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Planning for Enhanced Waste Separation to Optimize Urban Waste Recycling at Recycling Facilities

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Abstrak
Tantangan yang semakin meningkat dalam pengelolaan limbah dalam konteks urbanisasi yang bertambah dan pola konsumsi yang berubah telah menekankan perlunya praktik pemisahan dan daur ulang limbah yang efektif. Penelitian ini menyelidiki proses rumit pemisahan limbah di dalam fasilitas daur ulang, dengan fokus khusus pada optimalisasi daur ulang limbah plastik. Pemisahan limbah memiliki peran penting dalam pemulihan sumber daya dan pengurangan dampak lingkungan. Limbah plastik, yang ditandai oleh beragam jenis polimer dan bentuk, memerlukan teknik pemisahan khusus. Tujuan utama dari penelitian ini adalah untuk menganalisis potensi pemisahan limbah di dalam fasilitas daur ulang dan mengusulkan strategi optimalisasi untuk daur ulang limbah plastik. Dengan secara komprehensif menilai proses pemisahan limbah, penelitian ini bertujuan untuk mengidentifikasi tantangan, hambatan, dan peluang untuk inovasi. Wawas an yang diperoleh dari analisis berbasis data akan membimbing perumusan pendekatan optimalisasi yang ditargetkan, berkontribusi pada transisi menuju ekonomi sirkular dan praktik pengelolaan limbah yang berkelanjutan.

Kata Kunci: pemisahan limbah, fasilitas daur ulang, limbah plastik, optimalisasi, ekonomi sirkular, pengelolaan limbah yang berkelanjutan

Abstract
The escalating challenge of waste management in the context of increasing urbanization and changing consumption patterns has accentuated the need for effective waste separation and recycling practices. This research investigates the intricate waste separation processes within recycling facilities, specifically focusing on optimizing plastic waste recycling. Waste separation plays a pivotal role in resource recovery and minimizing environmental impact. Plastic waste, characterized by diverse polymer types and forms, requires specialized separation techniques. The primary objective of this study is to analyze the potential for waste separation within a recycling facility and to propose optimization strategies for plastic waste recycling. By comprehensively assessing the waste separation processes, this research aims to identify challenges, bottlenecks, and opportunities for innovation. Insights derived from data-driven analysis will guide the formulation of targeted optimization approaches, contributing to the transition towards a circular economy and sustainable waste management practices.

Keywords: waste separation, recycling facility, plastic waste, optimization, circular economy, sustainable waste management

Introduction

Waste management has become a pressing concern due to its profound implications for environmental sustainability and community well-being (Sari et al., 2022; Suryawan et al., 2023; Suryawan & Lee, 2023). As urbanization accelerates and consumption patterns evolve, waste generation, particularly plastic waste, has emerged as a significant global challenge. The persistence of plastic waste in the environment, coupled with its potential to cause pollution, harm wildlife, and disrupt ecosystems, has underscored the urgent need for effective waste management strategies. Among these strategies, proper waste separation and recycling stand out as crucial steps toward mitigating the environmental impact of plastic waste (Phan et al., 2023). This research delves into the intricate waste separation processes within recycling facilities (Suryawan & Lee, 2023), focusing specifically on plastic waste, to unravel opportunities for optimization and enhanced recycling practices.

The primary objective of this research is to comprehensively analyze the potential for waste separation within a recycling facility, with a specific focus on optimizing the recycling processes for plastic waste. The intricate nature of waste separation involves intricate processes, methodologies, and technologies that warrant meticulous investigation to ensure their effectiveness. Scrutinizing the waste separation processes within recycling facilities, particularly those geared toward plastic waste, this study seeks to unlock avenues for improvement, innovation, and efficiency in recycling practices. Waste separation lies at the heart of recycling efforts, determining the success of resource recovery and minimizing waste in landfills or the environment (Gregson et al., 2015). The process involves sorting different waste materials based on their characteristics, such as composition, size, and recyclability. Effective waste separation is a crucial foundation for downstream recycling processes, as accurately separated waste streams (Pressley et al., 2015) can be efficiently processed, enhancing the overall recycling rate and reducing the strain on natural resources.

