



Circular economy opportunities for inorganic waste management: An applied analysis based on recycling center data

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ABSTRACT

Background: Waste is no longer regarded solely as refuse but also as a potential resource in the circular economy, particularly through recycling center (RC) mechanisms. This study aims to analyze the circular economic potential of inorganic solid waste based on actual selling price data from RC in Purbalingga, Central Java, Indonesia. Previous studies have highlighted the importance of waste separation and local RC in promoting community-based waste management, yet few have quantified the circular economic value of specific inorganic waste types. **Methods:** This research employs a descriptive quantitative approach using secondary data collected from government institutions and local RC. Analytical methods include compositional waste analysis and basic statistical comparisons (T-Test) across years and waste types (polyethylene terephthalate-PET, scrap papers, and cans). **Findings:** PET accounted for an average of 18.53% of total waste between 2021 and 2024, far higher than paper (8.96%) and cans (0.66%). Statistical analysis confirmed significant differences between PET and the other two types ($p < 0.05$, Cohen's $d > 3$). Scenario modeling showed that if 14.8% of the population participated by contributing 3 kg of PET per household, approximately 460 tons/day could be recovered, generating meaningful household income and reducing landfill burden. **Conclusion:** The study concludes that supporting RC and encouraging less than 20% household participation in PET separation could substantially reduce waste volumes while strengthening household income streams. **Novelty/Originality of this article:** The integration of compositional waste data and local price structures provides a data-driven valuation of inorganic household waste, offering practical guidance for policy and local planning in sustainable circular economy strategies.

KEYWORDS: waste bank; waste production; inorganic waste; circular economy; community participation.

1. Introduction

Solid waste management has become one of the most pressing environmental issues of the twenty-first century. Globally, municipal solid waste is projected to exceed 3.4 billion tons annually by 2050, only around 10% of the 6.8 million tons of plastic garbage produced in the nation each year gets recycled with plastics and other non-biodegradable materials because of rapid urbanization, population increase, and changing consumption patterns

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posing serious threats to ecosystems, human health, and climate stability (Kaza et al., 2018; Purnomo et al., 2024). Addressing this challenge requires moving away from the linear “take–make–dispose” model toward a circular economy (CE), which emphasizes resource efficiency through the 3Rs—reduce, reuse, and recycle (Kusumowardani, 2022). To respond, the Indonesian government has adopted the National Policy and Strategy on Waste Management, which targets a 30% waste reduction and 70% proper handling by 2025 (United Nations Environment Programme & IGES Centre, 2020). Achieving these goals demands innovative, community-based approaches that combine environmental and socioeconomic benefits.

One such approach is the establishment of recycling centers or waste banks, which serve as neighborhood hubs for sorting and trading inorganic waste. Residents can exchange separated materials for cash or savings, creating direct incentives for participation. More than 13,000 waste banks now operate across Indonesia, many led by local women’s groups and NGOs (Budiyarto et al., 2025). These facilities reduce the burden on municipal systems, foster household income, and promote behavioral change by embedding recycling within community routines (Iacovidou et al., 2025).

Although the importance of waste banks has been widely acknowledged, most existing studies are conceptual or qualitative, focusing on community engagement, governance, or awareness (Asih et al., 2022; Ilham & Yustianto, 2024). Few provide quantitative assessments of the economic value of specific inorganic waste types, particularly when linked to real market prices at the local level. National or city-level studies often generalize conditions without reflecting the diversity of Indonesia’s smaller districts. This lack of empirical valuation represents a crucial gap in the literature. Recognizing the economic value of waste is also crucial to the circular economy (CE) model. The ability of RC to convert small quantities of household waste into monetized outputs. These practices align with the CE principle of “waste-as-resource” and support broader sustainability goals by offering both environmental and economic returns (Maters & Luttk, 2021).

Purbalingga Regency, Central Java, offers a compelling case for localized assessment. With a population of more than one million and daily waste generation exceeding 2,400 tons, the regency faces mounting challenges in collection and disposal (Central Statistics Agency (BPS) of Purbalingga Regency, 2025). Household waste dominates total production, and plastic bottles made from polyethylene terephthalate (PET) are increasingly prevalent. At the same time, several active RC operate in the area, providing opportunities to measure how compositional waste data and local price structures can be combined to estimate circular economic potential. Compared with other Indonesian cities such as Yogyakarta or Semarang, where PET comprises 12–14% of household plastic waste, Purbalingga shows a notably higher proportion at over 18% (Zahrah et al., 2024). The informal sector, especially those who collect and sort solid waste, often underrecognized in national statistics, plays a pivotal role in collecting and sorting waste that would otherwise contribute to environmental degradation (Awasthi, 2022). This distinct profile underscores the need for district-level studies that can inform tailored waste management strategies.

Most existing studies on community-based recycling in Indonesia are conceptual or qualitative, with limited quantitative assessment of the economic value of inorganic waste. To fill this research gap, the present study provides a data-driven district-level valuation in Purbalingga by integrating official waste composition statistics with actual recycling center price structures, demonstrating how PET, paper, and aluminum cans can generate household income while supporting circular economy practices and environmental protection. The objectives of this study are to calculate the average production and composition of household inorganic waste in Purbalingga, to estimate the economic value of PET, paper, and cans using price data from local recycling centers, and to propose strategic, community-based waste management approaches that can strengthen circular economy practices and support regional sustainability.

