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Material Flow Analysis for Assessing the Sustainability Solid Waste Management Strategy

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ABSTRACT

With increasing income levels and accelerating consumption, municipal solid waste management (MSW) has become important in developing countries. This study intends to use material flow analysis (MFA) to assess the waste management strategy in Bogor-Indonesia. Moreover, this study also determines the extent of the waste flow path and provides suggestions for improvement. Waste volume data is carried out directly for ten days, referring to Indonesian Standards (SNI 3242: 2008 and SNI 19-3964-1994) related to waste management in settlements in Indonesia. Furthermore, the waste generation data were analyzed by applying the MFA Method. Data processing using STAN (Substance Flow Analysis Version 3) software makes Material Flow Analysis (MFA) images. The data shows that the waste generated is 20 kg to 140 kg per day. The existing conditions indicate that the waste is burned or disposed of in municipal landfills. The proposed waste management strategy model reveals 30.66 tons/year of inorganic waste that can be recovered through recycling and about 20.13 tons/year. The strategy that can be done is to establish a waste bank that applies Maggot BSF cultivation to recycle the organic waste produced. Decision-makers need future studies of material flows to be able to plan for changes in waste flows.

1. INTRODUCTION

Municipal solid waste (MSW) management has become more important in rising economies due to economic development, and trash creation has increased the acceleration of consumption. Increased trash generation has resulted in a critical scarcity of landfills and increased waste management expenses [1]. MSW is also one of the public management facets critical for capitalizing on benefits and mitigating municipal and rural difficulties associated with expanding urbanization. Integrated MSW management is a complete strategy for pollution avoidance, recycling, and efficiency to protect human health and the environment [2]. The integral approach to MSW management seeks to balance waste management: Environmental protection efficiency, social acceptability, and economic acceptability (acceptable price).

Solid waste management is a pervasive problem that affects everyone on the planet. Waste creation is rising daily; it consumes a substantial portion of municipal budgets and government resources for waste treatment and significantly impacts public health [3]. Waste management is the single largest source of money for all governments in low-income countries, accounting for around 20% of their budgets. Solid waste management generally accounts for at least 10% of solid funds in middle-income countries but only around 4% in high-income ones [4]. Waste management costs are expected to triple or quadruple in developing nations, from around 20 billion US dollars in 2010 to nearly 80 billion US dollars in 2025. Cost increases faster in less developed nations [5]. As a result, developing implementable, knowledge-based solutions is critical for nations with suboptimal performance in urban solid waste management.

Garbage disposal remains the least cost and most extensively employed method of waste management globally [6, 7]. UNEP examined the world's 50 biggest illegal dumps in its assessment, finding the majority in Africa, Asia, and Latin America, with just two in Europe (Serbia and Ukraine) [8]. In Europe, garbage disposal in landfills is still prevalent in developing nations, including various EU members and Romania, Cyprus, Greece, Malta, and Turkey [9]. MSW management in the former Yugoslavia (except Slovenia) is still extremely low and is a significant concern in the Balkan waste management strategy [10].

The United Nations Environment Program examined the present state of solid waste management in several different locations around the globe. As a result, the solid waste collection and regulated disposal rate was 50% in low-income communities [11]. Solid waste creation is expected to rise in lockstep with population growth. As a result of the growing volume of solid waste, emerging areas have been unable to build a waste management system. For instance, in the previous 50 years, India's entire population has expanded from 500 million to 1300 million [12]. Moreover, as economic expansion and industrialization progressed in this area, better living circumstances led to a rise in the volume of solid garbage [13]. Unfortunately, in several regions of India, the solid waste management system is still in its infancy, and recycling performance has been poor [13, 14]. It is critical to completely analyze and assess current solid waste management systems in fast-growing areas to construct a robust system and ensure a seamless transition to sustainable resource management.

