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Implementing Biodigester Technology for Sustainable Waste Management in Mojokerto City, Indonesia

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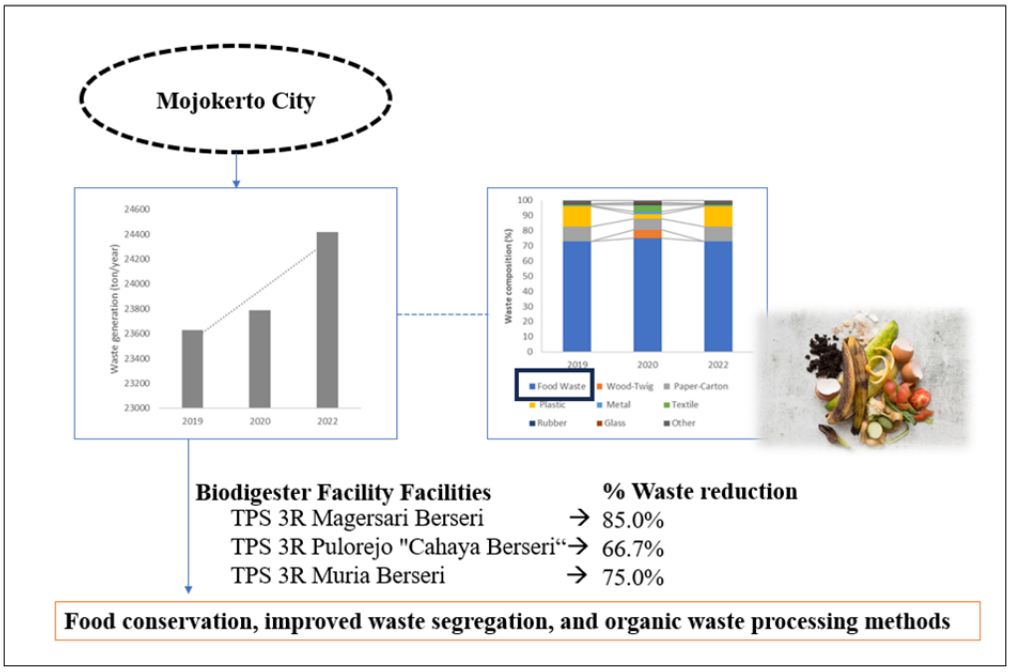
GRAPHICAL ABSTRACT



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ABSTRACT

Mojokerto City, located in East Java, grapples with a steadily rising waste generation trend accentuated by the COVID-19 pandemic. Drawing data from the National Waste Management Information System (SIPSN) and supplemented with an exhaustive literature review, this study scrutinizes the potential of biodigester technology as a solution to this mounting challenge. Mojokerto's waste, consistent in its composition from 2019 to 2022, is dominated by food waste, making it an ideal candidate for biodigester intervention. The study revealed that existing biodigester facilities in Mojokerto vary in their waste reduction efficiencies yet collectively demonstrate the viability of converting food waste to energy. For instance, the TPS 3R Magersari Berseri facility showcased an impressive waste reduction rate of 85.0%, processing 62.05 tons out of 73 tons of waste received annually. Comparative analyses of other facilities like TPS 3R Pulorejo "Cahaya Berseri" and TPS 3R Muria Berseri were also conducted, revealing varying degrees of efficiency. These facilities underscore the potential of biodigester technology in managing the rising tide of waste and contributing to sustainable energy generation. The findings of this study also call for increased awareness about food conservation, improved waste segregation at the source, and the promotion of composting and other organic waste processing methods, thereby optimizing the overall efficiency of waste management in the city.

