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RESEARCH ARTICLE

Performance Comparison of Waste Management Approach in West Java through Masaro and Waste-to-Energy (WtE) Power Plant Technologies

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ABSTRACT

Waste is often considered as something useless and valueless. However, as the world enters a new industrial era, there is a growing awareness that waste has a high economic value. With proper processing, the waste can be recycled and even used as a feedstock for power generators. With a waste production reaching 24,000 tons per day in West Java, waste becomes a sustainable raw material. There are several methods for processing waste, such as Zero Waste Management Technology (Masaro) and Waste-to-Energy Power Plant (WtE). This study aims to compare the performance of Masaro and WtE technologies from their potential and economic impact. Both methods certainly have their advantages and disadvantages in terms of waste reduction capacities, products obtained, and financial benefits. This study reveals that Masaro technology can reduce 100% waste, whereas WtE can only reduce up to 70–97%. Subsequently, Masaro technology offers more diverse products rather than WtE (6 products vs. 3 products). Moreover, the gross profit margin (GPM) shows that Masaro can reach 99.27% while WtE is still in the range of 12.23–25.30%. It can be concluded that Masaro has quite higher potential and economic benefits compared to WtE.

Introduction

Waste handling is a serious concern and challenge that continues to be faced, despite efforts to reduce production and improve management [1,2]. West Java is grappling with a waste production of 24,000 tons per day with the amount proportion of food waste at 41.62%, plastics at 18.16%, woods at 12.19%, papers at 10.74%, clothes at 3.05%, glass at 2.69%, metals at 2.33%, leathers/rubbers at 1.31%, and the rest are unclassified [3]. Although the West Java Provincial Government has made efforts to address this problem, the target of reducing waste by 30% by 2025 is still far from being achieved as expected, with only a 5 to 10% successful reduction so far. The main sources of waste in the West Java region are food and beverage packaging, consumer goods packaging, and shopping bags, which add complexity to the waste management approach. Therefore, innovative efforts are needed in waste management, such as transforming the Cikundul Final Processing Site in Sukabumi City into a waste education center for the community [3]. Additionally, there is a need for innovation in the use of waste processing technology to reduce the amount of waste. Technologies offered include Waste-to-Energy Power Plants (WtE) and Zero Waste Management (Masaro).

The technology of WtE Power Plants enables the utilization of waste as a source of energy to generate electricity rather than being considered for final disposal. The West Java Provincial Government initiated the development of a waste processing system at the provincial level with several innovations. The Bandung City Government plans to establish a WtE Power Plant in the Gedebage area after the landslide incident at the Leuwigajah Final Processing Site. This location was chosen in the eastern development zone of the city, considering the availability of sufficient land and the relatively low level of development in the area. The

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Bandung City Government hopes to gain full support from the community to realize the shared vision for the construction of the WtE Power Plant desired by the city government and its residents [4–6].

Furthermore, the proposed solution for waste management is Masaro. Masaro, which stands for Zero Waste Management (translated from "*Manajemen Sampah Zero*" in Indonesian Language), represents a waste management system that shifts the traditional waste processing paradigm from the "collect-transport-dispose" approach to a "sort-transport-process-sell" method. Its focus is on producing high-value products from various types of waste. This concept was designed to address the escalating waste volume issue while increasing community income through more efficient waste management [7].

The implementation of the Masaro concept in West Java has been the main focus of efforts to address increasing waste-related challenges. Masaro aims to change the paradigm in waste management to produce economically valuable products through integrated waste sorting and processing technology. West Java Province faces significant difficulties in handling complex waste issues, prompting the implementation of Masaro as a potential solution by transforming waste into high-value economic products such as planting media, organic pesticides, solid and liquid Masaro compost, *pupuk organik cair istimewa* (POCI), and *konsentrat pakan organik cair istimewa* (KOCI) [8,9]. Beyond solving waste problems, Masaro is expected to increase community income by providing opportunities to earn income from waste and reducing reliance on unprofitable waste disposal.

