

Analysis of Electronic Waste Flows and Urban Mining Potential in Surabaya

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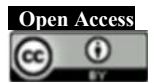
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Abstract

The rapid increase in population, consumption, and technology usage has led to a significant rise in electronic waste (e-waste), posing a serious environmental challenge. In Indonesia, e-waste management is predominantly handled by the informal sector, with minimal regulation and technology in place, creating potential risks to both the environment and public health. This study focuses on Gunung Anyar District to analyze household e-waste flows and the role of the informal sector in urban mining, employing Material Flow Analysis (MFA). The potential generation of household e-waste was estimated through questionnaires and interviews with 100 households. Additionally, surveys were conducted with informal sector actors, TPSSSS B3 (Temporary Storage for Hazardous and Toxic Waste), and waste banks to trace distribution pathways. Informal sector actors were selected using snowball sampling. The results indicate that Gunung Anyar generates approximately 303,957.35 kg of household e-waste per year. Most e-waste is either stored in households or sold to collectors, with only a small proportion entering waste banks and TPSSSS B3. Collectors, including dismantlers and non-dismantlers, serve as critical nodes in informal urban mining by channeling metal fractions to industries and other collectors, while generating substantial residues that end up at transfer stations and landfills. Although donations and repairs extend the lifespan of products, a significant portion of e-waste remains underutilized and environmentally hazardous. These findings emphasize the need for stricter regulations and the establishment of more structured systems to integrate informal sector actors and mitigate environmental and public health risks.

Keywords: electronic waste, urban mining, material flow analysis, valuable materials

1. Introduction

The increase in consumption, driven by population growth and development, has led to environmental challenges, particularly in waste management, including electronic waste (e-waste). Global electronic waste is estimated to reach 44.7 – 50 million metric tons per year, yet only about 20% is successfully recycled (Wong et al., 2007; Baldé et al., 2017; Forti et al., 2018). This waste contains hazardous materials such as lead, arsenic, cadmium, and mercury, which can contaminate soil, water, and air (Kaya, 2016; Schwarzer et al., 2005). In Indonesia, electronic waste generation reached 1.3 million tons in 2016, making it the fourth-largest contributor of e-waste in Asia (Baldé et al., 2017). However, electronic waste management is still predominantly handled by the informal sector, with minimal contribution from local governments (Nahor, 2019; Firmansyah et al., 2025).

Urban mining, the process of extracting valuable metals from urban waste, holds significant potential in

Indonesia, driven by urbanization and the increasing consumption of electronic devices (Arora et al., 2017; Firmansyah et al., 2025). Although electronic waste contains valuable materials, only 22% of the 62 million tons of global e-waste were properly recycled in 2022 (Baldé et al., 2024). Despite the growing volume of electronic waste and its environmental hazards, research on the distribution flow of e-waste management, particularly in Surabaya, remains limited, highlighting a critical gap for developing more effective urban mining and recycling strategies. Therefore, further studies are needed on the distribution flow and public participation in e-waste management to improve more effective management in the city (Kiddee et al., 2013; Azizi et al., 2023).

2. Methods

This research employs a systematic quantitative approach to evaluate electronic waste flows in Gunung Anyar District. To provide a clear overview of the procedural steps, the complete research framework is illustrated in Figure 1. The methodology is structured into several key stages, beginning with literature review and sample size determination,

followed by comprehensive data collection from both primary and secondary sources. The collected data is analyzed to determine household e-waste generation, as well as generation in the informal sector, TPSS B3, and waste banks. Subsequently, the potential of urban mining of electronic waste and its economic value is also estimated.

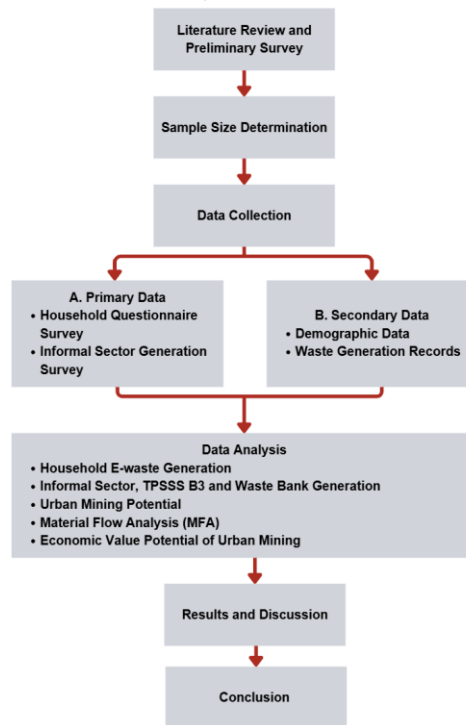


Figure 1. Schematic research framework

2.1 Study Area

This research was conducted in Gunung Anyar District, Surabaya, as shown in Figure 2. This location was strategically selected due to its substantial concentration of informal sector businesses, which reflects the economic dynamics of electronic waste, allowing for the quantification of e-waste volumes absorbed by these non-formal channels. Additionally, the availability of TPSS B3 (Tempat Penyimpanan