Analytical techniques and approaches aid in the waste management decision-making process. The waste management system's analytical approaches may be grouped into engineering and system assessment models. Cost-benefit analysis (CBA), prediction models (FM), and optimization models (OM) are all examples of engineering models. System evaluation approaches include material flow analysis/substance flow analysis (MFA/SFA), as well as life cycle assessment (LCA) [15, 16].

In recent decades, McDougall et al. noted that integrative methodologies had been used to manage municipal garbage flow [17]. For instance, MFA (Material Flow Analysis) is a material flow analysis that systematically examines the flow and stock of materials within a given space and time system. Sfinx, FLUX, STAN, DYNFLOW, Gabi, and Umberto were created in MFA. Moreover, MFA was created using the mass balance model STAN (short for substance flow analysis), developed following the Austrian standard Norm Austria 2096 [18]. It has been applied to various waste applications, including home composting and material flow and substance scenarios [18]. The study by Markic et al. developed a scenario of municipal solid waste management (MSW) modeled by implementing the MFA/SFA (waste stream, carbon, and nitrogen) method in a Serbian City [19]. Furthermore, Applying the MFA method to better and systematic waste management in the city of Erbil [20].

One source that has the potential to contribute to increasing the rate of waste generation is Islamic boarding school educational institutions. Islamic boarding school is one of the traditional Islamic education institutions in Indonesia. The Ministry of Religion of the Republic of Indonesia reports that the number of Islamic boarding schools in Indonesia will be around 26975 in 2022. In addition, the number of students studying in Islamic boarding schools is around 2.6 million. The high population studying in Islamic boarding schools contributes to the increased volume of waste. A few researchers reveal the potential rate of waste generation in Islamic boarding schools in Indonesia. For example, a study by Auvaria noted that the waste generation rate in the Langitan Islamic boarding school was 496.66 kg/day, with the composition of the waste obtained consisting of 49.64% organic waste and 50.36% inorganic waste. Meanwhile, a study conducted by Hidayati et al. reported that the composition of waste in Islamic boarding schools in the Kendal Regency consisted of 24% organic waste, 16% paper, 57% plastic, 1.7% cloth, and 1.3%. The amount of waste produced by each individual at SMA PU Al Bayan is 0.2 kilograms per day or 2.26 liters per day, with the total weight and volume of waste generated each day being 85.75 kilograms or 970 liters. The findings at the Al-Amin Islamic Boarding School Mojokerto-Indonesia show the average generation rate of 31.54 kilograms per day, equivalent to about 0.11 kilograms per person per day, and the total composition of organic and non-organic values of 48, respectively, 54% and 51.46%. All of these studies only assessed the potential rate of waste generation, but the analysis related to the flow of waste has not been revealed in detail. The aim of this paper is to supplement the waste material flow assessment with new data. Case studies are examples of Islamic boarding schools. There has been no previous study that reviewed the rate of waste generation based on the flow of material in Islamic boarding schools. Considering the increasing number of Islamic boarding schools in Indonesia, this could potentially be a problem related to the rate of waste generation in an area. Thus, to provide scientific support, the topic of this article is measuring waste flow as part of the decision-making process for municipal solid waste management from Islamic boarding schools in Bogor-Indonesia. Thus, this article aims to investigate and propose a strategic and conceptual direction in the future and conclude the effectiveness of the waste management system.

2. MATERIAL AND METHOD

This research was conducted using current solid waste management practices at Islamic boarding school at Bogor, Indonesia. One significant concern is the daily growth in dynamic solid waste output. The data was obtained by weighing directly at the research site for ten days, referring to the Indonesian National Standard (SNI 3242: 2008 and SNI 19-3964-1994) for collecting and quantifying MSW samples and their composition. The waste is weighed for all sources such as student dormitories, kitchens, teachers' houses, and parks. The collected waste is then sorted based on the characteristics of the type of waste, such as paper, plastic, food waste, glass and metal. After the measurement data is obtained, it is processed using Microsoft Excel to obtain the total waste generation and its categories. Furthermore, the waste generation data were analyzed by applying the MFA Method.