Masaro also provides opportunities for the development of small businesses in the waste processing sector, potentially reducing economic inequality and increasing overall community income [8]. The West Java Governor encourages synergy between the government, academia, and various parties to address several challenges in the region, including inequality issues. Masaro is expected to be an effective tool in creating better cooperation between the government, businesses, the community, and the media. Collaborative efforts by Masaro have become an integral part of the steps taken to reduce and address the increasing and complex waste issues in West Java. Through various initiatives, both from the government and the community, West Java Province continues to strive to improve waste management and strengthen cooperation to address and overcome increasing and complex waste issues.

Waste processing using Masaro and WtE technologies certainly produces different performances in terms of the amount of eliminated waste, products obtained, and economic or financial benefits that encompass capital expenses (CAPEX), operational expenses (OPEX), and gross profit margin (GPM). Hence, the aim of this study was to compare the performance of these two waste-processing technologies in terms of potential and economic impacts.

Methods

Masaro Technology

The principles underlying Masaro's concept include the source segregation of waste and waste processing near the source. This principle stresses the need for waste processing to occur as soon as possible after segregation, ideally at a location, and the Involvement of the Community, Government, and Industry. It involves raising public awareness to separate waste according to predetermined categories, such as organic waste, plastics, paper, and metals. Source segregation ensures more efficient and effective waste processing as the waste is already separated from the beginning. The waste source concept aims to reduce the distance waste travels, minimize environmental impacts due to waste transportation, and enhance the processing efficiency [7].

In its implementation, Masaro categorized waste from the community into five different categories, each with a specific processing approach. This includes converting organic waste into liquid fertilizer, concentrated liquid feed, solid animal feed, and polybag planting media. Additionally, plastic film waste is processed into fuel oil, organic pesticides, and planting media in the Masaro plastic refinery unit as depicted in Figure 1. The concept also involves directly delivering recyclable waste to collectors or recycling centers [10–12] and utilizing the heat energy from waste to aid the conversion process of plastic film waste into fuel oil [13,14].

Fast-decomposing waste, such as food waste from vegetables and fruits, is processed into various useful products, such as liquid fertilizer, concentrated liquid feed, solid animal feed, and polybag planting media [15,16]. Plastic waste, including packaging, wrappers, and combustible waste, is processed using an incinerator. It is utilized to generate thermal energy from combustible waste, aiding the conversion of plastic film waste into fuel [9]. In addition, the flue gas was processed by a water scrubber treatment. Most components and particulates are absorbed in water, resulting in organic pesticides [17,18]. These products can be used to prevent plant and agricultural pests. Recyclable waste is handed over directly to collectors or recycling facilities for further processing. However, the management of hazardous waste is beyond the scope of Masaro.

By implementing this technology, Masaro successfully changed the public perception of waste from a burden to a valuable asset. The aim is to drive economic progress at the local level, support regional waste management efforts, reduce budget expenditures, and promote agriculture, livestock, and fisheries in surrounding areas.

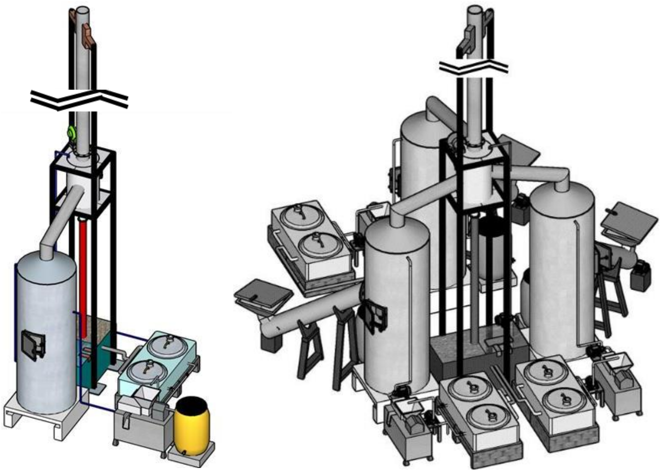

Figure 1. Masaro plastic refinery unit – 1 incinerator and 3 incinerators.