Sementara Limbah Bahan Berbahaya dan Beracun / Temporary Storage for Hazardous and Toxic Waste), which serves as a facility for the collection and temporary storage of household hazardous waste, renders this area strategic for evaluating the effectiveness of formal e-waste handling. Furthermore, waste banks, serving as community-based entities, provide a key indicator to assess the influence of direct community participation on the e-waste circulation loop.



Figure 2. Map of Gunung Anyar District

2.2 Sample Size Determination

To determine the flow of electronic waste, the potential generation of household electronic waste was calculated. The number of respondents was determined using the Stratified Random Sampling method. With this method, each member of the population has an equal chance of being selected as a sample (Ulya et al., 2018). Slovin's formula was used to calculate the sample size.

$$n = \frac{N}{1 + (N \times e^2)} \quad (1)$$

Where:

n = sample size (households)

N = total population (households)

e = sample error (0,1)

Below is the calculation of the sample size using Slovin's formula.

$$n = \frac{15.391}{1 + (15.391 \times 0,1^2)}$$

n = 99,35 ≈ 100 households

Based on the calculation, 100 households are needed as respondents. To determine the number of respondents in each sub-districts, population density was used to categorise respondents. There are three categories of population density: low, medium, and high. The selected research locations are Gunung Anyar Tambak Sub-district (low population density), Rungkut Tengah Sub-district (medium population density), and Rungkut Menanggal Sub-district (high population density). Table 1. shows the survey areas and the number of respondents.

Table 1. Survey area distribution and number of respondents

Categories of population density	Sub-district	Sample size (households)
Low	Gunung Anyar Tambak	34
	Gunung Anyar	-
Medium	Rungkut Tengah	36
High	Rungkut Menanggal	30

2.3 Data Analysis

Widmer et al. (2005) stated that one method to calculate the potential generation of electronic waste

is the consumption-and-use method, which involves determining the types of electronic goods used, their average lifespans, and the average weights. The potential electronic waste generation can be calculated using the following equation.

$$E = \frac{W \times N}{L} \quad (2)$$

Where:

E = estimated amount of electronic waste generated (kg/year)

N = number of electronic units (units)

L = average lifespan of electronic goods (years/unit)

W = weight of each type of electronic waste (kg)

To understand the flow of electronic waste, surveys were also conducted at TPSSSS B3 and waste banks, as well as in several informal sectors, including collectors and repair services. One specific large electronic waste collector was sampled over 16 days to determine both electronic waste generation and material waste dismantling. This sampling period was based on SNI 19-3964-1994, which outlines methods for sampling and measuring the generation and composition of urban waste, with a frequency of 8 days. In this study, the sampling duration was extended to 16 days to obtain more accurate data, covering two weekly cycles (workdays and weekends).

The Material Flow Analysis (MFA) of electronic waste was analyzed using the STAN 2.7 (SubSTANCE Flow Analysis) application to visualize, calculate, and analyze material movement within a system, and to perform mass balance calculations based on the principle of mass conservation. The stages involved in MFA of electronic waste include:

- (1) Data collection and defining the time period. The data used in this study were obtained from two sources: secondary data from literature reviews and primary data collected through field surveys and interviews.
- (2) Defining and setting system boundaries. The system boundaries include the scope and physical limits of the system to be analyzed. Defining the system boundaries is an essential step to ensure that the analysis is accurate and context-appropriate. The system boundaries for this study are shown in Figure 3.