The data provided will create a flow chart for MFA using STAN Software. Material Flow Analysis (MFA) analyzes the flow of materials and chemicals in a system over a certain time and space. Typically, the model or diagram produced by the MFA depicts the processing and movement of goods, chemicals, or materials. In MFA diagrams, processes are represented by black boxes, and flows are often depicted with arrows connecting all the processes in a system. The unit weight of waste kg/day will be converted into tons/year in the MFA system. In addition, the data entered into the system is referred to as input. MFA diagrams have three distinct elements: products, substances, and materials. Each selected element has a different significance [21].

Economic components with negative and positive values are goods like drinking water and fuel oil. A substance consists of one or more chemical elements having uniform units, for example, nitrogen (N) and carbon dioxide (CO_2). Finally, the intermediates of commodities and substances are elements characterized as carbon (C) or wood. STAN This software is open source and developed by the Vienna University of Technology. This program (version 2.7.101) was used to create MFA diagrams following Austrian Standard ONORM S 2096 (Waste management applications) [22].

An MFA research cannot be carried out in a standardized manner; nonetheless, a framework that includes the following three stages has been proposed: first, aim and scope definition; second, inventory and modeling; and third, interpretation [23]. Within the first step, it is decided, for example, what kinds of chemicals, processes, and geographical areas will be included. The subsequent phase involves collecting pertinent data, which can then be organized in one of three different ways: a straightforward bookkeeping, a static model that uses transfer equations, or, thirdly, a dynamic model that takes into account changes that have occurred over time. The very last thing that is done is interpretation. Sometimes this phase only means that the flows are presented in physical units, such as kg, but more comprehensive frameworks have been proposed. These frameworks contain the following categories: Quantification; exposure to humans and the environment; resource economy; function; and capacity to influence. In some cases, this phase only means that the flows are presented in physical units.

Once the MFA diagram is constructed from the data supplied to the STAN Software, it displays all the required results and quantities. This study aims to determine the total amount of solid waste created in Shah Alam during a certain period. All procedures and values related to municipal solid waste management will be considered to display the final results in the MFA diagram, also called the Sankey diagram. The exported figures in the MFA diagram show the amount of solid waste removed from landfills.

3. RESULT AND DISCUSSION

3.1 Waste generation rate and composition

Based on the direct measurement results, information related to the waste generation rate produced by the Boarding School in Bogor-Indonesia.

Based on Figure 1, information can be obtained that the waste generated from the Boarding School is 20 kg to 140 kg per day. The measurement of waste generation rate is carried out twice (morning and evening) for eight days. Furthermore, the graph also explains that the highest waste generation rate is on April 10, 2022, at around 140 kg. Meanwhile, the lowest waste generation rate is on April 8, 2022, which is around 22 kg. Furthermore, Figure 1 also provides anomaly information on the volume of waste generated. The anomaly mainly occurred on April 10, 2022 (Sunday), where every Sunday or holiday, there is a tradition of family visits from students who live in boarding school dormitories.