WtE Power Plant

WtE is a method for converting waste into energy, that is electricity [2,19]. This technology is believed to be an alternative to renewable energy, considering that energy generation from fossil resources causes severe environmental pollution [20,21]. The main component of a WtE is the incinerator [5]. An incinerator is used to combust waste, producing flue gas that still contains a large amount of heat [22]. Flue gas is then utilized to convert water into steam [23,24]. Steam is subsequently employed to drive the generator to generate electricity [25,26]. However, it can not be denied that Indonesian waste has a high water content, reaching 67.46%-wt on a wet basis [27]. Therefore, pretreatment in the form of drying plays an important role in increasing incineration efficiency [22]. A detailed schematic of this process is shown in Figure 2.

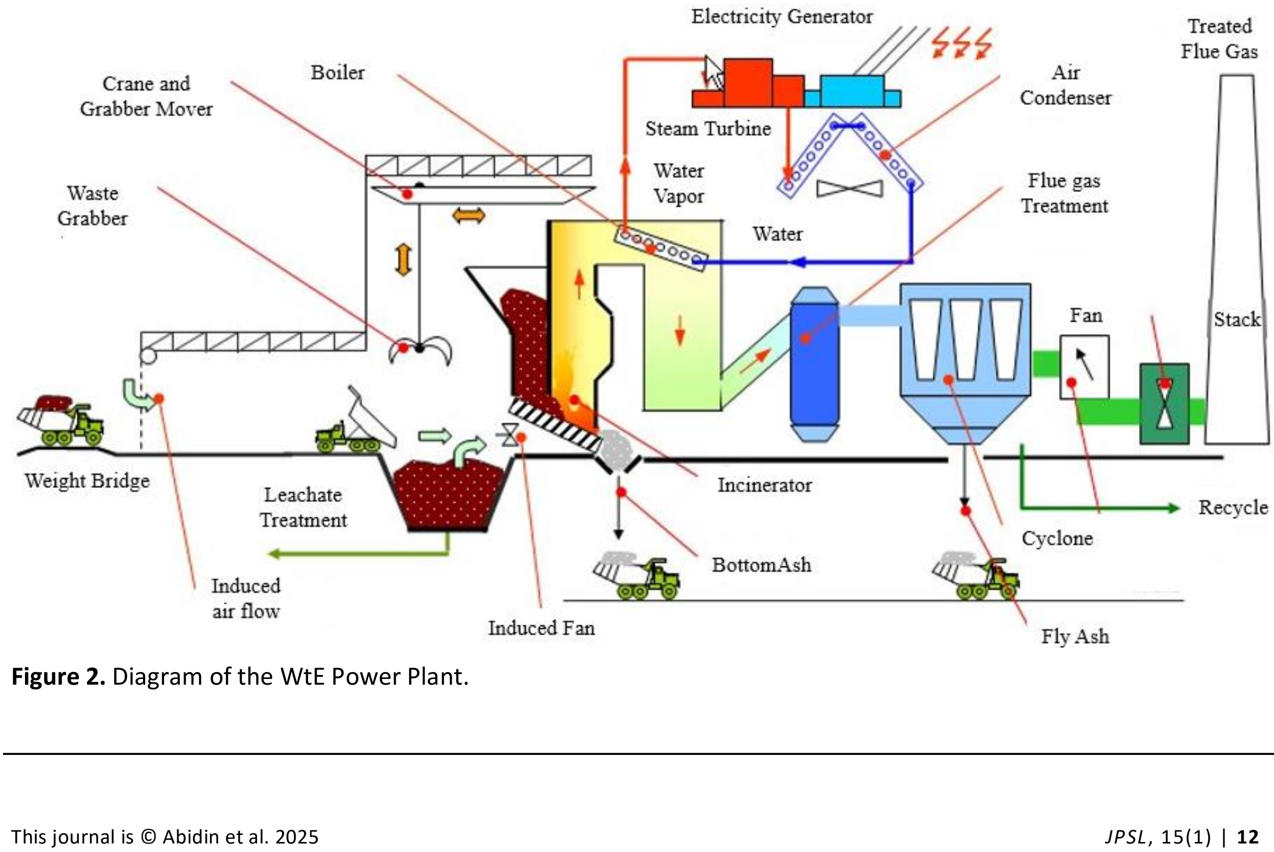

Figure 2. Diagram of the WtE Power Plant.

It can be observed that initially, the waste will be transported and weighed on the weight bridge. After weighing, the waste was stacked in the bunker. Subsequently, the waste was transferred from the bunker to the furnace using a crane. Once waste enters the incinerator, flue gas and bottom ash are generated. The bottom ash is transported by trucks out of the plant for processing by a third party. Flue gas is utilized to heat the water-filled pipes in the boiler [28].

The water in the boiler pipes turns into steam owing to the high temperature of flue gas [29]. Steam is then fed into the steam turbine to generate electricity [25]. The steam is directed to the condenser, turning the steam back into water [30]. This water was continuously recycled to serve as a steam source for the steam turbine. The remaining flue gas was directed to the flue gas treatment system [31,32]. Here, fly ash is formed and further transported for processing by a third party. The treated flue gas is then directed through the chimney for release into the atmosphere [33,34].

Methods in Comparative Analysis

This study compares the potential and economic aspects of Masaro and WtE to understand their performance. Potential analysis involves raw material requirements, product yield, and the merits and drawbacks of each approach. However, economic analysis requires actual data from field experiments for Masaro and data from experiments in the literature from Europe and China for WtE. All data were further processed to describe CAPEX, OPEX, and GPM.

Results and Discussion

Potential Analysis of Masaro Technology