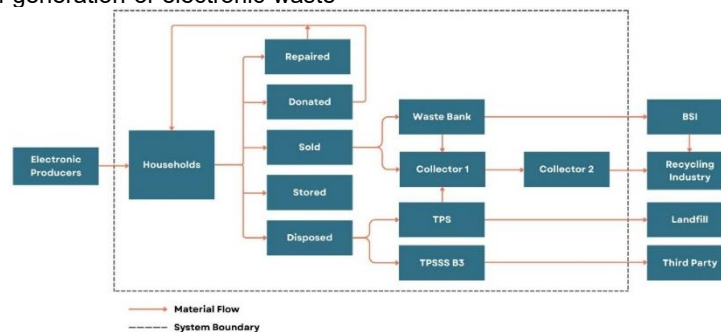


Figure 3. System boundaries of Material Flow Analysis (MFA)

3. Results and Discussion

The electronic waste management system in the Gunung Anyar District remains dominated by the informal sector. There is no official electronic waste management system in Gunung Anyar District. People tend to sell or donate their electronic waste to various informal sectors, such as collectors. The absence of specific regulations regarding electronic waste management could be one of the factors contributing to the informal nature of the management system in Gunung Anyar District, with no oversight from the relevant authorities. Although there is a TPSSS B3, the management of electronic waste still does not comply with the applicable regulations. The large amount of improperly managed electronic waste can have detrimental effects on health and the environment (Widyarsana, 2021).

3.1 Household Electronic Waste Generation

The potential generation of electronic waste was analyzed using a questionnaire distributed to 100 household respondents across three sub-districts representing different population density categories: Gunung Anyar Tambak, Rungkut Menanggal, and Rungkut Menanggal. The potential generation was calculated by documenting the ownership of electronic goods and their usage lifespan. According to the survey, the community owned 1,199 non-battery electronic items, including those no longer in use due to damage and those still in use. The potential generation was then calculated for the entire Gunung Anyar District, where Gunung Anyar Sub-district, with low population density, was calculated using the potential generation from Gunung Anyar Tambak Sub-district, which represents low population density. Table 2. shows the potential generation of electronic waste in Gunung Anyar District.

Table 2. Potential electronic waste generation in Gunung Anyar District

Sub-district	Potential generation (kg/household. year)	Total household	Potential generation (kg/year)
Gunung Anyar	21,21	5.781	122.604,41

Sub-district	Potential generation (kg/household. year)	Total household	Potential generation (kg/year)
Gunung Anyar Tambak	21,21	2.900	61.514,30
Rungkut Menanggal	15,19	3.313	50.320,67
Rungkut Tengah	20,46	3.398	69.517,97
Total			303.957,35

The potential generation of electronic waste in Gunung Anyar District is 303.957,35 kg/year. Other districts in Surabaya, such as Genteng and Tenggilis Mejoyo, have potential electronic waste generation of 502.072 kg/year and 16.977,78 kg/year, respectively (Rahmany, 2025; Rachmani, 2023). Demographic and socio-economic factors, especially population density, influence the volume of electronic waste (Adzania, 2023; Wang et al., 2013). However, Kelurahan Gunung Anyar and Gunung Anyar Tambak, with low population density, generate more electronic waste than other sub-districts. This is due to the larger number of households (Wang et al., 2013). Additionally, low-density areas are generally dominated by larger residential properties, which encourage hibernation or dead storage, where the disposal of electronic waste is delayed (Perdamaian & Zhai, 2024; Thiébaud et al., 2017). Social influences and lifestyle also contribute to higher consumerism of electronic goods (Park & Yun, 2024).

3.2 Informal Sector Electronic Waste Generation

The informal sector in Gunung Anyar Sub-district, which includes collectors, scrap dealers, repair services, and recycling industries, plays a significant role in the flow of electronic waste. Collectors, in particular, serve as an alternative for the disposal of household electronic waste and the removal of institutional assets. An analysis of electronic waste management in the informal sector was conducted through interviews with 24 informal sector participants, consisting of 18 collectors and 6 repair services. Figure 4. depicts the spatial distribution of the informal sector in Gunung Anyar District.



Figure 4. Map of Informal Sector Distribution in Gunung Anyar District

Eleven collectors dismantle electronic waste to extract valuable materials such as iron, copper, and aluminum, which are then sold to recycling industries or other collectors outside Gunung Anyar Sub-district. Meanwhile, 7 other collectors sell their electronic waste to collectors who dismantle it outside the sub-district. Table 3. shows the electronic waste generation in the informal sector.