Prior research on waste management in Indonesia has largely focused on community participation and the role of waste banks in cities such as Jakarta, Surabaya, and Yogyakarta. While these studies highlight important social and behavioral dynamics, they remain mostly

qualitative or conceptual, with limited attempts to quantify the economic value of recovered materials. District-level contexts such as Purbalingga are particularly underexplored, even though realistic financial projections are crucial for scaling circular economy initiatives. To address this gap, the present study quantifies the economic value of polyethylene terephthalate (PET), paper, and cans by integrating official household waste composition data with actual purchase prices from local recycling centers. The economic further model different levels of household participation to estimate potential income generation and waste diversion. The research is guided by two questions: what is the economic value of inorganic household waste when assessed using real recycling center market prices, and how do varying levels of community participation affect recovery potential and household income? By answering these questions, the study provides a data-driven assessment of local circular economy opportunities while offering practical insights for policymakers and community leaders.

2. Methods

The methodological framework of this study was designed to ensure transparency and reproducibility in evaluating the economic potential of inorganic household waste. A descriptive quantitative approach was employed, drawing on official secondary data sources and validated through cross-checks with local recycling centers. The process included defining inclusion criteria, converting waste statistics into standardized units, applying income formulas, and conducting statistical analyses to compare material categories. Ethical considerations were observed through the exclusive use of secondary datasets and informed consent for supporting interviews. The overall workflow of the research is illustrated in Figure 1.

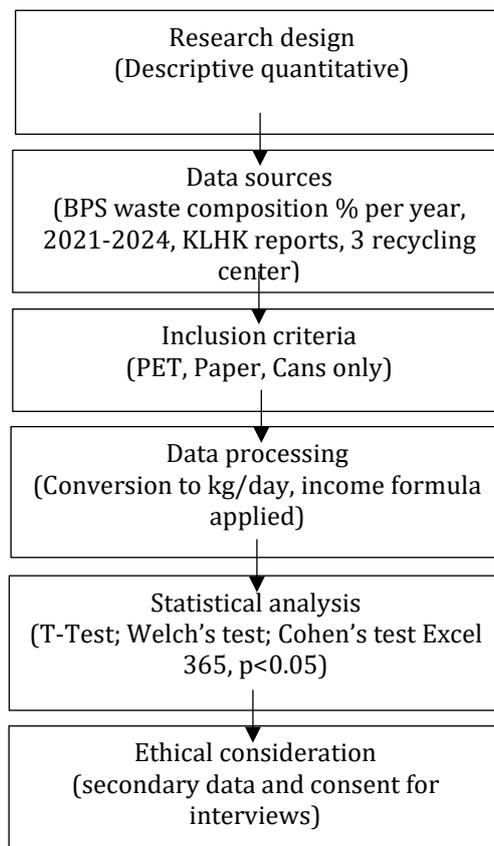


Fig. 1. Methodology flowchart

2.1 Research design and data sources

This study used a descriptive quantitative design to assess the circular economy potential of inorganic household waste in Purbalingga, Central Java. The coordinate location of Purbalingga is 7.3857°S and 109.3604°E. In order to determine the potential household income from recyclable materials, the study combines market price data from nearby recycling center with official waste composition statistics.

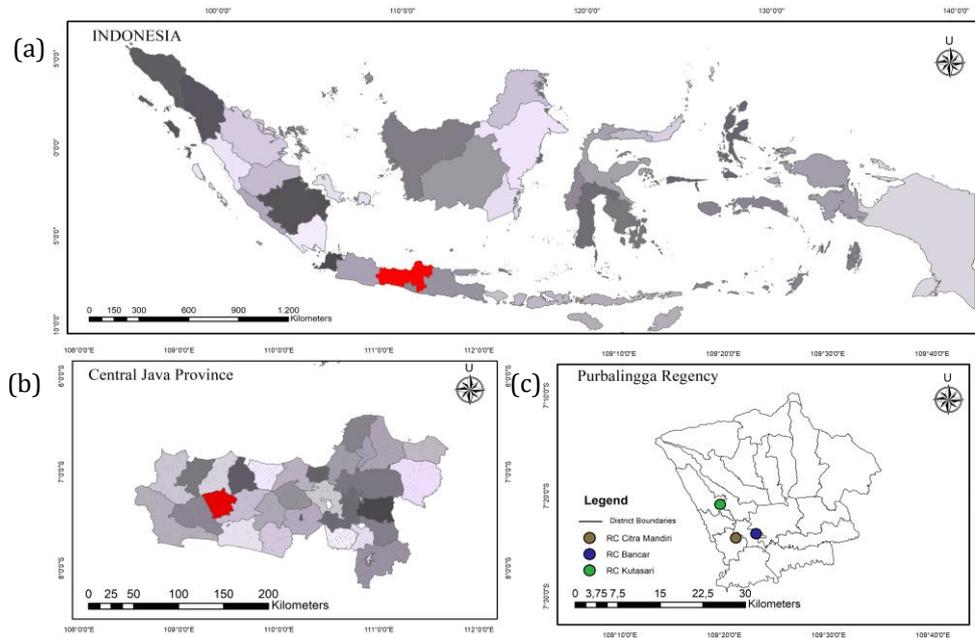


Fig. 2. Research location (a) Map of Indonesia; (b) Map of Central Java Province, Purbalingga was indicated in red colour; (c) Map of Purbalingga Regency with recycled center (RC) location, RC Citra Mandiri was indicated in brown dot colour, RC Bancar was indicated in blue dot colour, and RC Kutasari was indicated in green dot colour (Central Statistics Agency of Purbalingga Regency, 2025)

The Central Statistics Agency of Purbalingga Regency ($n = 4$ years, 2021–2024) and official reports issued by the Indonesian Ministry of Environment and Forestry (KLHK) provided secondary data. Waste composition data were grouped into the three most frequently traded inorganic categories at local WSFs: polyethylene terephthalate (PET), scrap paper, and aluminium cans.

