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Optimization of the Ubung Gemilang Material Recovery Facility in North Denpasar District

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ABSTRACT: North Denpasar District is one of four districts in Denpasar City, a tourism-based area that faces various challenges, including infrastructure, human resources, and sanitation issues. In response, the Provincial Government of Bali issued Governor Regulation No. 47 of 2019 on Source-Based Waste Management, emphasizing the 3R principles (Reduce, Reuse, Recycle) to minimize waste sent to final disposal sites. This study was conducted in North Denpasar District and focuses on technical aspects and community participation in optimizing the Ubung Gemilang Material Recovery Facility (MRF). The results show that the average waste generation in Ubung Subdistrict is 0.61 kg/person/day, with an average density of 164.91 kg/m³. The waste composition is dominated by plastic (29.21%), followed by leaves and ritual waste (23.5%), and food waste (16.95%). The highest recovery factor (RF) was found in metal (100%), followed by leaves/branches (90.45%) and glass (80.64%). A community participation survey revealed that 58.45% of respondents were willing to manage their waste through the MRF and pay the required service fee. Based on these findings, a service expansion projection was developed through 2034. With projected population growth and increased service coverage, the MRF is estimated to serve 7,255 people, managing up to 4,353 kg of waste per day. To support this capacity, projected equipment needs include two shredders, two screening machines, eight three-wheeled vehicles, and two residual waste containers. While the current total land area of 413.11 m² remains sufficient overall, several operational zones—such as compost maturation, screening, and recycled product storage—are projected to face land shortages. Therefore, optimizing spatial planning within the MRF facility becomes a critical strategy to meet future needs.

KEYWORDS: Community Participation, Material Recovery Facility (MRF), Recovery Factor, Waste Management

I. INTRODUCTION

North Denpasar District is one of the four administrative regions within Denpasar City, Bali. As a prominent tourism hub, the district faces various development challenges, including infrastructure, human resources, and sanitation issues. Among these, solid waste management has emerged as a critical concern, driven by rapid urban development and population growth that continuously increase the yearly volume of waste. In response to these challenges, the Governor of Bali issued Regulation No. 47 of 2019 (Pemerintah Bali, 2019), mandating source-based waste management to reduce waste volume sent to final disposal sites. One of the key infrastructures supporting this initiative is the Material Recovery Facility (MRF), locally known as TPS 3R, which focuses on minimizing waste by applying the 3R principles—reduce, reuse, and recycle. This facility is vital in promoting sustainable waste management practices and reducing the environmental burden of conventional waste disposal methods.

The MRF offers several advantages, including its proximity to waste collection points and the use of relatively simple technologies. However, several MRF units in North Denpasar—such as the Ubung Gemilang MRF—continue to face various operational challenges, including inadequate infrastructure, low community participation, limited funding, and labor shortages. These issues negatively impact the effectiveness of waste management and may hinder the long-term development of sustainable waste processing systems. Therefore, efforts to improve waste management effectiveness in Ubung Subdistrict are urgently needed. Waste management should not be confined to activities within the MRF facility alone, but must also involve active public participation through source-based waste separation at the household level (Alyka & Andari, 2025; Ketut Ayu Santhi Dipayani, 2025). As the primary waste generators, communities are expected to manage waste significantly, starting from its source.

This study aims to evaluate the current waste management practices at the Ubung Gemilang MRF, assess public responses to mandatory waste processing at the facility, and develop a ten-year projection and planning framework for improved waste management.

II. RESEARCH METHOD

This study needed primary and secondary data sources. Primary data were collected through waste sampling, field surveys, interviews, and questionnaires. Secondary data included demographic statistics, relevant journals, and literature. The research focused on two key aspects: technical analysis and community participation analysis. The technical analysis encompassed the assessment of waste density, waste generation rates, waste composition, recovery factor, and mass balance. Sampling procedures for density, generation, and composition were conducted by the Indonesian National Standard SNI 19-3964-1994 (Badan Standarisasi Nasional, 1994; Wardiha et al., 2014). Upon completion of the technical analysis, a mass balance was developed based on the obtained waste composition data and recovery factor.