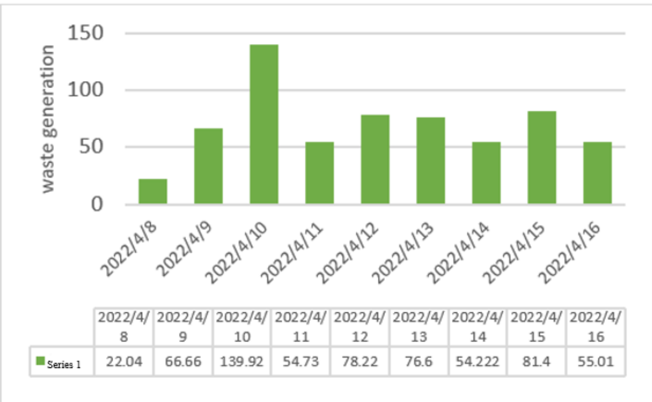

Figure 1. The results of measuring the rate of waste generation

As shown in Figure 2, information can be obtained that there are several characteristics of the waste generated in boarding schools, such as food, glass, metal, plastic, and paper. Furthermore, Figure 2 also provides information that food waste is the largest percentage of waste, around 65%. Meanwhile, plastic, paper, glass, and metal waste have around 27%, 5%, 2%, and 1%, respectively. Several researchers have also conducted studies on the measurement and characterization of waste. For example, a study conducted by Ramamoorthy et al. noted that the composition of food waste generation was the highest at around 39% in several schools in the Puducherry district of India [24]. Malakahmad et al. recorded about 30% of food waste generated at the University of Technology Petronas Malaysia [25]. On the other hand, about 7.25% of food waste is generated in higher education institutions in Ghana [26]. Adeniran et al. reported that only about 15% of food waste is generated at the University of Lagos, Kenya. A study by Payne and Hahn underlined that a school could produce around 4.3 pounds of solid waste/year [27].

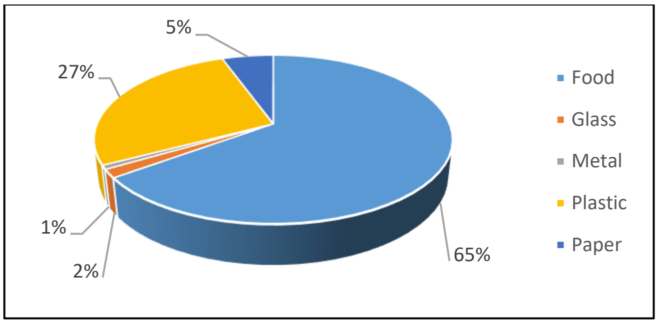

Figure 2. Composition by type of waste

Once considered a social burden, municipal solid waste is today viewed as a possible resource for producing new materials and as an alternative energy source [28]. The shift in perspective can be attributed to the rapid depletion of primary natural resources and a better understanding of the impacts of greenhouse gas emissions, which include but are not limited to biodiversity loss, increased air, water, and soil pollution, deforestation, and resource and material shortages, all of which are the result of over-consumption and unsustainable production processes [29]. Resource efficiency and recovery have recently received as much attention as energy efficiency. Nevertheless, the material flow into and out of a system is crucial for accurately measuring the degree of such resource utilization and recovery of secondary resources from waste.

3.2 Material flow analysis (MFA)

Material flow analysis (MFA) is a system evaluation tool that provides a method for determining the energy and material flow connections into and out of a specified system over a certain period. MFA can be used to evaluate an entire waste management hierarchy or a single waste stream. In addition, MFA is also used to identify sources of MSW generation, waste minimization, and internal material flow. Thus, there are potential opportunities for reuse and recycling and to account for hidden flows and discharges that may not be explained using more conventional MSW analysis techniques [30]. This research uses MFA to assess the material inside the boarding school's present waste management framework. The results obtained in the initial investigation are shown in Figure 3.

Based on Figure 3, information on the existing condition of all solid waste in the landfill can be obtained. This condition is because there is no good waste management process. Furthermore, Figure 3 also provides information that the source of waste comes from student rooms, teachers' rooms, gardens, and kitchens, with a total weight per year of around 30.13 tons/year. In addition, the calculation results also show that the total waste that is wasted in the TPA is around 30.13 tons/year. This situation explains that there is no waste management in the existing condition. As shown in Figure 4, burning waste is an option that is carried out at Islamic boarding schools. If this waste is not managed properly, it can increase environmental and human health problems. Program interventions are then carried out based on these results to reduce the waste sent to the landfill. The proposed program intervention is to develop a Waste Bank. The activity of the waste bank at the initial level is sorting waste based on the type of waste, which is then distributed to waste collectors for recycling. In addition, waste bank activities to reduce organic waste are carried out through Maggot BSF cultivation.