Price information was collected during January–March 2025 from three major RC surveyed ($n = 3$) in Purbalingga—Citra Mandiri (Kalimanah), Bancar AKA (Bancar), and Lestari Ponces (Kaligondang) which may not capture seasonal or longer-term fluctuations. These facilities were chosen for their high transaction volumes and consistent record-keeping. Data were cross-validated using facility records, WSF manager interviews, and collector market pricing lists to ensure reliability. Resource constraints limited this study to secondary data over three months, but cross-validation ensured reliability; future work should extend to longitudinal and primary surveys.

2.2 Data processing

Purbalingga's population statistics were used to transform all data into waste generation figures per capita on a daily and monthly basis. Assumptions included pricing variations established independently by each facility and a minimum donation of 3 kg per household per collection (based on RC operational standards). For calculation purposes, a minimum household contribution of 3 kg of inorganic waste per transaction, in line with RC operational standards. The economic value (IDR) of recyclable materials was calculated as

the product of the volume of waste (kg) and the corresponding selling price (IDR/kg), as shown in Eq. 1. Scenario modeling was conducted by applying different participation rates (5%, 10%, 14.8%, 15%) to the total daily inorganic waste production. The total potential collected volume was calculated by multiplying participation rate \times daily PET/paper/can generation (tons/day) and then converted to income using Eq. 1.

$$\text{Economic value (IDR)} = \text{volume (kg)} \times \text{selling price (IDR/kg)} \quad (\text{Eq. 1})$$

2.3 Statistical analysis and ethical considerations

Trends in waste composition were compiled using descriptive statistics. Independent sample t-tests were used to compare PET, paper, and cans. Normality was assumed based on prior distributional evidence, and variance homogeneity was checked with Levene's test. Where violated, Welch's t-test was applied when variances were unequal, as it does not assume homogeneity. T-tests were employed to determine whether observed differences in PET, paper, and can proportions be statistically significant.

This approach is appropriate for small-sample mean comparisons ($n = 4$ years per waste type), and Welch's correction was applied when variances were unequal. Effect sizes (Cohen's d) and 95% confidence intervals for mean differences were calculated to provide estimates of practical significance. Reporting both statistical significance and effect size enhances transparency and reproducibility. In cases where very small within-group variation inflated d to unrealistically high values, results were truncated (reported as $d > 3$, indicating an extremely large effect) or supplemented with eta-squared (η^2) as a bounded, interpretable measure of variance explained. All analyses were conducted using Microsoft Excel 365, with $p < 0.05$ considered significant. This study did not need formal Institutional Review Board approval because it only used secondary data and non-sensitive pricing information. Nonetheless, informed consent was obtained before conducting interviews with RC managers, guaranteeing the respondents' confidentiality and anonymity.

3. Results and Discussion

3.1 Result

Total area of Purbalingga is about 805.76 km² according to the Central Statistics Agency in 2024, comprising 18 districts with a total population of 1,037,637 people and an average daily waste production of 2,465.60 tons, of which only approximately 398.30 tons are collected using nine waste collection trucks, 15 waste carts, and only one landfill site and 23 temporary waste disposal facilities. The percentage composition of waste can is shown in Table 1, specifically for inorganic waste types such as PET, paper, and cans, which have a higher percentage compared to other general waste types (glass, rubber, wood, and others).

Table 1. Percentage of waste composition in Purbalingga (%) for 2021-2024

Waste type	2021 (%)	2022 (%)	2023 (%)	2024 (%)
PET	18.35	18.49	18.61	18.69
Papers	8.91	8.95	8.98	9.02
Cans	0.71	0.68	0.64	0.61

(Central Statistics Agency of Purbalingga Regency, 2025)

The analysis of inorganic household waste in Purbalingga between 2021 and 2024 reveals a clear pattern of dominance by polyethylene terephthalate (PET) waste, accompanied by relatively stable proportions of paper and a gradual decline in cans (Table 1). Specifically, PET accounted for 18.35% of total waste in 2021 and exhibited a steady annual increase, reaching 18.69% in 2024. This represents a relative growth of 0.34 percentage points over the four-year period. Paper waste accounted for 8.91% in 2021;

8.95% in 2022; 8.98% in 2023; and increased to 9.02% in 2024. The quantity of can waste tends to decrease year by year, amounting to 0.71% in 2021; 0.68% in 2022; decreasing to 0.64% in 2023; and continuing to decrease in 2024 to 0.61%, representing a reduction of nearly 15% in relative share.