1. INTRODUCTION

In recent decades, the rapid urbanization of cities worldwide has been paralleled by an exponential increase in waste generation [1, 2]. This waste poses significant environmental, health, and socio-economic challenges [3-5]. Mojokerto City, situated in the province of East Java, is a microcosm of this global trend [6]. Its growth and urbanization have led to mounting pressures on its waste management infrastructure, compounded further by the impacts of the COVID-19 pandemic [7, 8]. Historically, the predominant strategy to deal with urban waste has been the establishment of landfills and dumpsites. However, the limitations of these methods, including the vast land requirements, groundwater contamination potential, and methane emissions from decomposing organic waste, have necessitated the exploration of more sustainable waste management solutions. Traditionally, urban waste management often leans heavily on landfill and dumpsite strategies. While these methods have provided short-term solutions, they are fraught with long-term challenges. Landfills require extensive land resources, risk contaminating groundwater, and produce significant methane emissions from decomposing organic matter [9]. Given these environmental implications, there's a growing need for more sustainable, innovative solutions to the waste problem [10].

Across the globe, cities have been grappling with the challenges of burgeoning urban populations and their accompanying increase in waste generation. Proper and efficient waste management has become a quintessential aspect of urban planning [11], focusing on waste disposal, and optimizing waste as a resource. Mojokerto City in East Java is emblematic of this scenario, facing the dual pressures of rapid urbanization and the subsequent surge in waste production.

A characteristic of waste in many urban contexts, including Mojokerto, is its significant organic composition, primarily from food residues. This observation underscores both a problem and a potential solution. While organic waste in landfills can lead to harmful greenhouse gas emissions [12, 13], the same waste can be a renewable energy source when managed innovatively. This is where biodigester technology comes into play. Biodigesters process organic waste anaerobically, meaning in the absence of oxygen, they produce biogas primarily composed of methane [14-16]. This biogas can serve as a renewable energy source, converting a challenge into an opportunity. Additionally, post-biodigestion, the remaining material has potential uses as an organic fertilizer, thus further optimizing the value of organic waste [17, 18].

Considering the potential of biodigester technology and Mojokerto's specific waste composition and challenges, this study explores how biodigester technology can be sustainably implemented in the city. This study aims to delve into the intricacies of biodigester technology, assessing its suitability for the urban waste management context of Mojokerto. By analyzing data from the National Waste Management Information System (SIPSN) and reviewing extensive literature, the study develops a comprehensive understanding of Mojokerto's waste management scenario, mainly focusing on the potential of biodigester technology. By understanding the intricacies of this technology and its alignment with Mojokerto's urban context, this research aims to offer insights and strategies for effective and sustainable waste management.

2. LITERATURE REVIEW

Waste-to-energy methods are increasingly popular worldwide, offering waste reduction and energy solutions [19-21]. Small-scale anaerobic digestion systems, particularly for household use, efficiently manage on-site organic waste, reducing transportation costs and landfill use [22, 23]. These technologies are crucial in addressing energy poverty, especially in developing countries [24], where inadequate access to modern energy conversion methods hinders progress towards Sustainable Development Goals. Vulnerable groups, like women and children, often face exposure to harmful emissions from basic wood fuel combustion techniques [25]. Energy access, crucial for industrialization in developed countries [26], remains challenging in the developing world. The global shift away from fossil fuels due to their greenhouse gas emissions presents both opportunities and challenges for these nations. The main hurdles include political will, technological expertise, and financial resources for investing in clean energy conversion.

Biomass, a typical energy source in developing countries, offers a significant portion of the world's energy needs [27, 28], primarily for domestic heating. Despite contributing less to the energy mix in industrialized nations, biomass accounts for a substantial share in emerging countries [29, 30]. However, its potential to meet energy demands in these regions is often limited by economic, social, and technological challenges, along with inefficient conversion technologies. Progress in biomass utilization, from traditional to modern techniques, has enhanced efficiency and reduced health risks [31]. Biogas, a methane-rich gas from organic matter decomposition by microorganisms in moist environments [32, 33], also produces valuable by-products like humus and plant nutrients. The digestion process, facilitated by aerobic (oxygen-present) or anaerobic (limited oxygen) microorganisms, typically involves four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [34-36]. Various designs exist for harnessing biogas from feedstock, suitable for domestic and industrial purposes. Critical factors like volatile solids content, oxygen demands, carbon-nitrogen ratio, and inhibitory compounds influence the efficiency of the anaerobic digestion process [35, 37, 38].