Plastic waste presents a complex challenge due to its diverse polymer types, colors, and forms (Honus et al., 2018; Zahra et al., 2022). The variation in plastic properties demands specialized separation techniques to ensure that different plastic polymers are correctly identified and sorted. Since plastic waste constitutes a significant portion of the overall waste stream and has considerable environmental implications, optimizing plastic waste recycling processes is paramount. The optimization efforts can lead to increased plastic recycling rates, reduced energy consumption, and a decreased carbon footprint, contributing to the transition towards a more circular economy. Focusing on waste separation within a recycling facility, this research aims to shed light on the efficiency, accuracy, and potential for improvement in plastic waste recycling. The analysis will encompass a holistic understanding of the waste separation processes, including identifying challenges, bottlenecks, and technological limitations that may hinder optimal recycling outcomes. Through data-driven insights, this research strives to identify opportunities for innovation, propose targeted optimization strategies, and provide practical recommendations that recycling facilities can implement to enhance their waste separation practices.

Methods

The research method consists of several stages involving the research location in Kamibox, Jakarta, research planning through field surveys, and data analysis using literature review. Firstly, the research location was conducted in Kamibox, a focused area of the study. This location was chosen due to its characteristics relevant to the research objectives. Kamibox can provide significant insights into the issues being investigated in this study. The next step is research planning through field surveys. A field survey is a method of directly collecting data from the research location to obtain accurate information about the situation being investigated. In this context, the researcher plans and surveys Kamibox to collect data on various aspects relevant to the research objectives. Field surveys may involve interviews with related stakeholders, direct observations, sample collection, and measurements (Sutrisno et al., 2023a, 2023b; Sutrisno 2024a, 2024b).

After collecting data through field surveys, the next step is data analysis using a literature review. Data analysis is organizing, interpreting, and evaluating the collected data. In this case, the researcher will combine the field survey data with information already in the literature. This analysis aims to understand the findings from the field survey in a broader context, connect them with concepts already existing in the literature, and help formulate consistent and interpretable conclusions.

Results and Discussion

Evaluating waste sorting systems is an essential aspect of effective waste management practices. In recent times, waste sorting has evolved from being conducted solely upon the arrival and unloading of goods at storage warehouses to being initiated right from the beginning of the goods collection process. This paradigm shift aims to streamline the waste sorting process, improve efficiency, and enhance the overall waste management system. In this context, the role of environmental engineers and professionals in waste management becomes crucial to ensure that the sorting process is carried out meticulously and following industry standards. Traditionally, waste sorting was primarily executed upon the arrival of goods at storage warehouses. However, the current approach involves initiating the sorting process at the onset of goods collection. During this phase, collection personnel are responsible for segregating items using tools such as sacks and other relevant equipment. The shift to this early-stage sorting process offers several advantages. It optimizes the overall waste management timeline, allowing for a more streamlined flow of waste from collection to disposal (Iacovidou et al., 2018). Additionally, this approach facilitates the immediate separation of recyclable materials, thereby promoting sustainability by maximizing the recovery of valuable resources (Figure 1).

Upon reaching the storage warehouse, the items that have undergone preliminary sorting are arranged in designated areas corresponding to their respective types. This preliminary sorting performed by the collection personnel serves as an initial categorization, making the subsequent sorting process in the warehouse more efficient. While the primary responsibility for sorting rests with the client, the collection personnel also play a vital role in ensuring that the collected items adhere to the predefined criteria for sorting. However, there are instances where collection personnel might inadvertently overlook specific sorting criteria, highlighting the need for periodic reviews and assessments of the sorting process. Despite the initial sorting efforts, occasional oversights in the sorting process may occur. These oversights can result in the need for reevaluation and corrective actions within the storage warehouse. This step becomes essential to rectify any inaccuracies in the sorting and to

maintain the overall quality of the waste management process.
In the storage warehouse, a more thorough and meticulous sorting process is conducted by specialized personnel designated solely for this purpose. This refined sorting approach aims to categorize further and prepare the waste items for subsequent stages of processing and disposal. However, due to the preliminary sorting carried out during the collection phase, the number of personnel required for the warehouse sorting process can be optimized, leading to increased operational efficiency and reduced human resources requirements. Once the waste items have been systematically sorted and categorized in the storage warehouse, they are prepared for transportation to third-party facilities. It is important to note that not all third parties accept waste that has not been properly sorted according to their recycling standards. Hence, the waste items that require additional sorting are segregated into designated areas within the storage warehouse. These items are subsequently subjected to further sorting processes by specialized personnel to meet the recycling standards set by third-party facilities.

