Opsi
Vol. 19, No. 1, June 2026
p-ISSN 1693-2102
e-ISSN 2686-2352

Implementation of cleaner production in the refined sugar industry to reduce landfilling in waste management at sugar industry in Cilegon

Prio Utomo *, Fatah Sulaiman, Juwarin Pancawati
Department of Environmental Studies, Universitas Sultan Ageng Tirtayasa, Serang, Banten 42435, Indonesia

***Corresponding Author**: priou102@gmail.com

Article history:
Received: 9 October 2025
Revised: 7 December 2025
Accepted: 29 July 2026
Published: 30 July 2026

Keywords:
Cleaner production
Refined sugar
Zero landfill

ABSTRACT

Sugar Industry in this study is a company located in Cilegon City, Banten Province, operating in the refined sugar industry. The objective of this study is threefold: first, to identify the flow of materials, products, and non-products in the refined sugar production process; second, to identify potential cleaner production alternatives applicable to the industry; and third, to determine the priority scale of cleaner production opportunities in the refined sugar industry. The research methods employed encompass a comprehensive array of approaches, including a thorough literature review, observational studies, environmental assessments, and comparative analyses. According to the findings of the research study, the total amount of waste generated in 2023 was 19,025.36 tons. Of this, 5,575.52 tons (29.3%) were landfilled, and 13,449.84 tons (70.7%) were reused by other industries. In 2024, the total waste generated was 16,579.35 tons, of which 16,568.44 tons were utilized by other industries as alternative fuel or alternative raw materials, and a mere 10.91 tons were sent to landfill. According to the 2024 data, a mere 0.07% of the total waste was landfilled, while a staggering 99.7% was reused by other companies. The implementation of cleaner production and zero-landfill principles has the potential to repurpose the waste generated.

DOI:
https://doi.org/10.31315/opsi.v19i1.15669

1. INTRODUCTION

Sugar is one of the essential food commodities that plays an important role in Indonesia's economy, as the country's sugar needs cannot be fully met by local sugar mills and national production capacity remains relatively low [1]. The refined sugar industry is a key sector within the agro-industrial domain, contributing significantly to the supply of high-quality sugar for both domestic consumption and the food and beverage industry [2] ,[3]. However, the production process of refined sugar generates various types of waste solid, liquid, and gaseous that, if not properly managed, can pose serious environmental risks [4], [5]. One of the most commonly used methods for managing industrial solid waste is landfilling, which over time can lead to land degradation, groundwater contamination, and the emission of greenhouse gases such as methane (CH_4) [6], [7].

Industrial waste management should not only focus on reducing the level or severity of pollution from waste that has already been generated (*end-of-pipe* treatment), but must also include efforts to minimize waste generation at the source and enhance the economic value of waste through reuse or recovery [8]. This approach is known as cleaner production based waste management technology [9]. With the growing awareness of environmental sustainability, cleaner production has become an increasingly relevant strategy for industrial sectors, including the refined sugar industry [10]. Cleaner production based waste management technology in the refined sugar industry is an approach to waste management that emphasizes pollution prevention at the source by improving production process efficiency, optimizing resource utilization, and promoting the reuse of generated waste. This approach does not merely emphasize end-of-pipe waste treatment; rather, it integrates technical, economic, and environmental dimensions to mitigate adverse environmental impacts while concurrently enhancing sustainable industrial performance.

Cleaner production is a systematic and preventive approach aimed at reducing the environmental impact of production processes by optimizing the efficiency of raw materials, energy, and water usage, while minimizing waste and emissions at their source [9], [10]. This approach not only reduces environmental pollution, but also has the potential to improve process efficiency and enhance overall industrial competitiveness [11].

The implementation of cleaner production in the refined sugar industry is expected to reduce the volume of waste requiring landfill disposal through measures such as the reuse of process residues, recycling of waste materials, and substitution with more environmentally friendly raw materials. In addition, the identification of critical points within the production process that have the potential to generate waste can serve as a foundation for continuous process improvement [12]–[14]. The implementation of cleaner production–based waste management technology provides significant benefits for the refined sugar industry, both environmentally and economically. This approach has the potential to reduce the volume and pollution load of waste, lower greenhouse gas emissions, and improve resource use efficiency. Conversion of waste into value added products has been demonstrated to reduce operational costs and enhance industrial competitiveness. Consequently, the implementation of cleaner production based waste management technology constitutes a pivotal strategy for achieving an environmentally friendly and sustainable refined sugar industry [13], [14].