3. METHODS

2.1. Data Colletion

In this research study, we employ a comprehensive approach integrating two principal methodologies: empirical data analysis and comprehensive literature review. The primary source of our data is the National Waste Management Information System (SIPSN), an initiative spearheaded by the Ministry of Environment and Forestry of Indonesia [39]. This digital platform has been instrumental in providing intricate details about waste management practices across the vast archipelago of Indonesia, with a particular emphasis on Mojokerto City. By harnessing the capabilities of this digital resource, our research encompasses specific facets like the types of waste, the quantum of waste generated, and the distinct processing techniques employed in Mojokerto.

After acquiring pertinent data from SIPSN, we conducted an in-depth descriptive analysis. Through this analysis, we endeavour to dissect the inherent characteristics of the waste in Mojokerto, mainly focusing on its composition and overall volume. However, understanding waste management is not merely about numbers but the broader context and the ecosystem in which these numbers exist. Hence, we delved into a vast array of literature to provide a richer context and a deeper comprehension of the overarching waste management issues at a national scale. This literature-centric approach involves scrutinizing scientific publications, previous research reports, and relevant policy documents. This enriched our insight and offered a panoramic view of the waste management scenario, its evolution, and its current state.

2.2. Data Analysis

Combining the strengths of these twin approaches, this study aspires to present a holistic perspective on the challenges and potentialities of adopting biodigester technology in Mojokerto City. Furthermore, we emphasized more than just understanding the current situation; we also drew lessons from the past and insights for the future. By considering best practices and findings from other regions within Indonesia, we hope this research elucidates innovative and pragmatic recommendations for waste management in Mojokerto while also contributing meaningfully to the national discourse on waste management. The rationale for such a methodological blend arises from the intricate nature of waste management. Waste isn't just a by-product of human civilization; it's a mirror reflecting our consumption patterns, lifestyle choices, and even our values. We get a snapshot of the present by analyzing empirical data, but the literature review allows us to understand the journey. The history of waste management, policy shifts, technological innovations, and societal attitudes are pivotal in shaping the current landscape.

Moreover, as we navigated through the digital alleys of SIPSN, it became evident that the data was quantitative and qualitative. It offered narratives, success stories, challenges faced, and even future aspirations of different regions. Each dataset, number, and percentage had a story about people, a city, and a society in transition. This is where the literature review played a complementary role. It provided the cultural, social, technological, and even political context to these stories, making our research a collection of data points and a tapestry of interconnected narratives.

Our methodological approach, grounded in empirical data analysis from SIPSN and enriched by a comprehensive literature review, aims to paint a detailed picture of waste management in Mojokerto City. With the challenges of urbanization, changing consumption patterns, and environmental concerns, understanding and addressing waste management becomes pivotal. Through this research, we hope to provide a roadmap, drawing from the past, analyzing the present, and charting the way forward for a sustainable and efficient waste management paradigm for Mojokerto and Indonesia.

4. RESULTS AND DISCUSSIONS

3.1. Result

The waste generation in the city of Mojokerto, located in East Java, has experienced a marked escalation between 2019 and 2022, with the COVID-19 pandemic playing a notable role in this upsurge. A specific increase of 3.25% from 2019 points to a transformation in societal behaviors and consumption patterns during the pandemic. Household waste saw a significant uptick with the imposition of lockdowns and the widespread adoption of work-from-home modalities [40, 41]. This was due to increased home-based activities, such as more frequent cooking, a surge in online shopping deliveries, and the heightened use of takeaway services [42, 43]. Furthermore, the necessity to use medical supplies like masks, gloves, and sanitizers also contributed to the growing waste pile [8, 44, 45]. While a 3.25% rise might seem marginal briefly, in the realm of waste management, especially in an urban context, this percentage can translate to an overwhelming volume, placing considerable strain on existing waste disposal systems and landfills. Besides the evident impacts of the pandemic, one cannot overlook other potential driving forces behind this surge.