The analysis of community participation explored public knowledge (PG), attitudes (SK), and behaviors (PR) related to waste management. These variables were evaluated using Campbell's scoring formula, with a questionnaire constructed on a 5-point Likert scale (Istiqomah, 2019; Pambudi et al., 2025; Yansyah et al., 2021). The questionnaire was distributed via Google Forms and included five key questions: (1) waste separation, (2) waste processing through composting, (3) utilization of economically valuable waste, (4) willingness to pay for waste collection services, and (5) interest in managing waste at the MRF. The responses were then subjected to statistical testing, including validity and reliability tests, using SPSS software.

Based on the technical and community participation analyses, the least squares method developed a ten-year waste management projection for the Ubung Gemilang MRF using population projections for Ubung Subdistrict. The total projected waste generation over this period was the basis for determining land and equipment requirements up to the tenth year.

III. RESULT AND DISCUSSION

A. Existing Conditions of the Ubung Gemilang MRF

The Ubung Gemilang Material Recovery Facility (MRF) currently serves two community units (banjar), namely Banjar Sedana Mertha and Banjar Tengah. With a total of 318 households served and an estimated average of four individuals per household, the facility is estimated to serve approximately 1,272 residents. Banjar Sedana Mertha is serviced by two three-wheeled motor vehicles, covering 200 households, while Banjar Tengah is served by one three-wheeled vehicle, covering 118 households. This indicates that the Ubung Gemilang MRF currently serves only 14.03% of the total population of Ubung Subdistrict, which consists of 9,066 residents.

Waste collection is carried out using three-wheeled motor vehicles. Two of these vehicles are owned by the Ubung Gemilang MRF, while the third is operated independently by a private party (self-managed).

1. Waste Density Analysis

Estimating waste volume requires an accurate calculation of the average waste density in the containers of the three-wheeled vehicles. Waste density is determined by measuring the fluctuating height of the waste load and multiplying it by the cross-sectional area of the transport container. Based on eight days of measurement at the Ubung Gemilang MRF, the average waste density was 164.91 kg/m³. For comparison, previous studies in other regions reported slightly lower values. A survey in Rungkut Subdistrict, Surabaya, recorded an average waste density of 154.93 kg/m³ (Ratya & Herumurti, 2017), while research in Manyar Subdistrict, Gresik Regency, reported a value of 145.96 kg/m³ for waste at MRFs (Pradiptiyas, 2018). Differences in waste density can be attributed to several factors, including rainfall, waste collection methods, and the types of waste collected by the transport vehicles.

2. Waste Generation in Ubung Subdistrict

The volume of waste managed by the Ubung Gemilang MRF was recorded over an eight-day observation period, according to the Indonesian National Standard (SNI) 19-3964-1994. Waste volume for each three-wheeled vehicle was measured based on the waste load's fluctuating height, with the vehicle containers' length and width predetermined. Once volume was obtained, total waste weight was calculated by multiplying the volume by the average waste density, allowing for estimation of per capita waste generation.

Based on these calculations, the average waste generation rate at the Ubung Gemilang MRF is 0.61 kg/person/day. This value aligns with Indonesian National Standard SNI 8632:2018 (Badan Standardisasi Nasional, 2018), which states that daily waste generation in small to medium-sized cities ranges from 0.6 to 0.75 kg/person/day, while in large and metropolitan cities it ranges

from 0.65 to 0.8 kg/person/day. Daily variations in waste generation are influenced by population size, lifestyle patterns, population mobility, and food management practices (Ratnadewati & Juvitasari, 2024).

3. Waste Composition and Recovery Factor

The waste generated at the Ubung Gemilang MRF is categorized into nine components: food waste, leaves and branches, paper and cardboard, textiles, rubber and leather, plastics, metals, glass, and other waste (e.g., soil, stones, etc.). Plastic was the dominant component (29.21%), followed by leaves and branches (23.5%), food waste (16.95%), and other waste (15.65%). The composition at the Ubung Gemilang MRF differs slightly from the national average, where food waste dominates (39.25%), followed by plastics (19.25%) and leaves/branches (12.58%) (Kementerian Lingkungan Hidup dan Kehutanan, 2024). This discrepancy may be due to the predominantly Hindu population in Bali, where food waste, leaves, and ritual-related items are more common than in other regions. Conversely, the proportions of paper, cardboard, metals, glass, and others were similar to the national composition.