The potential analysis of Masaro Technology reveals advantages that significantly transform the waste management paradigm. Masaro introduced a new approach that goes beyond mere collection and disposal, instead focusing on sorting, collecting, processing, and selling. Its primary focus is the production of high-value products, which triggers greater efficiency in waste management. Through the Clean, Green, and Productive Environment Program, communities, governments, and industries are engaged in managing and processing organic waste at the household level. This encourages the transformation of 100% fast-decomposing waste to produce liquid fertilizer, concentrated liquid feed, solid animal feed, 100% slow-decomposing waste to acquire compost, and 100% non-biodegradable waste to form fuel, organic pesticides, and polybag planting media [17,18].

As much as 1 kg of fast-decomposing waste can produce 10–12 L of POCI valued at USD 6.37. Slow-decomposing waste, including leaves, hard fruit peels, bones, and softwood, is composted using various technologies. The composting period, which usually takes several months, was reduced to 7 days. In the meantime, 1 ton of non-biodegradable waste that is processed in the Masaro plastic refinery unit can produce approximately 988.7 L of fuel, 503.9 L of organic pesticides, and 80.1 kg of ash. The temperature recorded was in the range of 800 to 1,000 ^{o}C from the incineration of combustible waste, which was sorted with a heating value of up to 24 MJ/kg.

Masaro can process 100% of the waste without leaving any overlooked residues. Moreover, Masaro demonstrated waste processing close to its source through collaborations with various stakeholders. This approach can improve waste management efficiency, reduce costs, and minimize environmental impact. The adoption of environment-friendly technologies, such as making biomass briquettes from waste, is evidence of Masaro's commitment to environmental preservation.

The implementation of sustainability-based management programs is an integral part of Masaro. This not only enhances the overall waste management efficiency but also ensures that the management is sustainable. Masaro continues to strive to develop the technology by implementing it in various regions, such as Magelang, Gorontalo, Bali, and Garut to optimize waste management at the local level. Economically, Masaro's implementation allows government budget savings in waste management and provides additional income for local communities through the added value generated from more efficient waste management.