The objective of this study is to examine the implementation of cleaner production principles in waste management within the refined sugar industry and to evaluate their effectiveness in reducing reliance on landfill as the final waste treatment method. This approach is expected to facilitate the development of more efficient and sustainable waste management strategies that can support environmentally friendly industrial development [17]. The waste categories assessed in this study consist of fly ash and bottom ash, spent resin, filter bags, used lubricating oil, blotong (filter mud), scrap metal, domestic waste, used packaging materials, and plastic pallets. It is hypothesized that the waste generated by the refined sugar industry which was previously almost entirely sent to licensed waste treatment landfills can be repurposed by other industries as alternative fuel or raw materials, thereby achieving the Zero landfill concept in the refined sugar industry. In the implementation of zero landfill, the entire input–output material flow analysis (MFA) is calculated in detail.

2. MATERIALS AND METHODS

2.1. Research Stages and Scope

This study was conducted at the refined sugar industry, located in Cilegon City, Banten Province. The research consists of three main stages: (1) identifying the flow of materials, products, and non-product outputs within the sugar refining production process and its associated waste management practices; (2) analyzing the implementation of the *zero landfill* concept in managing various types of waste, including fly ash, bottom ash, spent resin, filter bags, used lubricating oil, blotong, scrap metal, domestic waste, used packaging, and plastic pallets and (3) comparing the application of cleaner production practices between 2023, when the *zero landfill* concept was not applied, and 2024, when the concept was implemented.

2.2. Identification of Cleaner Production Opportunities

Raw sugar is unrefined crystalline sugar that contains a layer of impure molasses due to minimal processing, resulting in brownish-colored crystals. The raw sugar used as raw material originates from Brazil, India, Thailand, and Australia. Refined sugar is raw sugar that has undergone a purification process to remove molasses. Refined sugar has a whiter color than white crystal sugar and a high level of purity. The quality of refined crystal sugar has been regulated by the Food and Drug Supervisory Agency (BPOM) of the Republic of Indonesia under SNI 3140.2:2011. In practice, refined sugar is not permitted to be sold in retail markets or for direct public consumption; it is intended solely for use in the food and beverage industry. This regulation is stipulated under the Decree of the Minister of Industry and Trade (SK Memperindag) Number 527/MPT/KET/9/2004. Raw sugar is imported by sea freight and then transported by truck to the raw sugar warehouse. The refining process is carried out through several key stages, namely affination, melting, carbonatation, filtration, decolorization, evaporation, crystallization, centrifugation, drying, screening, and packaging.

The planning and identification of cleaner production opportunities were carried out in collaboration with sugar industry experts through interviews, as well as by referring to previous literature studies, resulting in several alternative strategies. The interviews were conducted with the Production Manager and Engineer during the 2023 and 2024 period. The formulation of cleaner production alternatives under the *Zero landfill* concept was conducted through a literature review by collecting and analyzing secondary data from reference books, scientific journals, and other relevant sources. Potential improvement measures based on the *Zero landfill* approach include directing waste to other industries where it can be further utilized and possess commercial value. The measurement instruments were applied by collecting data before the implementation of the zero landfill method and after the zero landfill approach had been implemented [15],[16]. The validation of quantitative waste data was conducted with the Waste Management Officer and the Environmental Supervisor.

2.3. *Comparative Analysis of Cleaner Production Implementation*

A comparative analysis of cleaner production implementation was conducted by comparing the waste generated in 2023, which did not apply the Zero landfill concept, with the waste managed in 2024 under the Zero landfill concept in the refined sugar industry in Cilegon, Banten Province. The types of waste examined in this study include fly ash and bottom ash, spent resin, filter bags, used lubricating oil, blotong (filter mud), scrap metal, domestic waste, used packaging, and plastic pallets. The effective management of waste is imperative for the reduction of environmental impact and the enhancement of production efficiency. The objective of the refined sugar industry is to minimize the utilization of landfilling as a waste treatment process. The waste management concept applied by the refined sugar industry is illustrated in Figure 1.