The Recovery Factor (RF) is used to measure the proportion of waste with potential for utilization, calculated by dividing the recovered weight of a waste component by its total weight. The table below presents the daily weight, component percentage, recovered weight, and resulting RF for each waste type:

Table 1. Recovery Factor of Waste Components at TPS 3R Ubung Gemilang

Component	Daily weight (kg)	Component Weight (%)	Recovered weight (kg)	RF (%)
Food waste	141.5	16.95%	52.99	37.46%
Leaves, branches, and ritual waste	196.1	23.50%	177.40	90.45%
Paper and cardboard	124.9	14.97%	69.93	55.97%
Fabric and textile products	33.3	3.98%	0	0%
Rubber and leather	16.7	2.%	0	0%
Plastic	243.8	29.21%	67.24	27.58%
Metal	17.8	2.14%	17.83	100%
Glass	17.9	2.15%	14.46	80.64%
Others	42.6	5.10%	0	0%
Total	**834.7**	**100%**	-	-

Based on the analysis, waste types with high reuse or recycling potential include metals, paper, cardboard, plastics, and glass. In contrast, rubber, leather, textiles, and other non-recyclables have zero recovery potential under current conditions. Metal waste recorded the highest recovery factor (100%), followed by leaves and branches (90.45%)—which are often composted—then paper/cardboard (55.97%), and glass (80.46%). Conversely, waste with the lowest recovery factor includes textiles and rubber, indicating they are not reused or recycled at this facility.

A study by Priyono & Pramesetyawati (2024) at the TPS 3R in Prangdikan and Gresik Regency reported recovery factors of 79% for food waste and 67% for plastics. Meanwhile, the recovery factor for leaves and branches reached 68%, and for metals, it was 100%. These results indicate that Ubung Gemilang MRF demonstrates relatively good waste recovery performance.

4. Sorting Rate

Waste sorting at the Ubung Gemilang MRF is carried out manually without a conveyor system. Two sorting activities were recorded: (1) compostable waste sorting, which focuses on separating organic materials for composting, and (2) sorting conducted simultaneously with residual waste transport. Compostable waste sorting is approximately 1.2–1.3 meters high on a sorting table. Two workers place mixed waste onto the table, and three additional workers manually sort it using their hands or sticks.

Recyclable material sorting and residual waste transport are conducted by four workers who separate recyclable items during the collection and transport process. The average sorting rate for compostable materials was 114.25 kg/person/hour, while the average for recyclable materials and residual transport was 98.15 kg/person/hour. Sorting efficiency can be significantly improved by integrating a conveyor system, which has been shown to increase the sorting rate up to 299 kg/person/hour (Rahmah & Trihadiningrum, 2022).

5. Mass Balance

Mass balance analysis was conducted to quantify the distribution of incoming waste into recyclable materials, compostable materials, and residuals destined for final disposal. A total of 834.7 kg/day of municipal solid waste was processed at the Ubung Gemilang MRF. The incoming waste was categorized into two main streams: composting potential and recycling potential.

- Composting Stream

Organic waste with composting potential consisted primarily of food waste, leaves, branches, and ritual waste, with a combined weight of 337.59 kg/day (40.4%) of total incoming waste.

a. Food waste accounted for 141.5 kg/day, with 37.46% (52.99 kg/day) successfully utilized as compost raw material, while the remaining 62.54% (88.47 kg/day) became residual waste.

b. Leaves, branches, and ritual waste contributed 196.12 kg/day, of which 90.45% (177.40 kg/day) was compostable and 9.55% (18.73 kg/day) was residue.

The composting stream produced 230.39 kg/day (27.6%) of compost raw material and 107.2 kg/day of compost-related residuals.

- Recycling stream

Waste with recycling potential amounted to 497.59 kg/day (59.6%), which included paper, plastics, glass, metal, textiles, rubber, and miscellaneous materials.

a. Paper and cardboard contributed 124.94 kg/day, with 69.93 kg/day (55.97%) successfully recycled and 54.97 kg/day (44.03%) as residue.

b. Plastic waste was the most considerable recyclable fraction at 243.27 kg/day, but only 27.58% (67.24 kg/day) was recovered, with 72.42% (176.56 kg/day) as residue.

c. Glass waste (17.93 kg/day) had a high recovery rate, with 14.46 kg/day (80.64%) recycled.

d. Metal waste (17.93 kg/day) was fully recycled (100% recovery).

e. Textile (33.26 kg/day) and rubber/leather waste (16.7 kg/day) were non-recyclable and entirely counted as residue.

f. Other waste types, totaling 42.6 kg/day, were also entirely non-recoverable.