A statistical evaluation using Welch's t-test confirmed that PET proportions were significantly higher than both paper and cans across all years ($p < 0.001$). Conversely, pairwise comparisons between paper and cans indicated no statistically significant difference in their year-to-year changes ($p > 0.05$), suggesting a plateau for paper while cans showed a downward trajectory. Specifically, the PET share ($M = 18.53\%$, $SD = 0.14$) was significantly higher than paper ($M = 8.96\%$, $SD = 0.05$), Welch's $t(3.9) = xx$, $p < 0.001$, Cohen's $d > 3$, $\eta^2 = 0.99$, 95% CI [8.8, 9.6]; and cans ($M = 0.66\%$, $SD = 0.04$), with Cohen's $d > 3$ in both comparisons, indicating extremely large effects and negligible overlap between distributions. For interpretability, η^2 values were also reported (PET vs paper: $\eta^2 = 0.99$; PET vs cans: $\eta^2 = 0.99$), showing that nearly all variance was explained by group differences. These outcomes reinforce the observation that PET is not only the largest component of inorganic household waste but also the most dynamic in terms of growth, while paper remains stable and cans steadily decline.

These findings are consistent with broader national data indicating the rising consumption of PET bottles in Indonesia, largely driven by increased reliance on packaged beverages and bottled water in both rural and urban households. PET's lightweight, durable, and low-cost continue to make it a preferred packaging material, although it simultaneously poses challenges due to its persistence in the environment. The relatively stable percentage of paper waste can be attributed to its steady demand in packaging, education, and office use, while the decline in cans may reflect substitution effects, where aluminum containers are increasingly replaced by plastics for economic reasons (Ilham & Yustianto, 2024).

Table 2. The economic value of inorganic waste (PET, paper, cans) in Purbalingga in 2025

RC	Address	Waste type	Volume (kg)	Buying Price per kg (IDR)	Total economic value (IDR)	Beneficiaries
Citra Mandiri	Kalimanah, Purbalingga	PET	min.3 kg	4,500	13,500	customers, active members, local residents, collectors
		Papers		1,800	5,400	
		Cans		1,600	4,800	
Bancar AKA	Bancar, Purbalingga	PET		1,000	3,000	
		Papers		700	2,100	
		Cans		800	2,400	
Lestari Ponces	Kaligondang, Purbalingga	PET		2,200	6,600	
		Papers		1,500	4,500	
		Cans		1,000	3,000	

The purchase prices of inorganic waste at the Citra Mandiri are IDR 4,500.00/kg; IDR 1,800.00/kg; and IDR 1,600.00/kg for PET, paper, and cans, respectively. The same types of waste at the Bancar AKA have purchase prices of IDR 1,000.00/kg for PET; IDR 700.00/kg for paper; and IDR 800.00/kg for cans. Lestari Ponces purchases PET from the public at IDR 2,200.00/kg; paper at IDR 1,500.00/kg; and cans at IDR 1,000.00/kg. Residents who want to sell inorganic waste such as PET, paper, or cans must bring a minimum of three kilograms to the nearest waste storage facilities. To calculate the economic value generated, a simple formula used is Equation 1. The three types of waste examined in this study still have economic value for processing into recycled goods. The purchase prices of these three types of waste also vary, as shown in Table 2.

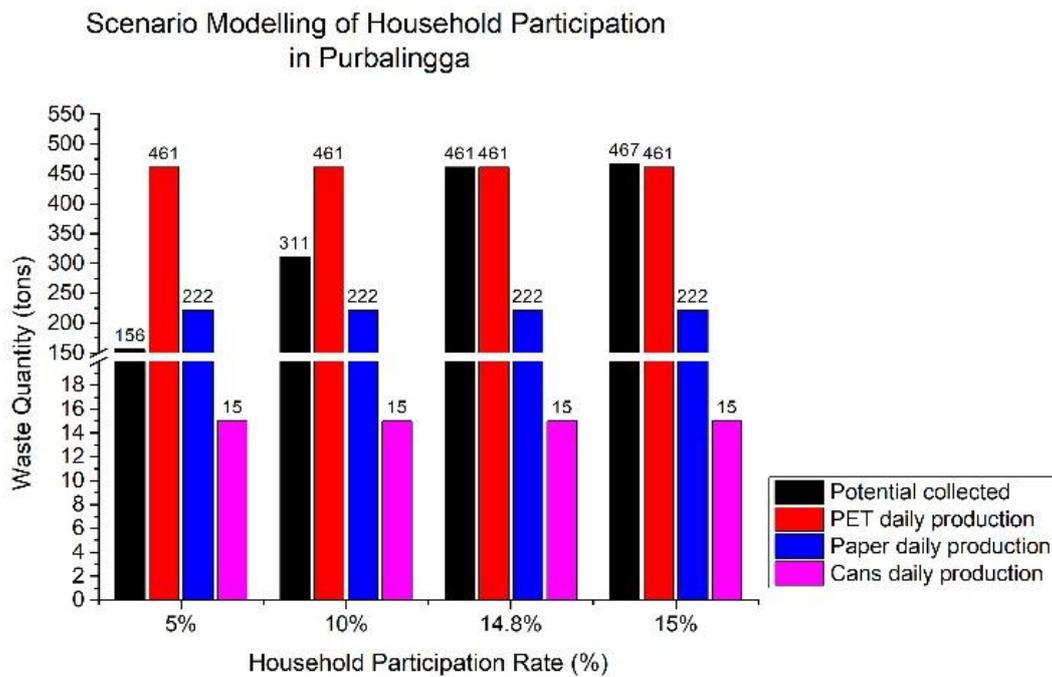


Fig. 3. Modeled outcomes of different household participation rates (5%, 10%, 14.8%, 15%), assuming a minimum 3 kg contribution per household, compared with daily PET, paper, and can production in Purbalingga