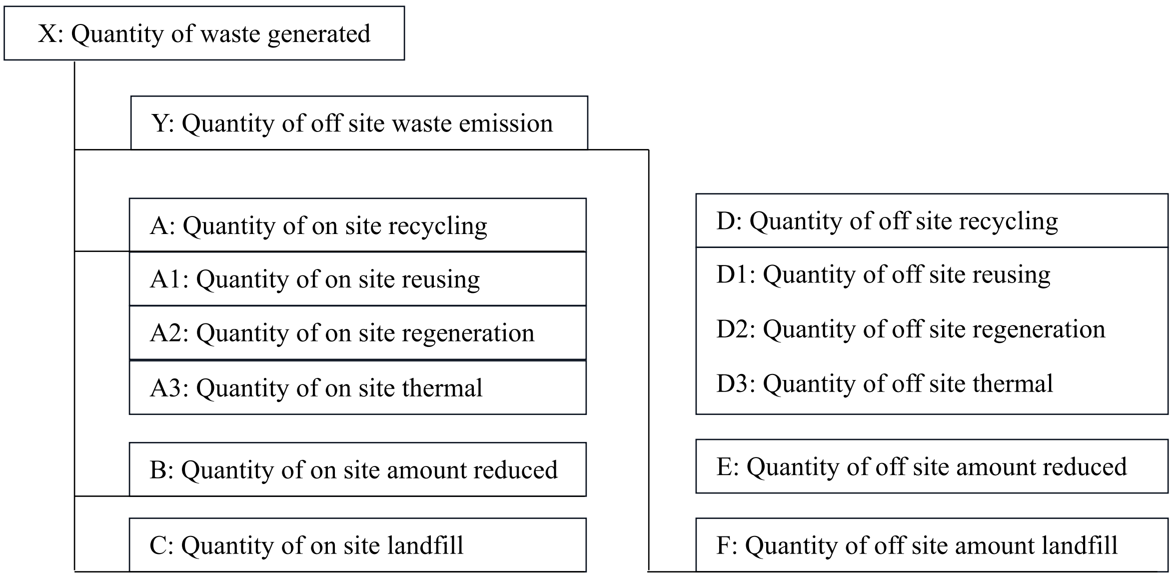

Figure 1. Waste management concept implemented by the refined sugar industry

X (quantity of waste generated) represents the total of Y, A, B, and C, which were generated prior to the implementation of the zero-landfill concept. Y, A, B, and C refer to wastes that are expected to be generated and treated within the plant. In contrast, D and E are wastes that are treated off-site by being transported to external waste management companies. The cost reduction used were in IDR.

3. RESULTS AND DISCUSSION

The results of this study consist of an explanation of the implementation of the zero landfill method in the production process, an analysis of waste data for the years 2023 and 2024. The implementation of the zero landfill approach is also described by comparing conditions before and after its application in order to identify differences in economic costs.

3.1. Production Process Stages

Refined sugar is a purified product derived from raw sugar, which typically originates from sugarcane or sugar beet. Raw sugar contains various impurities such as molasses, organic compounds, and minerals, necessitating a refining process to produce high-purity sugar. Based on interviews conducted with the Production Manager and Engineer during the 2023 and 2024 period, the average realized production capacity was approximately 800 tons per day. Raw sugar from the silo warehouse is distributed to the hopper and weighed to determine the melting per day. After weighing, it enters the Pre-Mingler Affination stage.

The production of refined sugar begins with the dissolution stage, where raw sugar is dissolved in hot water to form a sugar solution. This stage may be preceded by an affination process to remove the molasses coating from the sugar crystals. The resulting solution then undergoes purification, which involves the addition of lime ($Ca(OH)_2$) and carbon dioxide through carbonation or phosphatation methods. These steps function to precipitate impurities and suspended particles. The solution is then filtered to separate the formed precipitates [20].

Following the purification stage, the process continues with decolorization using activated carbon or ion exchange resins to remove residual color caused by organic compounds. The clarified solution is then concentrated through evaporation to increase the sugar content, followed by crystallization in vacuum pans to form pure sucrose crystals [21].