The total recyclable materials recovered were 169.46 kg/day (20.3%) and 328.13 kg/day of residue from the recycling stream.

- Residual waste to disposal site

Residual waste cannot be composted or recycled using the current facility and technology. From both composting and recycling streams, a significant portion remains as residuals:

a. Residue from composting stream: 107.2 kg/day

b. Residue from recycling stream: 328.13 kg/day

Total residual waste sent to the disposal site was 434.75 kg/day (52.08%). This indicates that over half of the total input waste is not yet recoverable and ends in the final disposal site.

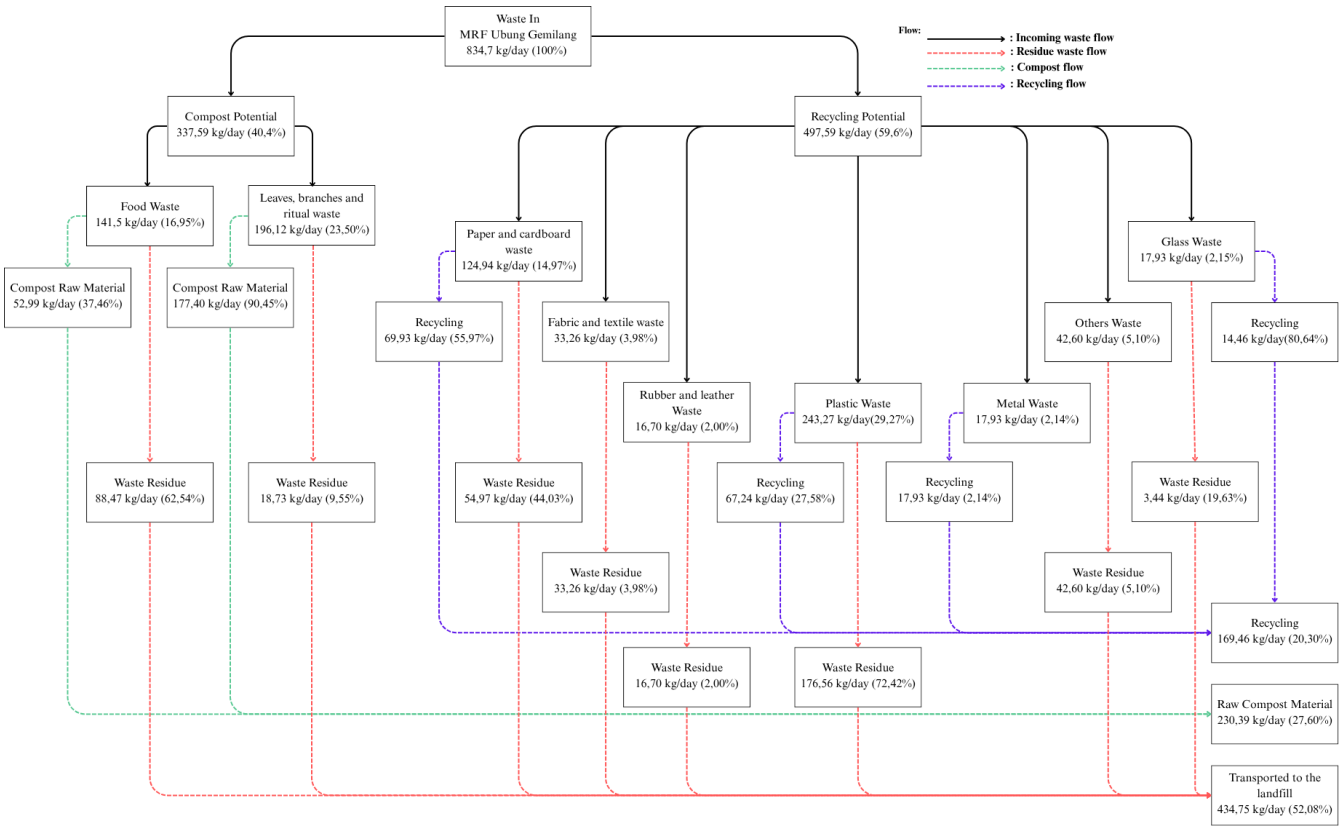

Figure 1. Mass Balance of TPS 3R Ubung Gemilang

B. Community Participation

Community participation plays a crucial role in enhancing the effectiveness of waste management systems. Without active involvement from residents, government efforts to address waste-related issues often face significant limitations. A survey conducted in Ubung Subdistrict assessed public participation through three main components: knowledge, attitudes, and behaviors related to waste management practices.

Table 2. Community Knowledge, Attitude, and Behavior on Waste Management in Ubung Village

Component	Indicator	Banjar Batur (n=4)	Banjar Sari (n=28)	Banjar Sedana Mertha (n=54)	Banjar Ubung Tengah (n=30)	Total (n=116)	Interpretation
Knowledge	PG1	70,00%	78,57%	81,48%	78,00%	**77,01%**	Informed
	PG2	60,00%	68,57%	79,63%	74,67%	**70,72%**	Informed
	PG3	60,00%	72,14%	77,78%	76,00%	**71,48%**	Informed
	PG4	50,00%	60,71%	76,30%	63,33%	**62,59%**	Informed
	PG5	35,00%	52,14%	72,59%	76,67%	**59,10%**	Slightly informed
Attitude	SK1	70,00%	71,43%	77,04%	72,67%	**72,78%**	Agree
	SK2	55,00%	72,14%	75,93%	74,00%	**69,27%**	Agree
	SK3	65,00%	55,71%	66,30%	61,33%	**62,09%**	Agree
	SK4	65,00%	55,71%	66,30%	61,33%	**62,09%**	Agree
	SK5	55,00%	52,86%	62,59%	62,00%	**58,11%**	Somewhat disagree
Behavior	PR1	50,00%	50,00%	55,56%	50,00%	**51,39%**	Occasionally
	PR2	45,00%	44,29%	49,26%	50,67%	**47,30%**	Occasionally