The economic value of these three types of waste is slightly different at the Bancar AKA, namely IDR 3,000.00 for PET; IDR 2,100 for paper; and IDR 2,400.00 for used cans. Lestari Ponces assigns an economic value of IDR 6,600.00 for PET; IDR 4,500.00 for paper; and IDR 3,000.00 for used cans. The validation of price data for each waste storage facility may vary depending on the purchase prices set by the targeted commercial waste collectors to ensure the waste economic cycle continues to function. The chart (Fig. 3) illustrates the outcomes of different household participation rates (5%, 10%, 14.8%, and 15%) under the assumption that each contributing household delivers 3 kg of inorganic waste per transaction. The black bars show the potential amount of waste collected under each scenario, while the red, blue, purple bars represent the daily production of PET, paper, and cans in Purbalingga, respectively.

3.2 Discussion

Efforts to reduce inorganic waste remain a public concern due to its non-biodegradable nature, which can disrupt ecological balance and indirectly contribute to climate change. In general, PET is widely used for mineral water packaging due to its strength and lightweight properties. Paper recycling is useful for restoring the economic value of used paper by processing it into new packaging products (Gumulya et al., 2023). Used cans can have new economic value as handicraft products and can be melted down to obtain pure metal, which is in high demand by industry (Yani & Ausat, 2024).

RC play an important role in reducing inorganic waste that still has economic value mixed with organic waste and also facilitates the composting process of organic waste. Inorganic waste such as PET, paper, and cans collected at the RC will be forwarded to waste collectors based on direct interviews with the RC managers. The purchase price at the RC is determined independently according to the market prices at the waste collectors. The beneficiaries of the RC are its customers and active members, typically nearby residents in the area who have developed the awareness to sort their waste to earn additional income by selling their inorganic waste to the nearest storage facilities. Waste collectors are also assisted by the role of the RC as they receive a supply of materials to sustain their business operations.

Studies in India and other low-middle income countries with similar district-level data reveal comparable challenges in price stabilization and community engagement (Gour & Singh, 2023; Vinti & Vaccari, 2022). High PET proportion in Purbalingga indicates both an opportunity and a vulnerability that global PET price fluctuations could directly influence household incentives to participate in waste separation and the informal sector, such as local waste pickers, could support the circular economy transitions, particularly in developing countries. Inorganic waste composition comparison across Indonesian cities, Purbalingga stands out with its PET share of 18.53%, significantly higher than in regional urban centers. Zahrah et al. (2024) studied in Yogyakarta City, PET bottles accounted for roughly 12% of plastic waste in 2022, with other plastic types like thick plastics exceeding that share (Bandung, Magelang, Yogyakarta comparison; Figure 6b). The Urban Ocean comprehensive assessment and prioritization (CAP) assessment in Semarang confirmed a typical PET share of around 14%, aligning more closely with national minimum of unit litter (MUL) guidelines (UNEP 2017 sample data: ~14% plastic, 9% paper). These contrasts suggest that Purbalingga's higher PET proportion may reflect both elevated consumption patterns and more effective separation infrastructure at the local level.

Community participation rates in waste bank programs also diverge across city contexts. In Yogyakarta City, only 14.6% of households became active waste bank members, reflecting barriers related to awareness and motivation despite waste bank availability (Asih et al., 2022). Purbalingga's modeled participation scenario (14.8% of population sorting minimum 3 kg PET) thus appears plausible and competitive relative to these real-world benchmarks. RC can also help reduce plastic waste in Purbalingga by utilizing a community participation scenario. If one-quarter of the total population of Purbalingga, approximately 259,409 people, were willing to contribute by sorting 3 kg of one type of inorganic waste and selling it to the nearest RC, then approximately 778 tons could be recycled to reduce environmental pollution from the total of 2,465.60 tons/day of waste produced from the 18 sub-districts in Purbalingga. The circular economy can also function under this scenario, enabling approximately 259,409 residents to earn additional income from collecting and selling waste to the RC.

Table 1 illustrates the temporal changes in PET, paper, and cans over the four-year study period. The upward trend in PET stands in stark contrast to the declining trajectory of cans, underscoring the shifting composition of household waste streams. Such patterns suggest that if community participation were focused primarily on PET collection, both environmental and economic gains would be maximized, given the consistent increase and market demand. The public participation scenario can also be used to determine the percentage of the population contributing to reducing waste production based on type, namely PET, paper, and cans (Table 3), using the average value for each type of waste from 2021 to 2024 in Table 1.

Table 3. Percentage of the population contributing to reducing the amount of PET, paper, and can waste produced in Purbalingga

Waste type	Average (%)	Waste amount (tons)	Waste production (tons/day)	Waste production (kg/day)	Volume (kg)	Resident contribution (person)	Percentage of the total resident contribution (%)
PET	18.53	0.18	460.82	460,820.64	3	153,606.88	14.80
Papers	8.96	0.09	222.39	222,397.12	3	74,132.37	7.14
Cans	0.66	0.01	15.04	15,040.16	3	5,013.38	0.48

Beyond composition trends, the data carry important implications for circular economy initiatives. The continuous growth in PET waste highlights the urgency of targeting PET in community-based recycling campaigns. PET's relatively high recyclability and strong demand from secondary markets make it the most economically viable material for collection RC. Paper recycling, while less profitable per kilogram, still contributes to significant waste diversion given its substantial share of total waste. Cans, though

representing a small fraction, remain valuable in terms of metal recovery, particularly for commercial metal waste collectors and industries reliant on aluminum and steel (Morais et al., 2022).