The formed sugar crystals are separated from the mother liquor by centrifugation or screening, then dried using hot air and cooled to prevent clumping. The final stage of the process is packaging, resulting in refined sugar that meets industrial standards [22]. The complete refined sugar production process is illustrated in Figure 2. The resulting refined sugar has a very high purity level, typically exceeding 99.8% sucrose, and is commonly used as a raw material in the food, beverage, and pharmaceutical industries due to its superior quality and cleanliness [20], [21]. Flowchart of the refined sugar production process stages at Sugar Industry shown in Figure 2.

Daily waste intensity is observed only for blotong, fly ash, and bottom ash, while the other types of waste are generated intermittently. Blotong waste is produced during the production process at the carbonation step, where calcium hydroxide and carbon dioxide are contacted with the sugar solution to capture impurities. Meanwhile, fly ash and bottom ash are generated from the power plant used to produce electricity for internal consumption.

Based on discussions with the Production Manager and Engineer, the average production in 2023 and 2024 was 800 tons per day. The production ratio indicates that for every 100% of raw sugar processed, 95% refined sugar, 2.5% molasses, and 2.5% filter cake (blotong) are produced. Accordingly, the daily output consists of approximately 760 tons of refined sugar, 20 tons of molasses, and 20 tons of blotong. The average generation of fly ash and bottom ash are generated at average rates of 22 tons per day and 20 tons per day, respectively. The conversion efficiency generally indicates that 1 ton of raw sugar produces approximately 0.97–0.99 tons of refined sugar. Minor losses (±1–3%) occur due to the refining process, molasses removal, and moisture content. This implies that producing 1 ton of refined sugar requires approximately 1.02–1.03 tons of raw sugar.

Fly ash and bottom ash waste are generated from a 6 MW power plant. On average, fly ash amounts to approximately 7 tons per day (around 200 tons per month), while bottom ash is about 30 tons per day (approximately 900 tons per month). This waste is temporarily stored at the Hazardous and Toxic Waste Temporary Storage Facility (TPS B3). Therefore, the data presented represent the quantity of waste transported from the TPS B3 to licensed hazardous waste treatment facilities.