Table 3. Electronic waste in the informal sector

No	Electronic type	Quantity	Weight (kg/unit)	Weight (kg/year)
a. Large collector				
1	AC (indoor)	15	26,7	9.136,41
2	AC (outdoor)	6	20	2.737,50
3	Water dispenser (desk)	2	5,86	267,36
4	DVD	2	1,43	65,24
5	Electric fan (stand)	6	9,98	1.366,01
6	Refrigerator (1-door)	15	31,65	10.830,23
7	Refrigerator (2-door)	11	60,04	15.066,29
8	Refrigerator (4-door)	1	119,56	2.727,46
9	Washing machine (twin-tub)	15	24	8.212,50
10	Washing machine (front-load)	10	61	13.915,63
11	Monitor/PC	1	8,03	183,18
12	CRT TV 21"	6	17,24	2.359,73
13	CRT TV 29"	3	23,19	1.587,07
Total from large collector				68.454,61
b. Small collector				
1	AC (indoor)	12	26,7	3.844,80
2	AC (outdoor)	10	20	2.400,00
4	Electric fan (stand)	2	9,98	239,52
6	Monitor/PC	1	8,03	96,36
8	Washing machine (twin-tub)	4	24	1.152,00
9	Washing machine (front-load)	2	61	1.464,00
12	LED TV 32"	2	5,39	129,36
Total from small collector				9.326,04
c. Repair service				
1	AC (indoor)	5	26,7	1.602,00
2	Electric fan (desk)	5	4,33	259,8
3	Electric fan (stand)	5	9,98	598,8
4	Electric fan (wall)	5	4,43	265,8
5	Monitor/PC	10	8,03	963,6

No	Electronic type	Quantity	Weight (kg/unit)	Weight (kg/year)
6	Refrigerator (2-door)	10	60,04	7.204,80
7	Washing machine (twin-tub)	10	24	2.880,00
8	Washing machine (front-load)	10	61	7.320,00
9	Printer	10	4,27	512,4
10	CRT TV 21"	1	17,24	206,88
11	CRT TV 32"	5	5,39	323,4
Total from repair service				22.137,48

Based on the calculation of waste generation, the electronic waste flow at the small collector is dominated by temperature exchange equipment (AC units), with the highest number reaching 22 units, and large equipment (washing machines) that contribute significantly to weight due to their size and material composition, despite the smaller number of units. The high volume of washing machines ending up with collectors aligns with the study by Mulyani et al. (2023). In the repair service sector, the dominance of washing machines (20 units) is driven by repair preferences due to high household demand (Nurhidayati, 2024). Additionally, while the number of fans is relatively high (15 units), the total weight generation is still lower compared to AC units and refrigerators, as they have much heavier material mass. Table 4. shows the electronic waste collected across all informal sectors.

Table 4. Generation of electronic waste in the informal sector

No	Type of informal sector	Waste collected (kg/year)
1	Large collector	68.454,61
2	Small collector	9.326,04
3	Repair service	22.137,48
Total		99.621,97

Electronic waste generated in the informal sector amounts to 99.918,13 kg/year, or 33% of total electronic waste generated in Gunung Anyar District. In both large and small collectors, the total waste generation is 77.780.65 kg/year, which constitutes 26% of the total potential household electronic waste generation. The high demand for electronic goods in developing countries is not matched by adequate infrastructure and technology to manage them at the end of their lifecycles, leading to the informal management of electronic waste under unsafe and risky working conditions (Ohajinwa, 2018).

3.3 TPSS B3 Electronic Waste Generation

TPSS B3 Gunung Anyar is located at the TPS 3R Gunung Anyar, specifically in Gunung Anyar Tambak Sub-district. The types of electronic waste entering TPSS B3 generally include light bulbs, batteries, cables, and other electronics, such as rice cookers, monitors, and others. The electronic waste is then sorted by type and stored in a dedicated drop box to prevent contamination with other specific waste Table

5. shows the electronic waste entering TPSSSS B3 over the last six months, totaling 184 days.

Table 5. Electronic waste collected at TPSSSS B3 Gunung Anyar

Month	Waste collected (kg/month)
May	15,20
June	15,60
July	17,20
August	19,00
September	20,60
October	47,00
Total	134,60
Average (kg/day)	0,73
Average (kg/year)	267,01

Based on calculations, the electronic waste entering TPSSSS B3 Gunung Anyar amounts to 0,73 kg/day or 267,01 kg/year, which is smaller compared to TPS 3R Tenggilis Mejoyo (454,8 kg/year) and higher compared to TPS 3R West Jakarta (0,4 kg/day) (Rachmani, 2023; Wardianto & Purwaningrum, 2023). The waste generated at TPSSSS B3 Gunung Anyar constitutes only 0.09% of the total potential household electronic waste, indicating that TPSSSS B3 is not the primary disposal route for electronic waste. The significant increase in waste generation in October may be due to dead storage, where broken devices are temporarily stored before disposal (Nøjgaard et al., 2020). However, the electronic waste at TPSSSS B3 is not transported by a licensed third party but is sold to informal collectors, providing additional income for workers. This, however, has not yet become a serious concern, as the Surabaya City Environmental Agency (DLH) focuses more on socio-economic aspects, where waste sales provide direct benefits to local workers.