With the existing potential analysis, Masaro offers a comprehensive solution to waste management that is not only economically effective, but also has a positive impact on the environment and society. All stakeholders, including the community, government, and industry, should participate to ensure the success of the long-term program. The community continues to segregate waste at the source; the government is responsible for providing education, facilities, and financial support; and the industry can collaborate in recycling and recovering materials from waste for reuse through corporate social responsibility.

Potential Analysis of WtE

Currently, in many areas, waste from various sources (streets, markets, public facilities, and residential areas) is collected and disposed of at Temporary Storage Sites before being transported to the Final Disposal Site [35]. With waste collection systems in landfills, issues such as soil and groundwater contamination around landfills often arise. According to the commercial WtE Power Plant in Bantargebang, Indonesia, and Gaziatep, Turkey, they have the potential to solve this problem and provide economic value to waste. The heating value of waste before drying is in the range of 5 to 8 MJ/kg [36]. The significant performance of waste reduction was achieved by up to 96%-wt with the typical range of 70 to 97%-wt [27,36].

Beyond energy, the remaining materials are fly ash and bottom ash, which can be further processed for construction purposes or plating media [37]. Besides, the maximum energy that can be harvested at 1,650 MWh in Turkey [36] and 784 to 956 MWh in Indonesia [19,27]. The incineration temperature was also recorded at 550 to 900 ^oC depending on the water content of the waste [27,34,36]. However, this technology still has some drawbacks, such as hazardous impurities in incineration smoke and high initial and operational investment costs [38].

Economic Analysis of Masaro Technology

Simple economic analysis using gross profit margin (GPM) is a commonly used method for evaluating the profitability of a project or business. In the context of Masaro, the GPM calculation is performed by comparing the raw material costs obtained from supplier data, which are averaged with the estimated total sales generated using the prices set by *PT Masaro Sukabumi Maju Mandiri* (commercial with 76% of domestic component level). The GPM calculation was 99.27% (Table 1), illustrating a high-profit margin from the sales of products produced by the Masaro factory. This value suggests that almost all production costs are covered by the selling prices of the products. A GPM value approaching 100% indicates that the factory has efficient cost management and optimized product selling prices, making the project economically feasible. The detailed domestic component level and component detail for Masaro's monthly depreciated tools and expenses are presented in Tables 2 and 3.

Table 1. GPM analysis.

Components	Amount	Price	Total price (USD/year)
Molasses	1.19 ton/day	USD 0.48/L	129,663
Water	237.8 ton/day	USD 1.21/m^3	106,950
Biocatalyst	672 L/day	USD 5.09/L	1,249,647
Total CAPEX			1,486,260
OPEX	2,400 tons/day	USD 12.74/ton	11,157,566
Compost	500 tons/day	USD 0.05/kg	8,716,848
Organic pesticides	90,000 L/day	USD 50.95 /L	167,363,484
POCI	124,000 L/month	USD 50.95/L	7,581,031
KOCI	124,000 L/month	USD 50.95/L	7,581,031
Total Income			202,399,959
GPM			99.27%

Table 2. Domestic component level details for the construction, operation, development, and maintenance of the Masaro Project.

Unit	Number of units	Domestic component level (%)	Price (USD)	Total (USD)
Conveyor 1	1	83	11,702	11,702
Conveyor 2	1	84	11,702	11,702
Conveyor to Kiln 1	1	84	12,538	12,538
Conveyor to Kiln 2	1	78	5,684	5,684
Screw Conveyor	1	75	12,737	12,737
Hopper	4	31	9,616	38,466
Rotary Screen	4	100	3,280	13,119
IT & OT Rotary Screen	1	100	1,580	6,320
Sorting Machine	1	86	19,105	19,105
Biocomposter	1	100	318	318
Composting Bin	1	100	2,979	2,979
Incinerator	1	100	31,842	31,842
Total		76		166,513

Table 3. Component detail for masaro's monthly depreciated tools and expenses.