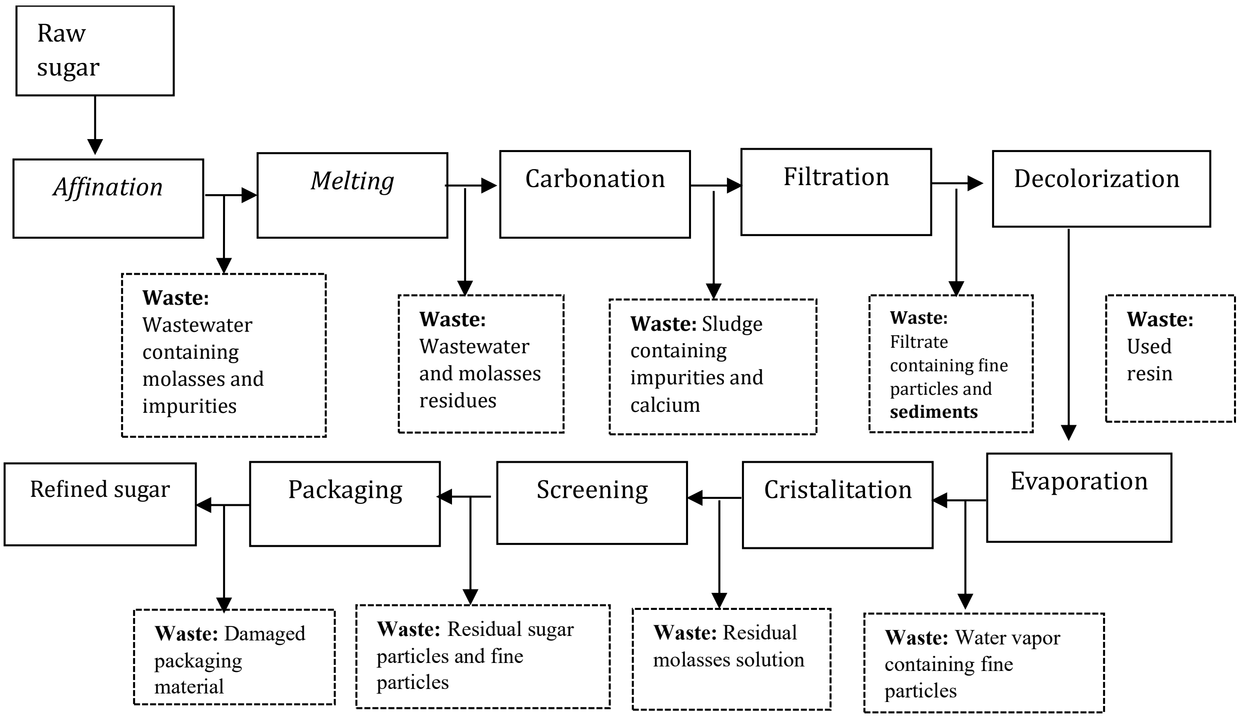

Figure 1. Flowchart of the refined sugar production process stages at Sugar Industry in Cilegon

Filter bag waste is generated from the filtration unit, specifically the candle filter/rotary leaf filter. When the filter becomes saturated, it must be replaced with a new one, depending on its condition. Based on the waste data, the replacement of saturated filter bags generates approximately 0.5–2 tons of waste. This waste is also temporarily stored at the Hazardous and Toxic Waste Temporary Storage Facility (TPS B3). Therefore, the data presented represent the quantity of waste transported from the TPS B3 to licensed hazardous waste treatment facilities.

Lubricating oil waste is generated from the replacement of lubricating oil in rotary machines by the maintenance department. This waste is temporarily stored at the Hazardous and Toxic Waste Temporary Storage Facility (TPS B3) in 200-liter drums. The amount of waste generated ranges from approximately 6 to 10 tons per year. Waste from expired chemicals in the laboratory, as well as waste generated from laboratory activities, is first collected in 25-liter containers. This waste is then temporarily stored at the Hazardous and Toxic Waste Temporary Storage Facility (TPS B3). Therefore, the data presented represent the quantity of waste transported from the TPS B3 to licensed hazardous waste treatment facilities. The amount of waste generated is approximately 1 ton per year, depending on laboratory activities and the quantity of expired chemicals.

Domestic waste originates from canteen activities and grass-cutting operations. This waste is first collected at the Temporary Storage Site (TPS). Therefore, the data presented represent the quantity of waste transported from the TPS to the final disposal site (TPA) by the municipal government. After undergoing treatment, the waste is utilized as an alternative fuel and sent to a coal-fired power plant (PLTU). The amount of waste generated ranges from approximately 4 to 5 tons per month.

3.2. Waste Data for the Years 2023 and 2024

The implementation of the Zero waste concept is instrumental in enhancing the management of waste, thereby reducing the volume of waste disposed of in landfills. The waste data generated during the 2023 period is presented in Table 1 while the waste data for 2024 is shown in Table 2.

According to the findings of the research, the total amount of waste generated in 2023 was 19,025.36 tons. A portion of this waste was sent to licensed waste treatment industries for neutralization, followed by landfill disposal. The amount of waste sent to landfill was 5,575.52 tons, which constitutes 29.3% of the total waste. Meanwhile, 13,449.84 tons of waste were reused by other industries, representing 70.7% of the total waste. In 2024, a mere 0.07% of the total waste was landfilled, with 99.93% being reused by other companies. Furthermore, the implementation of the Zero landfill concept has led to a substantial reduction in waste management costs, with a maximum decrease of 76% [25]. This is due to the fact that landfill disposal necessitates long-term management, which can extend up to 30 years [26]. Conversely, the Zero landfill concept facilitates the direct processing of waste as alternative fuel or raw material within the framework of cement industry rotary kiln units [27]. The following text is intended to provide a comprehensive overview of the subject matter.

Table 1 . Waste data for 2023 before implementation of the zero landfill concept

No	Types of waste	Characteristics	Treatment	Quantity (ton)
1	Fly Ash	Hazardous	off site reusing	2417.25
2	Bottom ash	Hazardous	off site reusing	10919.74
3	Used resin	Hazardous	off site landfill	29.37
4	Filter Bag	Hazardous	off site landfill	1.4
5	Lubricating Oil	Hazardous	off site reusing	6.1
6	Drum Plastic	Hazardous	off site landfill	1.24
7	Used lamp	Hazardous	off site landfill	-
8	Waste laboratory	Hazardous	off site landfill	-
9	Sludge IPAL	Hazardous	off site landfill	-
10	Blotong	Non hazardous	off site landfill	5543.51
11	Scrap metal	Non hazardous	off site reusing	46.84
12	Domestic Waste	Non hazardous	off site reusing	54.3
13	Packaging	Non hazardous	off site reusing	3.64
14	Plastic Pallet	Non hazardous	off site reusing	1.97
Totals				19025.36