	PR3	45,00%	42,86%	53,70%	45,33%	**46,72%**	Occasionally
	PR4	45,00%	42,86%	53,70%	45,33%	**46,72%**	Occasionally
	PR5	55,00%	58,57%	60,00%	60,00%	**58,39%**	Occasionally

A community survey conducted in Ubung Subdistrict involved 116 respondents from four different *banjar* (Batur, Sari, Sedana Mertha, and Ubung Tengah). It evaluated public participation across three components: knowledge, attitude, and behavior. Among the knowledge indicators, the highest average percentage was recorded for PG1 (77.01%), indicating strong public awareness of sound waste management principles. Indicators PG2 and PG3 also showed relatively high scores—70.72% and 71.48%, respectively. However, PG4 and PG5 reported lower averages (62.59% and 59.10%), suggesting limited public understanding of practical and technical aspects of waste handling, thus placing respondents in the “slightly informed” category.

In terms of attitude, overall results were positive. The highest score was found in SK1 (72.78%), reflecting general agreement with the need for community initiatives and order in waste management. Indicators SK2, SK3, and SK4 scored above 60%, placing respondents in the "agree" category. However, SK5 recorded the lowest score (58.11%), categorized as "somewhat disagree," suggesting that some of the community remains uncertain or partially disagrees with specific attitude statements.

Behavioral indicators showed the lowest scores among the three components. All five behavior indicators (PR1–PR5) were categorized as “occasionally,” with average scores ranging from 46.72% (PR1 and PR2) to 58.39% (PR5). This implies that while respondents have the knowledge and agree with good waste management practices, their actual behaviors remain inconsistent or irregular. Overall, this indicates a gap between awareness/attitude and actual practices. Although community support for waste management is relatively strong, behavior that aligns with that awareness must be reinforced through continuous public education, infrastructure improvement, and enhanced community involvement.

