipment, housekeeping, products produced, waste, and waste utilization. 44% of the industry sold waste to other industries, 42% of the waste was reprocessed, and 14% of the aluminum industry stockpiles production waste in open spaces.

The primary raw materials used in the production process are aluminum, aluminum slag ash, aluminum foil, and scrap. The fuel used in the aluminum slag production process is only firewood. There is no use of other fuels in the production process. The aluminum production process generally consists of 5 stages starting from the material preparation process and producing Aluminum and Plastic Shredder. The smelting process is carried out afterwards, which produces liquid aluminum. The following process is the cooling process and the printing process which produces the top product in the form of aluminum bars, and the process The last step is packing using sacks. There is no labeling on the aluminum packaging process. The aluminum industry produces the main product in form of aluminum bar, and dross powder is produced as a by-product during the smelting process. Figure 4 describes the aluminum industry material flow analysis chart.
3.2. Industrial Symbiosis

The aluminum production process produced waste in the form of hazardous waste or B3. The processing of B3 waste in Kesamben and Sumobito sub-districts varied, whether resold, reused as raw materials, used as backfill materials, and collaborated with third parties. In addition, there were still industries that allow the waste products to be processed without being processed or carried out by landfilling for sale at a nearby factory. The aluminum slag industrial centre interactions indicated that the industrial symbiosis that occurs was still in an open cycle. The open cycle means that the symbiosis that occurs still produces waste, and there is still waste that has not been utilized, but in fact, the waste had the potential to be used as a source of raw materials, energy, and materials in industrial processes. The existing condition of the aluminum industry symbiosis as open-cycle is illustrated in Figure 5.

The aluminum slag industrial center requires integration between industrial and natural systems, in this case, the application of industrial ecology for the application of sustainable development. Industrial ecology includes a mutuality relationship between various systems, including the environment, industry, institutions, and infrastructure. The concept of industrial ecology is applicable to develop renewable energy derived from the remnants of previous industrial processes. Applying the concept of industrial ecology in the industry could create a waste exchange system applied by other industries (companies). Waste from industrial activities can be waste that can be reused for new energy in other industries.
Recycled materials used in industrial processes have represented a fraction of the total materials used and using the waste from one process as the feedstock to another remains limited. Reuse, remanufacturing, and recycling of after-use products are far from achieving their full potential. The linear transformation process is still considered in operations management and much more needs to be done. The closed-loop system thinking should be adopted in operations management analyses to support business decision-making [2].

Figure 6 describes the potential of the aluminum industry symbiosis as a closed cycle. The potential for industrial symbiosis with a closed system found in the aluminum industry is performed by reusing the product by utilizing waste products as raw materials for other industries. Sharing of facilities and utilities with the construction of communal WWTPs or aluminum industrial waste treatment sites. Cooperating with third parties, in this case, PT. Semen Gresik is like an industry that has collaborated with PT. Semen Gresik. Sharing technology through research or utilization of waste products as paving and road fill materials can be used as road raisers and embankments to avoid flooding

Reuse, remanufacturing, and recycling of after-use products also need to be significantly increased, such as by industrial symbiosis, with the help of design for the environment [6], [10], [16]. The industrial symbiosis that occurs has a positive impact on the environment because it can reduce the burden of waste discharged directly into the environment; besides, the potential for industrial symbiosis that occurs can also be helpful for village infrastructure development. Ash waste generated during the production process can be used to improve village infrastructure. Some of them are utilized as embankment material for agricultural and plantation roads and can be used for paving materials.
4. Conclusion
The MFA analysis results indicated that the production elements of the aluminum slag industry consist of 11 elements ranging from raw materials, fuel, clean water, human resources, capital, production processes, production equipment, housekeeping, products produced, waste and waste utilization. 44% of the industry sold waste to other industries, 42% of the waste was reprocessed, and 14% of the aluminum industry stockpiles production waste in open spaces. Based on the interactions that occurred in the aluminum slag industrial centre in Kesamben and Sumobito sub-districts, industrial symbiosis was still in an open cycle. The potential of existing industrial symbiosis indicates cooperation with other parties related to marketing and utilization of residual waste from the production process. In addition, the remaining waste from the production process is utilized for construction materials. Additionally, based on the MFA, it has been estimated that the industrial symbiosis presents a beneficial impact on the village as it absorbs labor for the paving production process, provides village infrastructure materials, thereby providing raw materials for household equipment industry.

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