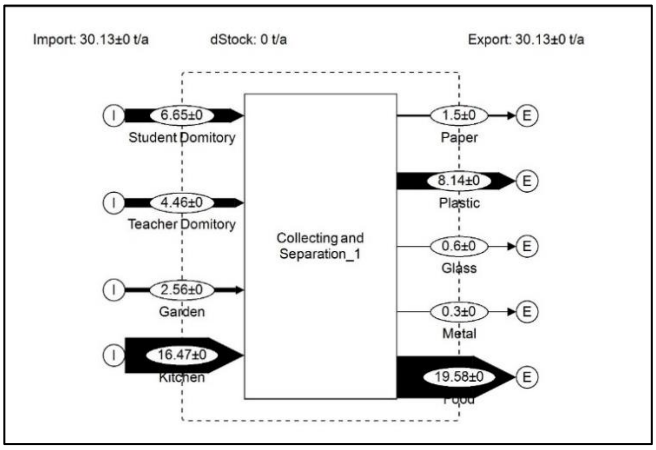

Figure 3. Material flow analysis existing condition

Figure 4. The existing condition of waste management

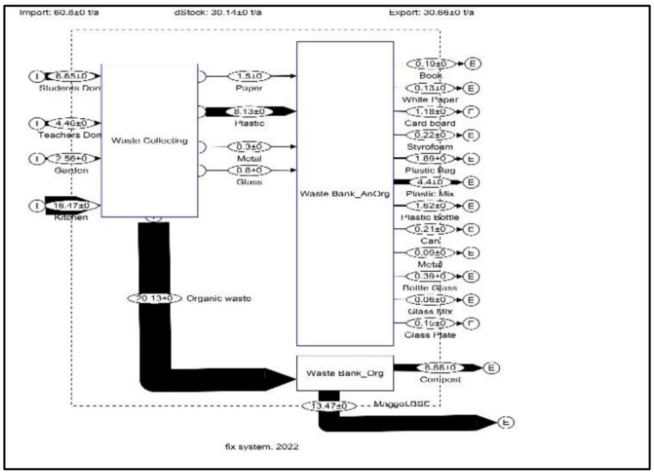

Figure 5. Scenario model for the proposed development of a Waste Bank

Figure 5 shows the model of the intervention program through the development of a waste bank. The waste bank proposed in the waste management program manages inorganic waste and manages organic waste through the development of Maggot BSF cultivation. Furthermore, from Figure 5, information can be obtained that the total solid waste included in waste management is around 60.8 tons/year. In addition, from the resulting model, information is also obtained that there are around 30.14 Tons/year in stock. This model shows that there will be a waste separation program at the waste bank, and the results of the waste separation will be sold directly to collectors or the recycling industry. Furthermore, separating inorganic waste from the MFA model is around 30.66 tons/year, sent to recyclers or informal waste collectors. Meanwhile, the MFA model also shows approximately 20.13 tons/year of food waste, which will be processed into compost and maggot cultivation in the waste bank. The results of organic waste processing will produce compost of around 6.66 tons/year and animal feed from Maggot BSF cultivation of around 13.47 ton/years.

Several studies have used the MFA method to model waste management scenarios. For example, Aydin used the Stan 2 software to illustrate a waste stream in the city of Ankara. According to research findings, the province collects nearly 1.6 million tons of solid waste annually—or 4,500 tons daily [12]. More than 400 thousand tons of compost are produced annually, and more than 470 thousand tons are used to produce methane. The model output also shows that 286 thousand tons accumulate annually in landfills. Mirzabayati et al. developed a scenario model for solid waste management using the MFA method in an integrated industry that considers economic and environmental factors. Moreover, this study hypothesized that the RDF process included in scenario one may have increased acid gas emissions. According to preliminary economic estimates, one's scenario cost of capital is higher, but the money raised from selling the RDF will pay off within five years [31]. Abdul Ghani also applied the MFA method to see the entry and exit of municipal waste (MSW) from a rural and urban scale in Terengganu, Malaysia. Furthermore, according to the findings in the study, the urban scale generates about 18% more annual waste stream inputs than the rural scale [32]. A study by Thushari et al. [33] created a waste flow model by applying the MFA and LCA methods which aim to improve the environmental profile of the waste management system. By applying the MFA method, Masebinu et al. revealed that about 4.41% of the 1,400,000 waste generated annually is recycled or recovered [28]. About 60% of the recycled percentage comes from unofficial recyclers. Furthermore, municipal landfills receive approximately 300,000 tonnes/year of recyclable waste, and 252,000 tonnes/year of organic waste are eligible for energy recovery in Johannesburg.