Correlation analysis showed that all knowledge-related items (PG1 to PG5) significantly correlated with the overall knowledge score (TotalPG), with Pearson correlation coefficients ranging from 0.533 to 0.659 ($p < 0.01$). Similarly, behavior items PR1 to PR5 showed moderate-to-strong correlations with the total behavior score (TotalPR), ranging from 0.600 to 0.666 ($p < 0.01$). Attitude items (SK1 to SK5) also correlated significantly with the total attitude score (TotalSK), with coefficients between 0.554 and 0.732 ($p < 0.01$). These findings confirm that the questionnaire items validly measured each construct. In terms of reliability, Cronbach's Alpha was 0.730 for knowledge, 0.607 for attitude, and 0.621 for behavior. While validity levels were acceptable, internal

consistency—especially for the attitude component—suggests room for improvement in instrument reliability to capture respondent attitudes better.

C. Planning of the Ubung Gemilang MRF

The waste management service projection at the Ubung Gemilang MRF was developed based on the percentage of residents from each *banjar* who indicated a willingness to manage their waste at the facility: 60% from Banjar Sedana Mertha, 60% from Banjar Tengah, 58.57% from Banjar Sari, and 55% from Banjar Batur. Based on these figures, the target for service expansion over the next ten years is 58.45% of the total population in Ubung Subdistrict.

Table 3. Ten-Year Projection of Waste Management Service Coverage at Ubung Gemilang MRF (2024–2034)

Year	Projected population (people)	Service Coverage (%)	Population Covered (people)	Waste Generation Rate (kg/person/day)	Total Waste Managed (kg/day)
2024	11742	12,4%	1459	0,6	875,5
2025	11809	17,0%	2008	0,6	1204,6
2026	11876	22,0%	2613	0,6	1567,7
2027	11943	27,0%	3225	0,6	1934,8
2028	12010	32,0%	3843	0,6	2306,0
2029	12077	37,0%	4469	0,6	2681,2
2030	12144	42,0%	5101	0,6	3060,4
2031	12211	47,0%	5739	0,6	3443,6
2032	12278	51,0%	6262	0,6	3757,2
2033	12345	55,0%	6790	0,6	4074,0
2034	12412	58,45%	7255	0,6	4353,0

The table above presents the projected waste management service coverage at the Ubung Gemilang Material Recovery Facility (MRF) from 2024 to 2034. The projection includes population growth estimates, increasing service coverage, and the anticipated daily waste generation and total waste managed. In 2024, the population is estimated at 11,742 individuals, with a service coverage of 12.4%, serving only 1,459 people. Assuming a per capita waste generation rate of 0.6 kg/person/day, the total managed waste amounts to 875.5 kg/day. Over time, the service coverage gradually increases, reaching 58.45% by 2034, serving 7,255 people out of a projected population of 12,412. Consequently, the total daily waste managed increases to 4,353 kg/day. This growing coverage reflects the planned expansion of the MRF's operational capacity to accommodate population growth and increased waste generation.

Currently, the Ubung Gemilang MRF is equipped with one shredding machine with a capacity of 300 kg/hour, one screening machine with a capacity of 300 kg/hour, two three-wheeled collection vehicles (1.8 m^3 per unit), and one residual waste container with a capacity of 8 m^3. A conveyor system will be added as part of the ten-year development plan, as it can significantly improve sorting speed up to 299 kg/person/hour (Rahmah & Trihadiningrum, 2022).

Table 4. Projected Equipment Requirements for Ubung Gemilang MRF (2024–2034)

Tahun	Conveyor (unit)	Shredder (unit)	Screener (Unit)	Three-Wheeled vehicle (unit)	Residual Waste Container (Unit)
2024	1	1	1	2	1
2025	1	1	1	3	1
2026	1	1	1	3	1
2027	1	1	1	4	1
2028	1	2	2	4	1
2029	1	2	2	5	2
2030	1	2	2	6	2
2031	1	2	2	6	2
2032	1	2	2	7	2
2033	1	2	2	7	2
2034	1	2	2	8	2

The table above illustrates the projected operational equipment requirements for the Ubung Gemilang MRF over 2024–2034. The projection was developed based on the increasing number of residents served and the volume of waste processed daily. The number of conveyors remains constant at one unit throughout the projection period, indicating that current capacity is sufficient.