The potential collected waste at 5% participation is far below PET's daily production, indicating limited impact. At 10% participation, the collected amount approaches half of PET's daily generation and exceeds can production entirely. At the modeled 14.8% scenario, the potential collection (~460 tons) nearly matches PET's entire daily production, while still surpassing paper and can quantities. At 15%, the collected amount slightly exceeds PET's daily output, indicating that relatively small increases in community engagement can produce disproportionately large gains in material recovery. Efforts to reduce total PET waste by 18.53% require public participation of 14.8% of the total population of Purbalingga to sort 3 kg/person of PET waste and deliver it to waste storage facilities. Community participation in recyclable waste segregation varies in some other Indonesian regions, providing an important benchmark for interpreting the Purbalingga scenario. As comparison in Prai Meke Village, Lombok, around 65–70% of households segregate recyclables, while Yogyakarta reports 14.6% active participation in waste bank programs (Ariani & Salahudin, 2025; Nursamsiyah & Qodir, 2024). Purbalingga's modeled requirement of 14.8% participation for full PET recovery aligns closely with urban participation benchmarks which indicates that the scenario is feasible to be implemented. The participation percentages in this study reflect the number of residents who will benefit economically from increased activity at the waste storage facilities and strengthening the local economy.

Integrating environmental implications further highlights the significance of the 14.8% participation scenario. The global PET supply chain generates about 534.6 million tons of CO₂-eq per year, exceeding 90% of the material's life-cycle emissions, suggesting that replacing virgin PET with recycled PET could significantly reduce GHG emissions across the supply chain and life-cycle analysis shows that PET production and manufacturing constitute over 90% of total emissions, reinforcing that substituting virgin PET with recycled PET would lead to substantial climate mitigation across the supply chain (Duan et al., 2024; Kanugrahan & Hakam, 2023; Zhou et al., 2023). The climate burden of virgin PET ranging from 1.7 kg CO₂e/kg for purified terephthalic acid (PTA) derived resins to 2.1 kg CO₂e/kg for PET produced with dimethyl terephthalate (DMT) process Recycling one kilogram of plastic waste reported could reduce 0.8-2.0 kg CO₂-eq and estimated higher climate benefit specifically for recycled PET that could reduce 1.5 tons CO₂-eq, this highlights the carbon-intensive aspect of primary PET synthesis (Faraca & Astrup, 2019). The community-based circular economy practices, particularly PET that recovery through RC, not only generate economic opportunities for households but also contribute substantially to provincial and national climate mitigation goals.

The emission reductions aligned with Indonesia's Nationally Determined Contributions (NDCs) under the Paris Agreement. Indonesia has committed to reduce 31.89% national greenhouse gas emission through domestic mitigation efforts, or reducing up to 43.2% together with international support by 2030. PET recovery could be enhanced through community-based RC by providing measurable mitigation benefits within the waste sector and contributing to the wider national strategy for climate stabilization. District-level circular economy initiatives can play an important role for Indonesia's climate commitments (Kanugrahan & Hakam, 2023).

Regarding economic incentive structures, regional variations in waste bank pricing and income also emerge. Malang City's public waste bank system can process up to 2.5 tonnes/day, offering stronger micro-income opportunities to residents involved. Further, Depok City's modernization strategies—including digital transaction systems—have improved both sorting participation and effective household revenue streams (Hartono et al., 2022; Dahlan et al., 2024). These comparative perspectives help contextualize the pricing and income figures reported in Purbalingga (e.g., PET income ranging from IDR 1,000–4,500/kg) within a broader national framework of diverse RC performance.

RC are important for reasons other than waste reduction. They can yield quantifiable economic benefits, according to empirical research. PET, paper, aluminium cans or any other types of inorganic waste that collected through RC could greatly increase recycling rates and provide participating households with a consistent source of income, according to a recent material flow analysis (MFA) conducted in Metro City (Alifa et al., 2024). Likewise, Maros Regency case studies demonstrate how active involvement in waste bank initiatives can improve community well-being and lessen environmental stresses (Ilham & Yustianto, 2024). These results highlight how RC can be used to balance socioeconomic benefits with environmental sustainability.

Moreover, these composition dynamics should be interpreted in the context of infrastructure and behavioural factors. The growth in PET may not solely reflect higher consumption but could also indicate more effective sorting and collection efforts, particularly as waste bank initiatives expanded in the region during this period (Iacovidou et al., 2025). This underscores the dual challenge for policymakers: while consumption drives waste generation, improvements in waste sorting infrastructure may paradoxically raise the recorded share of recyclables.

The diagram titled Purbalingga's Local Circular Economy in Figure 4 illustrates the cyclical flow of inorganic waste—specifically PET, paper, and metal—from households to recycling industries through RC. The process begins with households generating and segregating inorganic waste, which is then transported to RC for sorting and storing. These facilities act as intermediaries, linking the community with formal recycling industries that convert collected materials into new products such as plastic pellets, paper pulp, and reusable metals.