3.3 Waste bank as a sustainable solution to reduce the waste generation at boarding schools

The Indonesian government has enacted national and municipal solid waste management laws and technical restrictions. The only responsibility of the city administration is to implement the established regulations. For example, Act Number 32 of 2009 (Environmental Management), Government Regulation Number 81 of 2012 (Management of domestic solid waste), Regulation of Minister of Home Affairs Number 33 of 2010 (Guidelines of waste management), Regulation of Minister of Public Works Number 03/PRT/M/2013 (The infrastructure of domestic solid waste management), Regulation of Minister of Environment Number 13 of 2012 (Guidelines for the Implementation of Reduce, Reuse and Recycle Through Waste Banks). Because composition and recycling potential are crucial aspects of solid waste management planning, the government enacted legislation to aid the community in analyzing the characteristics of garbage by understanding its composition and recycling potential. In addition, there is a need to change the new paradigm of waste management in the community so that waste can be utilized as a resource with economic value. Regulation of the Minister of Environment Number 13 of 2012 on Guidelines for the Implementation of Reduce, Reuse, and Recycle (3R) through Waste Banks explains that waste banks are locations for sorting and collecting waste with economic value that can be recycled or reused. The process involves the community [34].

Figure 6. Intervention to reduce organic waste through Maggot BSF cultivation at the Waste Bank

The 3R concept is a new paradigm in consumption and production patterns at all levels by putting the highest emphasis on trash management to prevent waste, minimize waste by encouraging reusable and biodegradable goods, and use environmentally friendly waste disposal. The implementation of 3R involves social issues to stimulate changes in attitudes and mindsets toward realizing an ecologically friendly and sustainable society and proper management (regulation) of its implementation. In many towns, waste banks are now operational to serve the 3R program of government waste management. Schools participate by creating and maintaining garbage banks, primarily for instructional purposes. The Boarding School is among the educational institutions that operate a garbage bank. In addition, Islamic boarding schools can apply Maggot BSF cultivation as one of the 3R program interventions in the waste bank as shown in Figure 6. Even though it looks to be operating smoothly, waste banks in schools may not be in stable shape. It is necessary to sustain the viability of waste bank operations, including for educational purposes [35].

The waste bank is comprised of two terms. A bank is an intermediary entity that serves as a location for saving and lending money and conducting financial transactions. All undesired or unsuitable materials their owner typically dumps are considered waste [36]. The waste bank is a program for rubbish management that repurchases waste using a deposit-like financial system [37]. People in a town, sub-district, or district can utilize a waste bank similar to a bank to deposit their garbage or extract money from the value of the garbage they offer to the facility [38]. Waste Bank began to develop in numerous Indonesian cities, including Bantul, Malang, Surabaya, Gresik, and Cilacap and is expanding to nearly every city and regency in the country. It was a commendable effort, particularly in addressing trash issues [39].

The waste bank management concept contributes to environmental cleanliness and offers economic benefits. The trash bank management approach is also related to the local community's adoption and management of its waste for waste reduction and economic gain. According to Pariatamby and Tanaka, the waste bank not only helps to clean the environment but also generates extra cash for the community [37]. Garbage bank educates individuals on waste sorting and raises public awareness about waste management to reduce landfill waste [40]. The innovation of trash management at the local level through waste banks can boost the income of the city's disadvantaged [39]. Thus, the existence of a waste bank as a solution for reducing waste will support sustainable development.