3.4 Waste Banks Electronic Waste Generation

Gunung Anyar District has approximately 6 active waste banks across 3 sub-districts, which generally accept electronic waste, though in small quantities. Most waste banks collaborate with Bank Sampah Induk (BSI), but some also channel electronic waste to collectors. The higher prices offered by collectors are why the community prefers to sell their electronic waste to them. The waste banks categorize electronic waste as hard plastic or metal, which lowers its value. Table 6. shows the electronic waste entering the waste banks in the last six months.

Table 6. Electronic waste collected at the waste banks

Month	Waste collected (kg/month)
May	11,39
June	40,59
July	10,1
August	0,15
September	11,36
October	11,42
Average (kg/month)	14,17
Average (kg/year)	170,02

A total of 170,02 kg of electronic waste enters the waste banks each year, which is only 0,06% of the household electronic waste collected. The waste

banks in Gunung Anyar District are more focused on managing plastic and paper waste. A significant increase in June due to the entry of TV waste. Neither the waste banks nor BSI dismantles; instead, they sell electronic waste directly to industries. According to Firmansyah et al. (2025), waste banks play a role in increasing community participation, but electronic waste management should be carried out by licensed entities as per Government Regulation No. 27 of 2021, which does not include waste banks. Therefore, the role of waste banks in electronic waste management needs further consideration.

3.5 Electronic Waste Urban Mining Practice

Electronic waste urban mining in Gunung Anyar District is carried out by collectors who perform manual dismantling to recover valuable materials. This recovery process creates challenges due to the complexity of electronic waste components (Marwati, 2009). Some collectors use burning to recover materials, which poses the risk of releasing harmful substances from incomplete combustion, yet no standard operating procedures are applied (Lundgren, 2012). A total of 11 collectors dismantle electronic waste to extract valuable materials such as iron, copper, and aluminum, which are then sorted and sold based on their market value.

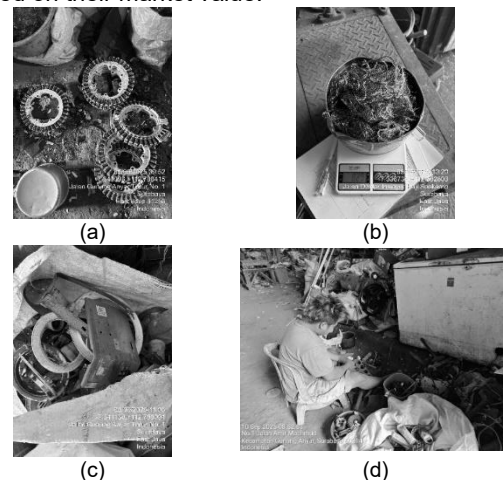


Figure 5. (a) Aluminum; (b) Copper; (c) Iron; (d) Manual Dismantling

The practice of urban mining is influenced by the growing demand for resources such as metals, minerals, and rare earth elements, along with the awareness of the environmental impacts of conventional mining methods, including deforestation, habitat destruction, and pollution (Bódizs et al., 2025).

Table 7. presents data on the dismantling of materials from various electronic waste types by large collectors over 1 year, along with recovery and residue percentages. Some types of electronic waste are temporarily stored before being dismantled, so for items like dispensers and DVDs, the estimated results are based on literature studies, whereas other items that are not dismantled are assumed to have component sizes similar to those of their counterparts. Table 8. summarizes the dismantled electronic waste weight from both large and small collectors over one year.

Table 7. Material dismantling by large collector

Electronic type	Iron		Aluminum		Copper		% Recovery	% Residue
	kg/unit	%	kg/unit	%	kg/unit	%		
AC (<i>indoor</i>)	10	37,45%	1,5	5,62%	3,5	13,11%	56,18%	43,82%
AC (<i>outdoor</i>)*	-	-	-	-	-	-	56,18%	43,82%
Refrigerator (1-door)	20	63,19%	1,5	4,74%	2	6,32%	74,25%	25,75%
Refrigerator (2-door)*	-	-	-	-	-	-	74,25%	25,75%
Refrigerator (4-door)*	-	-	-	-	-	-	74,25%	25,75%
CRT TV 21"	2,5	10,78%	0,5	2,16%	1	4,31%	17,25%	82,75%
CRT TV 29"	-	-	-	-	-	-	17,25%	82,75%
Electric fan (stand)	3	30,06%	0,5	5,01%	0,5	5,01%	40,08%	59,92%
Monitor	1	12,45%	0,5	6,23%	0,3	3,74%	22,42%	77,58%
Washing machine (twin-tub)	10	41,67%	1	4,17%	1	4,17%	50,00%	50,00%
Washing machine (front-load)	20	32,79%	2,5	4,10%	2	3,28%	40,16%	59,84%
Water dispenser (desk)**	-	29%	-	9,30%	-	17%	55,30%	44,70%
DVD**	-	36%	-	5%	-	4%	45,00%	55,00%