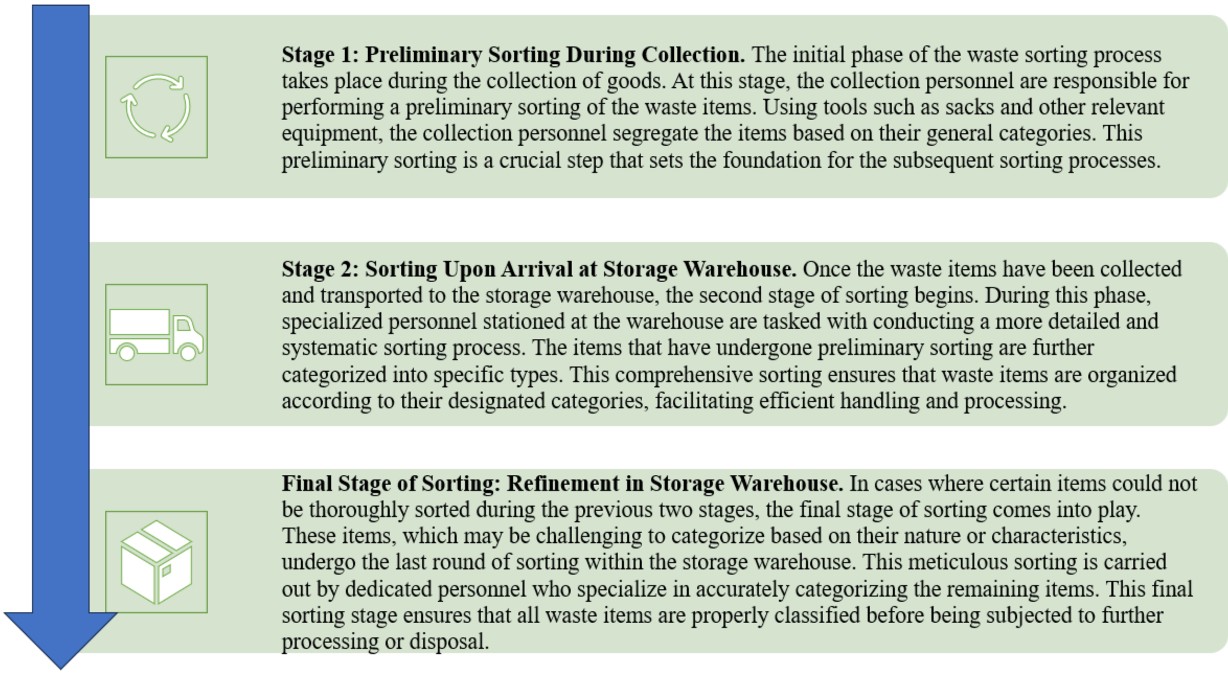

Figure 1. Shorting stage planning in Kamibox

The three stages (Figure 1) of waste sorting outlined above form a comprehensive process that ensures the efficient and accurate categorization of waste items. From the preliminary sorting conducted during goods collection to the detailed sorting in the storage warehouse, culminating in the final refinement of items requiring additional attention, this systematic approach contributes to effective waste management practices. By adhering to these sorting stages, waste management systems aim to enhance resource recovery, minimize environmental impact, and promote sustainable waste management practices.
Sorting paper in waste holds significant importance in recycling for several compelling reasons. First and foremost, effective sorting ensures that only clean and relevant paper materials are directed toward recycling facilities. By removing contaminants like non-paper items, liquids, and dirt, the quality of recycled paper products remains high, enabling their use in producing new paper items (Onusseit, 2006). Moreover, proper sorting leads to enhanced efficiency within the recycling process. Different paper types possess distinct properties, such as thickness, texture, and ink content. By segregating paper waste based on these properties, recycling facilities can streamline operations, processing similar materials together to optimize resource utilization, minimize processing time, and reduce energy consumption. One of the critical benefits of thorough sorting lies in minimizing contamination. Contaminated paper waste can disrupt recycling machinery and compromise the integrity of paper fibers, resulting in inferior recycled paper products (Suryawan et al., 2022).
Another compelling reason for prioritizing paper waste sorting is its impact on market value. Clean

and well-sorted paper waste commands a higher market price, as recyclers are willing to pay a premium for materials that require minimal processing and meet specific quality standards. This fosters a competitive recycling market and benefits waste generators and recyclers alike. Classification of paper waste in existing area including:

1. Mixed Archive: This category encompasses a combination of high-quality paper (HVS) and colored paper. These mixed archives often consist of documents, papers, or materials, including standard white paper and various colored paper types.
2. HVS/White: This type of paper waste includes used high-quality paper (HVS) originally used for printing purposes. Once printed materials have served their intended purpose, they fall into this category for appropriate waste management.
3. Books, Magazines, Brochures, and Newspapers: This category covers a wide range of reading materials, such as books, magazines, novels, comics, essays, brochures, and newspapers. Once these materials are no longer used, they are classified as paper waste and subjected to proper disposal or recycling.
4. Cardboard: Cardboard waste consists of corrugated cardboard materials commonly used for packaging and shipping purposes. This type of paper waste is recognized for its sturdiness and is often collected separately for recycling.
5. MIX A/Boncos: This category includes colored paper waste, paper bags, and duplex (cardboard packaging) that may have been used for various purposes. Additionally, it encompasses shredded archive materials, including ATM slips and sensitive documents that have been securely destroyed.
6. Dirty Boncos: This classification pertains to boncos that are soiled or wet. Such paper waste may have been exposed to moisture or contaminants, rendering them unsuitable for conventional recycling processes.
7. Cement Bags: This category comprises cement bags made from paper material. These bags are often used for packaging cement products and contribute to the paper waste stream.
8. Cores: Paper cores, rolls, tissue rolls, and bubble wrap rolls fall within this category. These items often serve as packaging or material support and can be recycled separately to optimize resource recovery.
9. Tetra Pak/UBC: This type of paper waste encompasses milk and coconut milk packaging, often referred to as Tetra Pak or UBC (used beverage cartons). These multi-layered packages require specialized recycling processes due to their composite structure.

Sorting plastic waste is equally essential and significant in recycling (Sari et al., 2023; Septiariva & Suryawan, 2023; Sianipar et al., 2022) for various compelling reasons. Like paper waste, sorting plastic materials ensures that only clean and appropriate plastic items are directed to recycling facilities (Phan et al., 2023). This process helps maintain the quality of recycled plastic products and supports their utilization in producing new plastic items. Efficient sorting of plastic waste leads to streamlined recycling operations. Different plastics have distinct characteristics, including polymer composition, color, and density. Recycling facilities can optimize processing, minimize sorting time, and reduce energy consumption by sorting plastic waste based on these properties, ultimately enhancing overall operational efficiency.

A critical reason for emphasizing plastic waste sorting is to reduce contamination. Contaminants in plastic waste can damage recycling equipment, compromise the integrity of plastic polymers, and result in subpar recycled products. Proper sorting significantly reduces the risk of contamination, ensuring higher-quality recycled plastic materials and improved recycling processes. Market value is another driving factor for thorough plastic waste sorting. Clean and well-sorted plastic waste fetches better prices in the recycling market, as recyclers are willing to pay more for materials that require minimal processing and meet specific quality standards. This economic incentive benefits waste generators and recyclers, encouraging responsible disposal practices. Classification of plastic waste in existing area including:

1. Clean PET Bottles: These are transparent and light blue PET plastic bottles stripped of their labels and caps. This category also includes gallon containers used for storing mineral water. These bottles are typically free from contaminants or residues that might hinder recycling.

2. Dirty PET Bottles: Similar to clean PET bottles, these are clear and light blue PET plastic bottles. However, the labels and bottle caps are still attached to the bottles in this case. This category encompasses both regular PET bottles and disposable gallon containers, which are still in use and haven't been cleaned yet.
3. Mixed Plastic Packaging Bottles: This category covers a variety of PET bottles with different colors and purposes. It includes PET-colored bottles, soy sauce, solution, coffee, cooking oil, and more. These bottles may have paper labels, providing information about their contents or branding.
4. PC Gallon refers to the commonly used mineral water gallon containers. The distinguishing characteristic is that the body of the gallon is fully intact, with no missing parts or significant damage.
5. Clean PP Cups (Clear): These transparent plastic cups are often used for packaging and serving mineral water. The key feature is that the cups have been thoroughly cleaned and their labels removed.
6. Colored PP Cups: This category includes various colors and designs of plastic cups. This encompasses colored cups with printing or designs and clear cups with attached labels.
7. Impact/Rigid Plastics: Items such as helmets, wall clocks, rice cookers, mosquito rackets, computer keyboards, and similar rigid plastic objects fall into this category.
8. Plastic Containers: This category covers many plastic containers used for different purposes. Examples include buckets, jerry cans, black/grey bottle bottoms, shampoo/soup bottles, medicine/vitamin bottles, and lunchboxes.
9. CD Cases: CD and DVD cases are used for storing discs.
10. PVC: PVC pipes are used for plumbing, guttering, and hoses.
11. White Crystal: Clear white jars and CD/DVD cases with a clear white appearance.
12. PVC Pipe refers to PVC pipes commonly used for plumbing, roof guttering, and hoses.
13. PE Plastic: Clear plastic materials without any printing on them. This includes plastic wrap, bubble wrap, and similar items.
14. Cooking Oil Plastic: Used plastic containers that previously held cooking oil, often for refilling.
15. Styrofoam: Clean styrofoam materials without food residue or significant contamination.
16. Bottle Caps: Caps from beverage packaging bottles, excluding black caps.
17. Gallon Caps: Caps used for PC gallon containers.
18. Yakult Bottles: Clean Yakult bottles with the bottle caps removed.
19. Miscellaneous Plastic: This category excludes plastic shopping bags and includes other items not specified in the previous categories.
20. Multilayer Plastic refers to packaging like coffee sachets and multilayer plastic packaging, where the inner layer is usually silver.