Waste and its management are also mentioned several times in the indicators of the Sustainable Development Goals or Sustainable Development Goals by the United Nations (UN) or the United Nations (UN). This situation is, of course, because the environment, in general, is one thing that is focused on developing the concept of sustainable development itself. In Indonesia, this is also in line with one of the pillars of the SDGs or Sustainable Development Goals put forward by the Ministry of National Development Planning and the National Development Planning Agency (BAPPENAS). This concept is contained in a document entitled 'Metadata Indicators: Sustainable Development Goals (SDGs) Indonesia's second edition in 2020, namely the Pillars of Environmental Development. This document aims to realize the sustainable management of natural resources and the environment as a support for all life. This pillar consists of 6 SDGs goals. They are Goal 6 (Clean Water and Adequate Sanitation), Goal 11 (Sustainable Cities and Human Settlements), Goal 12 (Responsible Production and Consumption), Goal 14 (Ocean Ecosystems), and Goal 15 (Land Ecosystems).

Waste management is viewed as a multi-actor, multi-layer agreement on social engineering systems, or ISWM (Integrated Sustainable Waste Management) [38]. ISWM integrates both official and informal enterprises in the entire technological and social system of waste management. The ISWM framework acknowledges three key areas of waste management: Stakeholders, waste system components, and sustainability-related factors [41, 42].

All parties and factors must work together for an integrated waste management system. The inadequate legislative framework for waste management legislation, which affects Indonesia's ineffective waste management, is one of the key factors. The current legislative laws do not expressly regulate the waste management system. Due to the poor quality of waste management services, the most recent legislation, Law No. 18 of 2008, was not fully implemented. Table 1 compares the municipal waste management implementation features throughout three time periods in Indonesia. Meidiana contrasts Indonesia's waste management system over three (three) periods: before decentralization (1999), from 1999 to 2004, and from 2005 to 2010 [43]. Meidiana found that only one factor was the training program which had increased over the three periods [43]. This study indicates the poor progress of Indonesia in terms of the quality of waste management.

Waste Bank's implementation could reduce the high amount of waste in the community and in the final disposal site (TPA). As a result, the volume of waste in the community and landfill can be reduced. Waste Bank Management also follows the rules contained in Law Number 18 of 2008 concerning Waste Management, which has the 3R principle. The independent waste management program through the Waste Bank is currently one of the alternative solutions for the government and the community to reduce the increasing volume of waste that is increasingly out of control.

Table 1. Comparison of waste management systems in Indonesia in three periods

Waste Management Aspects	Before Decentralization 1999	1999 – 2004 (UNEP)	2005 Present
Integrated waste management system policy	Not available	Not available	Not available
Waste management regulation	Not available	Not available	Not available
Institutional arrangements for managing waste	Available	Available	Available
Waste management regulatory framework	Available	Available	Available
Financing support	Not available	Not available	Not available
Training program	Not available	Not available	Not available
Private sector participation	Not available	Not available	Not available
Community participation	Available	Available	Available
Information systems	Not available	Not available	Not available
Economic instruments	Available	Available	Available

4. CONCLUSIONS

In this study, MFA has been utilized to graphically depict the material flows within the waste management strategy of the Boarding School. This study relies on primary data from quantitative investigations based on the 1994 SNI method of waste generation assessment. In addition to the quantity and composition of the given waste, this study shows that waste management is still not good at existing conditions that can cause problems in environmental quality degradation. This paper describes the basics of MFA applications. Develop a comprehensive study with scenario analysis of alternative waste management approaches compared to current approaches, measuring the amount of waste and the potential, process efficiency, inherent by-products, and environmental impact of the applicable waste management technology. If this approach is generally adopted as the systematic method for solid waste management in other schools in Indonesia, it will facilitate the comparative assessment of solid waste management performance. Thus, a comprehensive solid waste management system that promotes sustainable resource management and serves the needs of communities might be built.

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