*The dismantling percentage follows the proportions of comparable electronic waste types

**Source: Nahar et al. (2017)

Table 8. Material dismantling by all collectors

No	Electronic type	Iron (kg/year)	Aluminum (kg/year)	Copper (kg/year)
1	AC (<i>indoor</i>)	4.741,88	711,28	1.659,66
2	AC (<i>outdoor</i>)	1.744,38	261,66	610,53
3	Refrigerator (1-door)	6.843,75	513,28	684,38
4	Refrigerator (2-door)	9.520,56	714,04	952,06
5	Refrigerator (4-door)	1.723,52	129,26	172,35
6	CRT TV 21"	254,39	50,88	101,76
7	CRT TV 29"	171,09	34,22	68,44
8	Electric fan (stand)	446,63	74,44	74,44
9	Monitor	22,81	11,41	6,84
10	Washing machine (twin-tub)	3.781,88	378,19	378,19
11	Washing machine (front-load)	5.042,50	630,31	504,25
12	Water dispenser (desk)	77,54	24,86	45,45
13	DVD	23,49	3,26	2,61
Total (kg/year)		34.394,40	3.537,09	5.260,95
Total all materials (kg/year)				43.192,44

Based on calculations of electronic waste generation potential, iron is the most significant contributor, with 34.394,40 kg/year, as it frequently dominates the composition of electronic waste in terms of both size and weight (Shittu et al., 2021). Wiwik (2018) notes that iron constitutes 19.6%–62.6% of electronic waste in air conditioners (ACs), washing machines, and refrigerators, with iron in refrigerators accounting for 58.1% (Sutanto et al., 2017). This indicates that iron is easily obtained during the urban mining process of electronic waste. In contrast, aluminum and copper are found in smaller quantities, with AC units containing 9.4% aluminum and 15.6% copper, much lower than iron (54.4%) (Al-Khatib & Fraige, 2024).

However, not all materials in electronic waste can be reused. Some materials that lack resale value are discarded at Waste Transfer Stations (TPS). Total recovery refers to the amount of material that can be reused, while residue is the remaining material that is discarded. Refrigerators have the highest recovery rate, with 74.25% of the material recovered and only 25.75% as residue. The high non-ferrous metal content makes up more than half of the refrigerator's components. On the other hand, CRT televisions have the lowest total recovery rate at 17.25%, resulting in a high residue of 82.75%. Based on previous calculations, the total amount of recoverable materials is 43.192,44 kg/year, while the remaining material that cannot be reused becomes residue. Table 9. shows

the amount of residue generated from the dismantling of electronic waste.

Table 9. Residue from electronic waste dismantling

No	Electronic type	Weight (kg/year)	% Residue	Residue (kg/year)
1	AC (indoor)	4.741,88	43,82%	5.547,99
2	AC (outdoor)	1.744,38	43,82%	2.040,93
3	Refrigerator (1-door)	10.830,23	25,75%	2.788,83
4	Refrigerator (2-door)	15.066,29	25,75%	3.879,63
5	Refrigerator (4-door)	2.727,46	25,75%	702,33
6	CRT TV 21"	2.359,73	82,75%	1.952,70
7	CRT TV 29"	1.587,07	82,75%	1.313,32
8	Electric fan (stand)	446,63	59,92%	890,27
9	Monitor	183,18	77,58%	142,12
10	Washing machine (twin-tub)	3.781,88	50,00%	4.538,25
11	Washing machine (front-load)	5.042,50	59,84%	9.202,56
12	Water dispenser (desk)	267,36	44,70%	119,51
13	DVD	65,24	55,00%	35,88
Total				33.154,33

In one year, the residue from electronic waste dismantling reaches 33,154.33 kg/year, with front-loading washing machines contributing the most, totaling 9,202.56 kg/year. Although televisions have the highest residue percentage, the large volume of washing machines and their over 50% residue content result in a higher total residue. Plastic, which cannot be reused and accounts for 21% of the weight of electronic waste, is the primary cause of the high residue (Zeng et al., 2018). However, engineering plastics used in electronic products can be mechanically or chemically recycled (Liu et al., 2023).