Table 2. Waste data for 2024 after implementation of the zero landfill concept

No	Types of waste	Characteristics	Treatment	Quantity (ton)
1	Fly Ash	Hazardous	off site reusing	2166.25
2	Bottom ash	Hazardous	off site reusing	9628.00
3	Used resin	Hazardous	off site reusing	24.249
4	Filter bag	Hazardous	off site reusing	5.61
5	Lubricating oil	Hazardous	off site reusing	9.48
6	Plastic drums	Hazardous	off site reusing	1.17
7	Used lamp	Hazardous	off site landfill	0.10
8	Waste laboratory	Hazardous	off site landfill	8.71
9	Sludge IPAL	Hazardous	off site landfill	2.10
10	Blotong	Non hazardous	off site reusing	4665.48
11	Scrap metal	Non hazardous	off site reusing	142.3
12	Domestic waste	Non hazardous	off site reusing	40.58
13	Packaging	Non hazardous	off site reusing	10.04
14	Plastic pallet	Non hazardous	off site reusing	17.59
		Totals		16579.35

3.3. Implementation of Cleaner Production with the Zero Landfill Concept

The refined sugar production process at sugar industry generates both solid and liquid waste. The solid waste produced includes fly ash and bottom ash, spent resin, filter bags, plastic drums, blotong (filter mud), scrap metal, domestic waste, used packaging, and plastic pallets. The liquid waste generated consists of lubricating oil. The waste management approach adopted sugar industry, which utilizes the Zero landfill concept, is outlined in Table 3.

The effective management of waste is imperative for the reduction of environmental impact and the enhancement of production efficiency. The objective of the refined sugar industry is to minimize waste management through landfilling. Prior to 2024, the management of waste typically involved its shipment to certified waste processing facilities for subsequent landfilling. In 2024, the Zero waste concept was implemented. As demonstrated in Table 3, "Waste Management Balance," the refined sugar industry implemented a waste management concept in 2023 and 2024. This concept, known as the Zero Landfill concept, had a significant impact on reducing the volume of waste sent to external landfills [28]. Specifically, it was observed that in 2024, the application of the Zero Landfill concept led to a substantial decrease in waste sent to external landfills compared to the conditions prior to its implementation in 2023.

Table 3. Waste management concept implemented by sugar industry with zero landfill approach

No	Types of waste	After Zero landfill concept
1	Fly Ash dan Bottom Ash	Sent to licensed industries to be processed as raw material for brick (batako) production.
2	Spent resin	Sent to the cement industry as an alternative fuel in rotary kilns due to its calorific value >2500 kcal.
3	Filter Bag	Sent to the cement industry as an alternative fuel in rotary kilns due to its calorific value >2500 kcal.
4	Lubricating Oil	Sent to used oil processing companies for reuse
5	Plastic drums	Sent to the cement industry as an alternative fuel in rotary kilns due to its calorific value >2500 kcal.
6	Blotong	Sent to the cement industry as an alternative raw material due to its high $CaCO_3$ content or for use in briquette container or fertilizer production.
7	Scrap metal	Sent to steel processing industries for reuse.
8	Domestic Waste	Managed by the Cilegon City government and sent as alternative fuel to coal-fired power plants (PLTU).
9	Used Packaging	Sent to plastic waste collectors for reuse.
10	Plastic Pallet	Sent to plastic waste collectors for reuse.

As illustrated in Figure 2, there was a decline in the volume of waste generated in 2024, amounting to 16,579.35 tons, compared to 19,025.36 tons in 2023. The total amount of waste discharged externally from the factory in 2023 was 19,025.36 tons, whereas in 2024 it underwent a reduction to 16,579.35 tons. The total amount of waste that could be recycled in 2024 reached 16,568.44 tons, in comparison to 13,449.84 tons in 2023. Conversely, the amount of waste landfilled outside the factory in 2024 was only 10.91 tons, a significant decrease from the 5,575.52 tons recorded in 2023. This suggests that in 2024, the amount of waste managed through landfilling accounted for a mere 0.07%, while 99.7% of the waste was reused. Improving the performance of the waste management supply chain in the sugar industry should be focused on elements according to their priority level [29].