Rapid urbanization, burgeoning population density, and evolving consumption patterns inherent to urban locales like Mojokerto could also be pivotal contributors. An increasing proclivity for packaged and disposable commodities exacerbates this scenario. From an environmental perspective, this uptrend in waste production flags potential hazards such as pollution, soil degradation, and increased in greenhouse gas emissions, especially if most of the waste is organic and left to decay. In Figure 1, Mojokerto's waste generation trajectory from 2019 to 2022 exemplifies the challenges that urban centers globally grapple with, accentuating the imperative for innovative and sustainable waste management strategies.

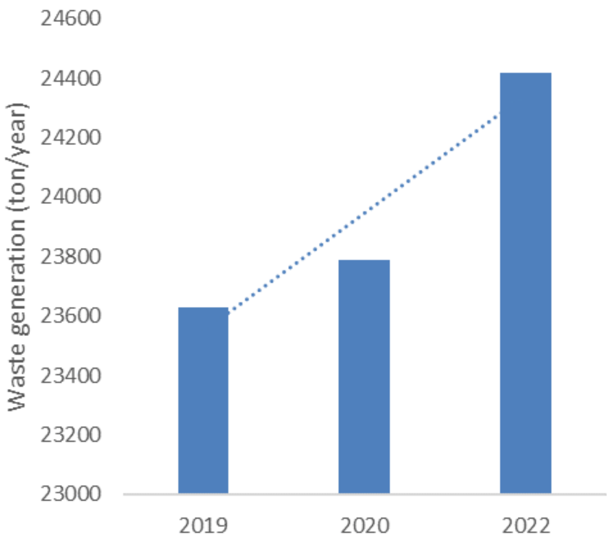

Figure 1. Waste generation in Mojokerto.

The composition of waste in Mojokerto has remained relatively consistent from 2019 to 2022, indicating a lack of shift in the city's residents' consumption patterns. This stability in waste composition underscores a continuity in lifestyle and preferences within the community. However, leftover food is a dominant feature of the waste profile, consistently comprising 73.1% to 75% of the city's total waste (as illustrated in Figure 2). This statistic shows a significant amount of food wastage within the urban center.

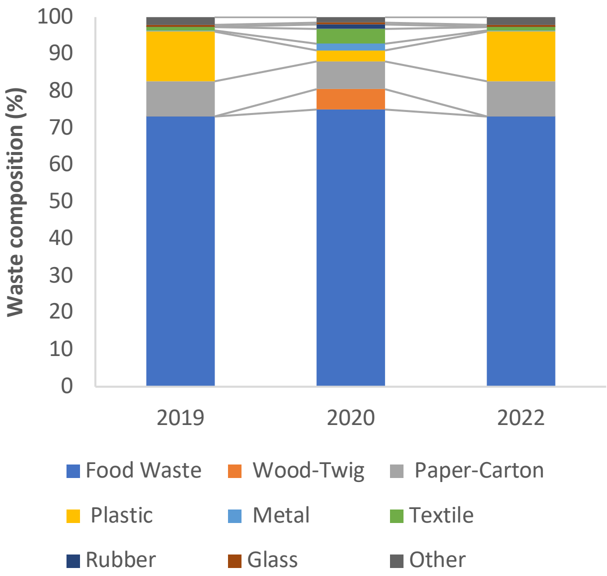

Figure 2. Waste composition in Mojokerto.

The consistent proportion of leftover food waste presents both challenges and opportunities. On the one hand, it highlights potential inefficiencies in food consumption and possible socio-economic factors that lead to wastage, such as purchasing habits or lack of awareness about food conservation [2, 46]. On the other hand, it offers an avenue for potential recycling or composting strategies, turning organic waste into valuable resources [1, 47]. n global urban waste management narratives, food wastage is a pressing concern due to its environmental and resource conservation implications, especially in such high proportions. Leftover food decomposing in landfills releases methane, a potent greenhouse gas contributing to climate change [48, 49].

Moreover, Mojokerto has maintained a consistent waste composition over the years, which provides a level of predictability that can benefit waste management planning. Yet, the high percentage of food waste signifies an urgent call for awareness campaigns about food conservation, enhanced waste segregation at the source, and promotion of composting and other organic waste processing methods. In essence, while Mojokerto's consistent waste composition offers certain strategic advantages for planning, the predominant food waste factor emphasizes the importance of revising and optimizing food consumption behaviors and waste management techniques in the city.