However, shredders and screening machines are expected to increase from one to two units starting in 2028, reflecting the anticipated growth in daily waste volume.

The most significant increase is observed in the number of three-wheeled collection vehicles, which is projected to grow from two units in 2024 to eight units by 2034, demonstrating the intensification of waste collection and transport activities. Meanwhile, residual waste containers will increase from one to two units, accommodating the greater volume of non-recyclable waste. Overall, this plan reflects a gradual effort to expand the operational capacity of the MRF to support more efficient and sustainable daily waste management.

Following the waste service projection, a land requirement analysis was conducted based on the estimated volume of waste to be managed. Based on calculations up to 2034, the total land area at the Ubung Gemilang MRF remains sufficient; however, several zones are expected to experience shortages, while others may have surplus capacity. The table below outlines the projected land requirements by 2034.

Table 5. Projected Land Area Requirements for Functional Zones at Ubung Gemilang MRF in 2034

Functional Zone	Existing area (m^2)	Required area in 2034 (m^2)	Area Deficit/Surplus in 2034 (m^2)
Receiving area	45,00	14,69	30,31
Sorting area	10,50	14,35	-3,85
Shredding area	9,10	0,00	9,10
Compost maturation area	45,50	96,08	-50,58
Screening area	5,00	13,44	-8,44
Recycled product warehouse	7,00	5,51	1,49
Equipment storage area	7,00	30,87	-23,87
Residual waste area	8,75	8,75	0,00
Residual waste area	25,00	41,58	-16,58
Office	20,00	20,00	0,00
Toilet	3,00	3,00	0,00
Prayer space	3,00	3,00	0,00
Total area of MRF	**413,11**	**413,11**	
Utilized land	**188,85**	**251,27**	
Remaining land	**224,26**	**161,83**	

The table above illustrates the projected land area requirements at the Ubung Gemilang MRF through 2034, based on estimates of increasing waste management activities. The total current land area of the MRF is 413.11 m^2, with 224.26 m^2 of unused space. However, by 2034, land utilization is expected to increase to 251.27 m^2, reducing the remaining available area to 161.83 m^2.

The distribution of projected land needs across functional zones indicates significant increases, particularly in the compost maturation area, which initially required only 45.5 m^2 but is projected to expand to 96.08 m^2, resulting in a land deficit of 50.58 m^2. Similarly, the screening and recycled product storage areas are projected to face deficits of 8.44 m^2 and 23.87 m^2, respectively. In contrast, several zones, such as the equipment storage area, office, toilet, and prayer space, remain within their existing capacity and are not expected to experience land shortages.

Thus, while the overall site still has sufficient space, several functional areas will require spatial layout adjustments or area expansion to accommodate operational demands by 2034. This projection is essential for long-term infrastructure planning to ensure efficiency and sustainability.

IV. CONCLUSION

Ubung Subdistrict has a waste generation rate of 0.61 kg/person/day with a 164.91 kg/m^3 waste density. The waste composition is dominated by plastics (29.21%), followed by leaves, branches, and ritual waste (23.5%), and food waste (16.95%). The highest Recovery Factor (RF) was found in metals (100%), followed by leaves and branches (90.45%), and glass (80.64%). In contrast, textiles and rubber showed no recovery value due to their non-recyclable nature.

Regarding community participation, although knowledge levels are relatively high (with PG2 and PG3 indicators above 70%), behavioral indicators such as waste separation at the source remain low, with most respondents only occasionally practicing sorting and composting. However, the questionnaire results revealed that 58.45% of residents are willing to process waste at the MRF and pay collection fees, indicating a promising level of public support that can be further strengthened.

By 2034, the Ubung Gemilang MRF is projected to serve 7,255 residents, managing up to 4,353 kg of waste per day. The facility's operational equipment requirements will increase, including two shredding machines, two screening machines, eight three-

wheeled vehicles, and two residual waste containers. Land area analysis indicates that of the total 413.11 m² site, 251.27 m² will be utilized by 2034, leaving 161.83 m² of remaining space. Nevertheless, several functional zones will face significant land shortages, including the compost maturation area, screening area, and recycled product storage. Therefore, spatial reorganization and layout optimization are necessary to ensure efficient and effective waste management operations.

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