Unit	Number of units	Depreciation (USD)	Total (USD)
Waste Shredder Machine	1	318.42	318.42
Bioreactor 225 L	16	76.42	1,222.75
Bioreactor 1000 L	16	305.69	4,890.99
POCI-Supplementary Feed Filling Tank 1000 L	2	63.68	127.37
Liquid Pump POCI-Supplementary Feed	2	38.21	76.42
Slurry Pump POCI-Supplementary Feed	3	382.11	1,146.33
Piping System	4	382.11	1,528.43
Safety System (Sink, Safety Shower)	1	63.68	63.68
Slurry POCI-Supplementary Feed Press Machine	2	636.85	1,273.69
Filling Unit	1	1,592.12	1,592.12
Total			12,240.21

Economic Analysis of WtE

The economic analysis of WtE Power Plants is examined using CAPEX and OPEX. The CAPEX data for the WtE in various regions are listed in Table 4. Based on this comparison, WtE Power Plants in Indonesia have a CAPEX ranging from 450 to 770 USD/ton/year, plus an additional 10 to 40% for civil and logistics structures [4]. A WtE with a capacity of 100,000 tons/year has a CAPEX value of 45,000,000 to 77,000,000 USD. The OPEX from WtE is assessed based on the labor costs of WtE and the maintenance costs of WtE itself. The labor cost data in Table 5 were taken from a WtE in Indonesia. The maintenance costs can be assumed to be 2% of CAPEX. The total OPEX from WtE is presented in Table 5. It can be seen that the OPEX value of WtE with a capacity of 100,000 tons per year is 1.18 Million USD per year. According to a study by Xin-Gang et al. [39], the GPM for WtE was in the range of 12.23 to 25.30%. Finally, a comparison of the potential and economic analyses of Masaro and Wte is presented in Table 6. It can be concluded that Masaro was, to some extent, superior to WtE in terms of potential and economic analysis.

Table 4. CAPEX data for Waste-to-Energy power plants (WtE) in several countries.

Country	Value (USD/ton/year)
China	190 – 400
Europe	600 – 1,000

Table 5. OPEX in WtE.

Category	USD/year
Plant manager (2 people)	38,742
Skilled workers (25 people)	193,711
Staff admin, unskilled workers (13 people)	50,365
Equipment Operation	900,000
Total	1,182,818

Table 6. Comparison summary for masaro and WtE.

Parameter	Masaro	WtE
Waste reduction (%-wt)	100	70 – 97
Product obtained	6 (POCI, KOCI, compost, fuel, organic pesticides, planting media)	3 (energy, construction, planting media)
Economic potential, GPM (%)	99.27	12.23 – 25.30
The level of technology use	Commercial	Commercial

Conclusions

WtE generates electricity from waste and contributes to the production of renewable energy. WtE helps to reduce the volume of waste and addresses waste management challenges. In contrast, Masaro offers a zero-waste management system with lower processing costs and cutting-edge technologies. Masaro applied circular economy principles, ensuring that non-biodegradable waste is processed and utilized for various agricultural purposes and as an energy source for human needs. Further studies should highlight the active participation of all stakeholders in waste management through the triple-helix linkage of local communities, government, and industry. Communities play a role in segregating waste at the source, whereas the government is responsible for educating the public about waste segregation, providing facilities for hazardous waste management, and overseeing the processing of hazardous waste. Furthermore, the industry, through corporate social responsibility, plays a crucial role in recycling and recovering materials from waste for reuse through CSR (Corporate Social Responsibility).

Author Contributions

AZA: Conceptualization, Supervision; **SS**: Writing - Review & Editing, Formal Analysis, Validation, Visualization; **ABAS, AAC**: Writing Original Draft, Methodology, Visualization; **MMAS, ESAS, EVY, AM, RPP**: Writing - Review & Editing, Formal Analysis.

Conflicts of interest

There are no conflicts or competing interests to declare.

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