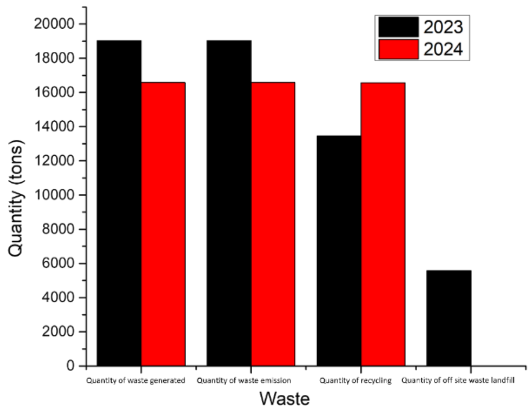

Figure 2. Graph of Waste Management Balance

The principles of cleaner production and zero landfill, as well as the concepts of reduce, reuse, and recycle, offer a framework for the utilization of waste generated by the refined sugar industry. This waste can be repurposed by other industries as alternative fuel or alternative raw materials, thereby reducing the environmental impact of the production process [30]. Moreover, the financial implications of waste management under the zero-landfill concept are substantially lower, with costs approximately 76% reduced compared to those incurred without its implementation. Consequently, the refined sugar industry has effectively implemented the principles of cleaner production across its entire production process and waste management practices [31]–[33]

As of 2024, the total waste generated amounted to 16,579.35 tons, of which 16,568.44 tons were utilized by other industries as alternative fuel or raw materials. A total of 10.91 tons of waste were sent to the landfill, including hazardous waste (B3) such as sludge from the wastewater treatment plant, laboratory waste, and mercury-containing lamp waste. The average of cost reduction is 76%. The data sown in Table 4.

Table 4. Waste management cost comparison

Number	Type of Waste	Landfill Cost (IDR)/tons in 2023	Reused Cost (IDR)/tons after 2023	Cost Reduction (IDR)
1	Blotong	1,000,000/tons	300,000/tons	5,011,000,000 /year
2	Ion Exchange Resin	3,300,000/tons	1,200,000/tons	25,200,000 /year
3	Filter bag	5,000,000/tons	1,200,000/tons	7,600,000 /year
4	Fly ash & Bottom ash	1,000,000/tons	160,000/tons	11,344,200,000 /year
5	Lubricating Oil	1,000,000/tons	1,500,000/tons	25,000,000 /year
6	Drum bahan kimia	5,000,000/tons	1,200,000/tons	4,560,000,000 /year
7	Used Lamp	120,000/kg	120,000/kg	-
8	Waste laboratory	4,900,000/tons	1,200,000/tons	3,700,000 /year
9	Sludge IPAL	2,300,000/tons	1,200,000/tons	2,200,000 /year
10	Scrap Metal	3000/kg	3000/kg	-
11	Waste domestic	250,000/tons	250,000/tons	-
12	Packaging	4,000/kg	4,000/kg	-
13	Plastic pallet	4,000/kg	4,000/kg	-

Landfill cost efficiency was determined by comparing waste management companies that apply a landfill-based concept with those implementing reuse strategies, such as utilization as alternative fuel or raw material. The landfill cost was IDR 5,000,000 per ton, whereas the reuse cost was IDR 1,200,000 per ton.

4. CONCLUSION

The implementation of cleaner production principles and the zero-landfill concept, predicated on the reduction, reuse, and recycling of materials, has proven effective in reducing the amount of refined sugar industry waste sent to landfills. Specifically, from 5,575.52 tons (29.3%) in 2023 to only 10.91 tons (0.07%) in 2024, there has been a marked decrease in the quantity of waste sent to landfills. The majority of the waste was effectively repurposed as alternative fuel or raw materials. In addition to reducing environmental impact, this approach is economically more efficient. Specifically, landfill management costs are recorded as being 76% higher than those associated with reuse-based waste management. These findings suggest that the industry has effectively implemented cleaner production principles in a sustainable manner, demonstrating a strategic focus on a circular economy.

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DECLARATION OF AI-TOOL USAGE

AI tools were used exclusively for grammar checking. No AI tools were used to assist with data analysis.