Fig. 4. The cyclical flow scenario of inorganic waste illustration

The value created in the recycling stage is partially redistributed to the community in the form of income, thus reinforcing participation and closing the material loop. This localized model exemplifies the core principles of the circular economy, which emphasize keeping materials in use, regenerating natural systems, and minimizing waste (Kirchherr et al., 2022). Importantly, this system aligns with Indonesia's national waste strategy (National Policy and Strategy on Waste Management), which promotes community-based waste management and economic inclusion (Center for Circular Economy Transition, 2021). By incorporating social, economic, and environmental dimensions, the Purbalingga model represents a practical and scalable application of circular economy principles at the regional

level. The economic feedback loop—where sorted waste leads to real income—creates an incentive structure that fosters ongoing participation and behavioral change (Budiyarto et al., 2025).

This study has several limitations. It relied on secondary data from government agencies and RC, which may not capture informal sector contributions, seasonal variation, or household-level differences. Price data were restricted to a three-month period (January–March 2025), limiting the ability to reflect longer-term fluctuations. The assumption of a 3-kg minimum household contribution, though consistent with RC practice, may oversimplify actual behavior. The scope was also confined to PET, paper, and cans, emphasizing economic rather than environmental outcomes. Future research should incorporate longitudinal datasets, household surveys, and life-cycle environmental assessments to provide a more robust understanding of waste generation and circular economy potential.

Recycling polyethylene terephthalate (PET) significantly reduces greenhouse gas (GHG) emissions and petroleum use, since virgin PET production is fossil-fuel based and highly energy-intensive. Producing recycled PET (rPET) can cut emissions by up to 65% compared to new PET, mainly through energy savings and reduced extraction impacts (Faraca et al., 2019). In Purbalingga's circular economy, diverting PET waste from landfills into recycling facilities directly contributes to national climate mitigation targets and aligns with Indonesia's low-carbon development strategies. To maximize these contributions, policy frameworks should integrate local initiatives with formal and informal sector actors, supported by Extended Producer Responsibility (EPR) schemes and transparent pricing systems, thereby creating a pathway that connects local economic incentives with national circular economy goals (Apriadi et al., 2024). European countries, such as Germany, France, and Belgium have established strong EPR frameworks that require producers be responsible for the entire lifecycle of their own products, including organization and financing of post-consumer collection and recycling. These country examples demonstrate the process of transferring responsibilities upstream can stabilize material flows, increase recycling rates, and lessen the environmental impact of virgin PET production (Mallick et al., 2024).

Paper recycling also offers significant environmental benefits, particularly in the conservation of forest resources, water, and energy. Recycling one ton of paper saves approximately 17 trees, 26,500 liters of water, and 4,000 kWh of energy, which equates to reduced deforestation, lower emissions from pulping processes, and decreased pressure on water resources (United States Environmental Protection Agency, 2021). In Purbalingga, where paper accounts for 8.96% of total inorganic waste, increasing the recycling rate not only diverts waste from limited landfill space but also enhances ecosystem protection. Furthermore, recycled paper production emits 40% less greenhouse gases than virgin paper manufacturing, offering both climate and resource-use benefits (Silva et al., 2022).

Aluminum can recycling is one of the most energy-efficient practices in waste management, offering up to 95% energy savings compared to producing new aluminum from bauxite ore (United States Environmental Protection Agency, 2021). This process also significantly reduces carbon emissions and industrial pollution. In the Indonesian context, where energy generation still heavily relies on fossil fuels, such savings are even more impactful for climate goals. Although aluminum waste constitutes only a small share of Purbalingga's inorganic waste stream (0.66%), its recovery and reintegration into the industrial supply chain represents a high-leverage point in circular economy strategies. The concept of using waste as a resource supports broader arguments that recycling reduces raw extraction and aligns with circularity metrics across sectors (Slootweg, 2020).

Effective policy and governance frameworks are essential for scaling the success of localized circular economy initiatives such as those observed in Purbalingga. Indonesia's national waste management strategy provides a foundational roadmap for reducing waste by 30% and ensuring 70% proper handling by 2025 contributing to Indonesia's broader circular economy objectives (Center for Circular Economy Transition, 2021). To support these goals, local governments can introduce incentive-based policies that reward

households and businesses for sorting and delivering recyclables, while penalizing non-compliance. Policies could also help regulate the pricing systems and operational capacities of RC to ensure transparency, competitiveness, and financial viability across regions.

Indonesia's high PET consumption and low recycling rates highlight significant potential for circularity improvements, particularly through design-for-recycling initiatives and investment in both mechanical and chemical recycling technologies (Han et al., 2025). Mobile applications and digital tracking systems can simplify waste transactions, allow residents to monitor contributions, and facilitate coordination between households and RC. Pilot projects in Depok and Surabaya have shown how such platforms improve participation and traceability, while recent community studies further emphasize the role of digital tools in enhancing public participation (Pambudi et al., 2025).

Incentive-based scheme is related to Amirudin et al. (2023) study which explain the role of the circular economy in managing polyethylene terephthalate (PET) waste, emphasizing strategies to minimize environmental impacts while maximizing resource efficiency. It outlines current PET production and consumption trends, identifies challenges in recycling processes, and highlights opportunities for improving PET circularity through technological innovation, policy measures, and stakeholder collaboration. The study underscores the importance of integrating design-for-recycling principles, enhancing collection systems, and expanding secondary markets to achieve sustainable PET lifecycle management and this might be applicable for Purbalingga area.