Figure 6. shows that iron dominates all types of electronic waste, while copper is more prevalent than aluminum, especially in AC units, which use copper pipes as heat exchangers (Al-Khatib & Fraige, 2024; Hu et al., 2021). In CRT televisions, the residue exceeds the recoverable material, mostly glass (more than 80%) containing lead, which is harmful to the environment (Herat, 2008). Managing CRT TV residues requires high costs, reaching 30% of total recycling costs compared to the value of the recoverable materials (Kang & Schoenung, 2006). Similarly, India and China generate large amounts of electronic waste, but much of the valuable material is discarded without proper recycling (Awasthi & Li, 2017).

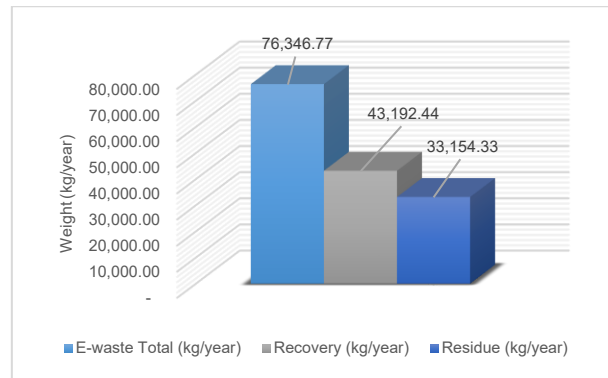


Figure 6. Urban mining results from collectors

3.6 Electronic Waste Flow

The electronic waste flow in Gunung Anyar District follows diverse pathways, including disposal, storage, sale, repair, and donation. This analysis maps the flow of electronic waste from its origin (households) to its final destination outside the study area. Based on the survey results, the community tends to sell electronic waste because of its resale value. Additionally, many people store electronic waste either for repair or for other reasons. The distribution flow of electronic waste in Gunung Anyar District is illustrated through Material Flow Analysis, as shown in Figure 7.

3.7 Economic Potential of Urban Mining

Urban mining is part of the circular economy, aiming to transform waste into valuable secondary resources (Erdiaw-Kwasie et al., 2024). This approach helps provide raw materials by recycling valuable metals, thereby reducing resource consumption (Kazançoglu et al., 2020). In 2016, the value of raw materials in electronic waste was estimated to reach 55 billion Euros, and by 2022, it was projected to reach 91 billion USD, with copper, gold, and iron as the primary metals (Baldé et al., 2017; Baldé et al., 2024). Interviews with collectors revealed that the prices of electronic waste materials vary, with iron priced between Rp4.500 and Rp6.000 per kilogram, aluminum between Rp5.500 and Rp60.000, and copper between Rp120.000 and Rp185.000 per kilogram, depending on location and material quality. Some collectors sell their dismantled materials directly to recycling industries or to other collectors located outside Gunung Anyar District, while others distribute materials to both parties simultaneously. Table 10. shows the estimated revenue from the sale of iron, aluminum, and copper at the highest selling prices.

Table 10. Estimated revenue from material sales

Material	Economic value potential	
Iron (Rp6000)	Rp	206.366.414
Aluminum (Rp60000)	Rp	212.225.578
Copper (Rp185000)	Rp	973.275.067
Total	Rp	1.391.867.059