Efficiently sorting metal and glass waste is important in recycling due to its positive impact on environmental sustainability and resource conservation (Ayodele et al., 2018). Properly categorizing these materials streamlines their handling, sorting, and processing, yielding several key benefits. First, it simplifies the overall handling process by allowing recycling facilities to manage these diverse materials more efficiently, minimizing the risk of damage during transportation and processing. Second, efficient sorting enhances the accuracy of the recycling process by grouping similar items, aiding in more precise sorting and reducing the potential for contamination. Furthermore, effective shorting of metal and glass waste optimizes the processing phase. Recycling facilities can adjust their specialized machinery according to specific categories, boosting processing speeds, lowering energy consumption, and ensuring higher-quality output (Rue, 2019; Suryawan & Lee, 2023). Resource recovery also benefits from proper categorization, as valuable materials like aluminum and glass can be recycled indefinitely without compromising quality, making them essential resources for producing new items including:

1. Aluminum: Aluminum cans, aluminum pans, etc.
2. Iron: Iron, rusty iron, etc.
3. Tin Cans: Tin cans for milk, sardines, etc.
4. Zinc/Wire: Umbrella wire, etc.

5. Cabinet: Nails, hollow iron, lightweight steel, fans, dispensers, pans, radios, stainless steel, faucets, etc.
6. Brass: Brass materials.
7. Copper Wire: Copper wire materials.
8. Mixed Glass Bottles: Glass bottles of green, white, and brown colors. Caps are removed.
9. Clear/White Glass Bottles: Clear or white glass bottles like syrup bottles. Caps are removed.
10. Brown/Red Glass Bottles: Brown or red glass bottles like soy sauce. Caps are removed.
11. Green Glass Bottles: Green glass bottles such as beer bottles. Caps are removed.
12. Glass: Glass plates, cups, etc.

Efficiently managing waste cooking oil is paramount in environmental sustainability and waste management (Chozhavendhan et al., 2020; Rahman et al., 2020; Ramdja et al., 2010). Proper handling and disposal of used cooking oil significantly reduces negative environmental impacts and promotes the circular economy. Waste cooking oil can severely affect the environment and public health if not properly managed. Improper disposal, such as pouring oil down drains or into landfills, can lead to clogged pipes, sewer blockages, and water contamination. These actions pose immediate environmental risks and have long-term implications for aquatic ecosystems and human well-being. By recognizing the value of waste cooking oil as a potential resource, proper sorting and collection can pave the way for beneficial recycling processes. Used cooking oil can be recycled into biodiesel, a renewable fuel source that reduces reliance on fossil fuels and lowers greenhouse gas emissions. When waste cooking oil is efficiently sorted and collected, it provides valuable input for biodiesel production, contributing to the diversification of energy sources and promoting sustainability in the transportation sector. Efficient sorting of waste cooking oil also reduces the strain on waste management systems. Instead of burdening landfills or contaminating waterways, properly collected waste cooking oil can be directed towards recycling facilities or repurposed for energy generation. This not only lessens the environmental impact but also enhances the overall effectiveness of waste management practices.

Conclusion

This research underscores the pivotal role of waste separation in enhancing recycling practices, particularly in the context of plastic waste. The findings highlight the significance of accurate waste separation as a foundation for efficient recycling processes, contributing to higher recycling rates and reduced environmental impact. The investigation revealed the intricate challenges of plastic waste's diverse characteristics, necessitating specialized separation techniques. The study's primary objective of analyzing the potential for waste separation within a recycling facility has yielded insights into opportunities for optimization and innovation. By proposing targeted strategies, this research aims to empower recycling facilities to enhance their waste separation practices and contribute to the broader objectives of reducing plastic pollution and conserving natural resources. As the world grapples with the consequences of improper waste management, the insights and recommendations from this study offer a step forward in achieving a more sustainable and circular approach to waste management.

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