Strengthening PET circular economy practices in Indonesia requires source segregation, improved collection infrastructure, and investment in recycling technologies (Ahmed et al., 2022). Digital platforms piloted in cities such as Depok and Surabaya have demonstrated how technology can enhance participation and traceability (Hartono et al., 2022). Evidence from Purbalingga's RC model shows that integrating community-based systems with National Policy and Strategy on Waste Management, Extended Producer Responsibility (EPR) schemes, and transparent pricing can align local economic incentives with national circular economy and low-carbon development goals.

Furthermore, policies must address the formalization of the informal waste sector, which remains a crucial but under-supported component of Indonesia's recycling landscape. Informal waste pickers contribute significantly to material recovery but often lack legal recognition, safety protections, or fair compensation (Iacovidou et al., 2025). Through decentralized governance models, municipalities can develop community-led cooperatives, issue formal work permits, and link informal actors to formal RC networks. This participatory governance approach empowers communities while advancing national sustainability objectives, ensuring that the circular economy not only scales effectively but does so equitably and inclusively.

The majority of research still focuses on the need to reduce waste without sufficiently quantifying the economic results, although there has been a substantial increase in the discussion of the circular economy in Indonesia. Prior studies frequently focus on large cities, ignoring smaller towns with less developed infrastructure, such as Purbalingga. Accurate estimation of community revenue potential is compromised by the lack of research that specifically integrates waste composition data with local market purchase prices. This research is new since it uses a data-driven method that integrates local price structures across several RC with compositional waste analysis. This study offers a reproducible, policy-oriented approach for assessing the circular economy potential of inorganic waste in Indonesia by using statistical comparisons and simulating community engagement scenarios (Iacovidou et al., 2025; Alifa et al., 2024).

This study proceeded the secondary data and three-months observation period that limits its capacity to capture and give more information about fluctuation, informal contribution, and household-level behaviour patterns. The reliability of future assessments needs brief longitudinal datasets, primary household surveys, and life-cycle environmental analysis to provide a comprehensive understanding of waste separation and circular economy potential. Future research should include a pilot cost-benefit analysis of

household incentive schemes to determine whether financial or non-financial rewards can effectively enhance the community-based participation in separating PET, paper, and cans.

Waste amount reduction and increasing material recovery could be prioritized to improve waste separation and recycling at the community level which could also contribute to Indonesia's National Policy and Strategy on Waste Management program. Efforts from all sectors would help to achieve the Sustainable Development Goals, particularly SDG 11 by improving the urban environmental quality, SDG 12 by responsible with consumption and production patterns, and SDG 13 by lowering greenhouse gas emissions associated with virgin material production and landfill disposal.

4. Conclusions

The findings of this study confirm that inorganic waste in Purbalingga, particularly polyethylene terephthalate (PET), paper, and cans, holds measurable economic potential when managed through RC. PET was found to dominate the waste composition, followed by paper and cans. These materials, though often overlooked in unmanaged waste systems, represent valuable resources when separated and sold through structured collection systems. The price range obtained from RC (e.g., IDR 1,000–4,500/kg for PET) demonstrates that even small household contributions can generate meaningful income if channelled effectively.

By modelling a realistic participation scenario, this projection not only illustrates the tangible value of community participation but also shows how semi-urban areas can significantly contribute to Indonesia's broader circular economy objectives. Community-based waste management strategies require less than 20% Purbalingga residents to contribute in sorting PET waste, papers and cans then sell it to waste storage facilities. A relatively modest level of citizen engagement can already unlock substantial environmental and economic benefits, particularly in terms of waste diversion from landfills and the stimulation of local recycling markets.

This study underlines the potential of community-based waste management systems in advancing circular economy practices. The RC model in Purbalingga showcases how decentralizing waste collection and empowering local residents can create sustainable and economically beneficial systems. Scaling this approach in similar districts could offer a pathway to achieve national waste reduction targets while supporting local livelihoods. Future efforts should focus on improving participation rates, optimizing pricing mechanisms, and integrating digital tools to further enhance the impact and efficiency of RC operations. Future studies are encouraged to incorporate longitudinal data covering multiple seasons or years, as well as environmental indicators such as greenhouse gas reductions, landfill diversion, and energy savings, to provide a more comprehensive assessment of circular economy impacts.

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Author Contribution

Conceptualization, A.L.A, P., Y.A.S.; Methodology, A.L.A, P., Y.A.S.; Investigation, G.E.L., A.F., A.P.A, A.N.S, F.W.S.; Writing –Original Draft Preparation, A.F., A.P.A, A.N.S, F.W.S.; Writing – Review & Editing, A.L.A.; Supervision, P., G.E.L., Y.A.S.

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Data Availability Statement

The data that support the findings of this study were obtained from publicly available secondary sources, including the Central Statistics Agency of Purbalingga (BPS, 2021–2024) and reports from the Indonesian Ministry of Environment and Forestry. Price data were collected directly from three local recycling centers (RC) in Purbalingga—Citra Mandiri, Bancar AKA, and Lestari Ponces—during January–March 2025. Additional information is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the author(s) used a generative AI tool to assist in paraphrasing certain sections for clarity and Grammarly to assist in improving the grammar and academic tone of the manuscript. After using these tools, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

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