In Mojokerto's pursuit of sustainable waste management, various waste conversion processes have been introduced, including the biodigester facility specifically designed for food waste processing. This is particularly crucial given the high food waste composition in the city's total waste profile.

Among the established facilities, the TPS 3R Magersari Berseri stands out with an impressive waste reduction rate of 85.0%. It receives about 73 tons of waste annually, processes 62.05 tons, and leaves only 10.95 tons as residue. This indicates a highly efficient conversion mechanism, maximizing the utility of incoming waste while minimizing the residuals. Meanwhile, the TPS 3R Pulorejo "Cahaya Berseri" demonstrates a slightly different performance pattern. It processes a total of 54.75 tons of waste per year. Out of this, 36.5 tons are managed, and 18.25 tons are left as residue, resulting in a waste reduction percentage of 66.7%. This figure, while commendable, indicates room for further optimization to match the efficiency of its Magersari counterpart. Lastly, the TPS 3R Muria Berseri has an annual incoming waste of 58.4 tons. It manages to process 43.8 tons, leaving a residue of 14.6 tons. This translates to a waste reduction rate of 75.0%, positioning it between the other two facilities in terms of efficiency (Table I).

Biodigester facilities in Mojokerto represent a tangible commitment to reducing food waste's environmental footprint. They help divert significant amounts of organic waste from landfills and transform them into valuable resources. However, comparing the three facilities suggests varied efficiencies and, potentially, methodologies in waste processing. Continuous monitoring, learning from each facility's best practices, and investing in technological advancements can further bolster Mojokerto's sustainable waste management agenda.

TABLE I. Biodigester Facility in Mojekerto City.

No	Biodigester Facility	Incoming waste (ton/year)	Managed waste (ton/year)	Residue (ton/year)	% Waste reduction
1	TPS 3R Magersari Berseri	73	62.05	10.95	85.0%
2	TPS 3R Pulorejo "Cahaya Berseri"	54.75	36.5	18.25	66.7%
3	TPS 3R Muria Berseri	58.4	43.8	14.6	75.0%

3.2. Discussion

As urban centers continue to grow, efficient waste management solutions are imperative. Mojokerto City, located in East Java, is a poignant example of the burgeoning challenges and opportunities associated with urban waste. With its waste predominantly composed of food residue, Mojokerto's emphasis on biodigester technology is not just a mere practical solution; it's a necessary step towards sustainability. Biodigester technology, at its core, leverages the action of specific microorganisms that break down organic material in an oxygen-deprived environment [50]. The primary yield from this process is biogas, mainly methane, which serves as a renewable energy source. By capturing methane through biodigesters, Mojokerto City can effectively prevent the gas's release into the atmosphere from decaying food waste, which is a noteworthy benefit considering methane's potency as a greenhouse gas.

The preliminary data showcases biodigester facilities in Mojokerto, namely TPS 3R Magersari Berseri and Its Counterparts, Pulorejo "Cahaya Berseri" And Muria Berseri. Their operational metrics, including incoming waste and the percentage of waste reduction, highlight Mojokerto's earnest efforts in harnessing this technology. But beyond the numbers lies the story of Mojokerto's forward-thinking approach to addressing its waste management problem.

The multi-faceted benefits of biodigesters cannot be understated. On the environmental front, the technology's role in methane capture and conversion to biogas is a significant stride in climate change mitigation efforts [51, 52]. Economically, biogas presents an opportunity to slash energy costs, positioning it as a viable alternative to non-renewable energy sources [53, 54]. Moreover, the residual digestate from biodigesters is a potential organic fertilizer, converting what was once waste into a resource with agronomic value [17, 18]. The tangible waste reduction achieved through biodigesters also means fewer loads directed to landfills, resulting in extended landfill lifespans and cost savings in the long run.

However, while Mojokerto's pioneering steps in biodigester technology are commendable, it's crucial to understand and address the associated challenges. For one, the varying efficiency levels across different facilities indicate the need for standardized protocols and routine technological enhancements. Achieving operational efficiency isn't merely a matter of technical tweaking but also necessitates building a competent workforce with specialized skills in biodigester management. Moreover, the public's perception and acceptance of such technology are decisive in its success [4]. Transparent communication, outreach programs, and educational campaigns can demystify biodigester technology for the citizens of Mojokerto, enabling them to see its immediate and long-term benefits.

Expanding biodigester facilities requires substantial capital on the infrastructure and investment front [10]. Herein lies the potential for innovative financing mechanisms such as public-private partnerships, grants, and collaborations with international environmental bodies [55, 56]. The government's role is pivotal, with clear policies and regulations as catalysts for attracting private investment [57, 58]. Moreover, a structured approach to research and development can propel Mojokerto City's biodigester journey. By partnering with academic institutions, research bodies, and global environmental organizations, the city can tap into the latest advancements in biodigester technology. Such collaborations can facilitate knowledge exchange, ensuring Mojokerto remains up-to-date with international best practices.

A decentralized biodigester model involves setting up smaller-scale units managed by local community clusters rather than relying on extensive, centralized facilities [59]. This approach can significantly reduce the logistical complexities and costs of transporting waste to a central location. By situating biodigester units closer to the source of organic waste generation, such as local markets, residential areas, and food processing centers, Mojokerto can ensure a more efficient and environmentally friendly waste management process. Community involvement is a crucial aspect of the decentralized model [60, 61]. By engaging residents and stakeholders in the operation and maintenance of these biodigesters, the city can foster a sense of ownership and responsibility toward sustainable waste management practices. This involvement can range from segregating organic waste at the household level to participating in the monitoring and upkeep of the biodigester units. Such active participation not only enhances community cohesion but also raises awareness about the importance of waste management and sustainability.

Regular monitoring of biogas quality is essential to ensure that the gas produced is safe and effective for use [62, 63], whether for cooking, heating, or electricity generation. This involves checking the methane content and removing contaminants to meet household or industrial use safety standards. Proper maintenance and regular checks can prevent issues like gas leaks or inefficiencies in biogas production. Additionally, adherence to safety and agronomic standards for the digestate [64], the by-product of the biodigestion process, is crucial. The digestate can be a valuable organic fertilizer, rich in nutrients that benefit soil health and crop growth. However, it’s vital to regularly test its quality to ensure that it’s free from harmful pathogens or contaminants and meets agricultural standards. This guarantees the safety and health of crops and soil and builds trust among local farmers and end-users who might utilize this organic fertilizer. Ensuring the long-term viability of the biodigester framework in Mojokerto involves establishing clear guidelines and protocols for the operation of these decentralized units. This includes training community members in their management, creating a system for reporting and addressing operational issues [60], and setting up a feedback loop with stakeholders to continuously improve the biodigestion process. By focusing on these aspects, Mojokerto can effectively leverage decentralized biodigesters as a critical component of its sustainable waste management strategy.

4. CONCLUSIONS

The research reveals two critical aspects of waste management in Mojokerto. The first aspect highlights a significant increase in waste generation post-COVID-19 pandemic, signaling a pressing need for advanced waste processing methods to supplement or replace traditional practices. If the current trend of waste generation continues, conventional methods may soon become insufficient. The second key observation pertains to the consistent composition of waste from 2019 to 2022, predominantly food waste. This consistency suggests a stable consumption pattern among residents, underscoring the potential for specialized waste management solutions, such as biodigesters, which are particularly adept at handling organic waste. The effectiveness of existing biodigester facilities in Mojokerto, evident from their waste reduction capabilities, affirms the feasibility of this technology within the city's framework. The study posits that utilizing biodigesters not only addresses the waste management challenges of Mojokerto but also harnesses the energy potential of its primarily organic waste. However, it is essential to consider that the efficiency of biodigester facilities may vary due to local factors. The study seeks to understand these variations and provide insights for optimizing waste management strategies in Mojokerto.

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