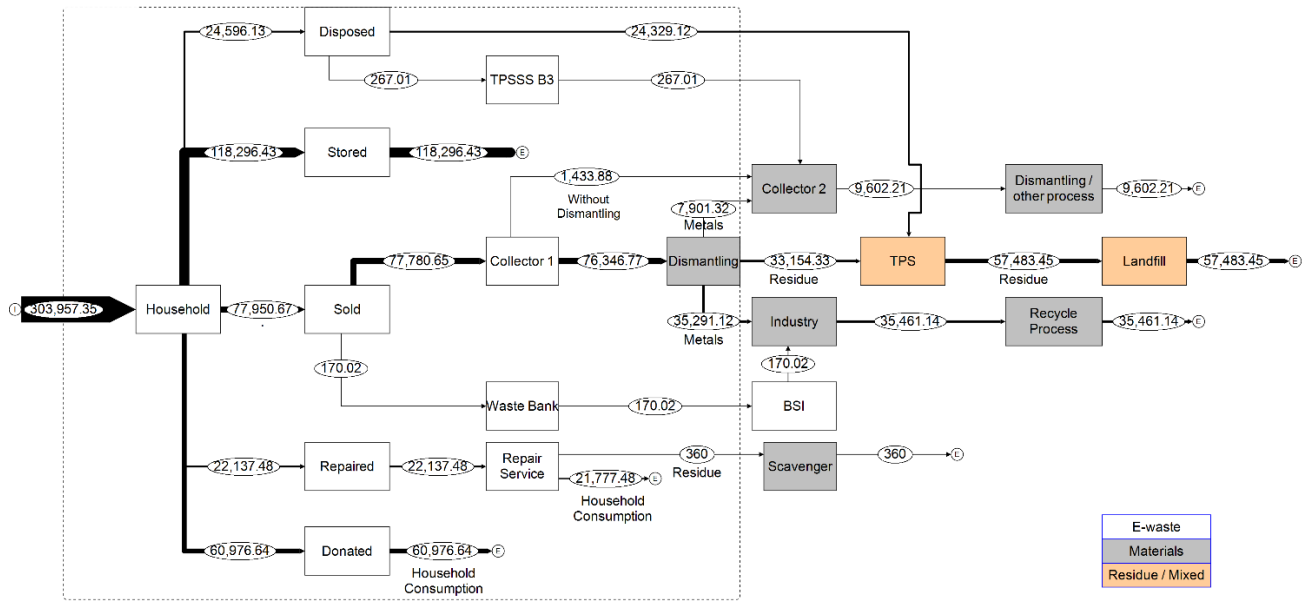


Figure 7. Material Flow Analysis of electronic waste in Gunung Anyar District

The calculation results indicate that copper has the highest economic potential (Rp973.275.067), followed by aluminum (Rp212.225.578) and iron (Rp206.366.414). Although aluminum and copper have a lower urban mining potential than iron, they have a higher economic value, especially copper. Research in Pontianak City shows that collectors not only collect iron, aluminum, and copper but also plastic and PCBs. However, the prices of these materials are lower than in Gunung Anyar District (Mulyani et al., 2023). Unfortunately, technological and economic constraints may lead to the loss of critical metals and rare earth elements, which would otherwise increase the economic value (Thiébaud et al., 2018). Table 11. compares the selling prices of materials across various countries, where, as in Gunung Anyar District, copper is priced higher than iron and aluminum.

Table 11. Material prices in other countries

Country	Unit	Iron	Aluminum	Copper
Jordan ¹⁾	USD/kg	1,28	2,45	9
Italy ²⁾	€/kg	0,12	1,5	5,2
Thailand ³⁾	Baht/kg	8,99	43,88	168,24
Nigeria ⁴⁾	€/kg	1,2	1	4,5

¹⁾Al-Khatib & Fraige, (2024)

²⁾Cucchiella et al. (2015)

³⁾Phoochinda & Kriyapak (2021)

⁴⁾Odeyingbo et al. (2025)

Electronic waste recycling activities in Agbogbloshie, Ghana, significantly contribute to the local economy, with workers earning higher daily wages than the national minimum wage, such as waste pickers who earn GH¢ 25 (Rp37.900) per day, far exceeding the national minimum wage of GH¢ 6 (Rp9.100) (Amankwaa et al., 2016). Similarly, in Gunung Anyar District, the informal sector dominates over the formal sector. However, many are reluctant to formalize their businesses due to concerns about stricter regulations.

The dismantling of materials and selling them to recycling industries creates a closed-loop supply chain. According to ISO 14044:2006, recycling is considered closed-loop when the recycled material becomes the same type of product, or its inherent properties do not change. The informal sector is more efficient in collecting electronic waste due to direct incentives and low costs (Chi et al., 2011). When collectors in Gunung Anyar District connect with recycling industries, they benefit from selling high-value materials, creating a symbiosis between the industry and collectors (Widmer et al., 2005). To ensure the proper functioning of the closed-loop supply chain, development involving multiple stakeholders is required (Pongen et al., 2024).

3.8 Impact of Informal Sector Urban Mining

The informal sector's practice of electronic waste urban mining contributes to the local economy by creating job opportunities and applying recycling principles to valuable materials. However, this sector lacks official authorization to dismantle electronic waste, leaving no proper procedures in place to ensure the work is done safely and correctly. Without appropriate procedures, this practice leads to adverse environmental and health impacts. The dismantling of electronic waste can contaminate soil, air, surface water, and groundwater with heavy metals and persistent organic pollutants (Li et al., 2024). These environmental impacts increase health risks for workers and nearby communities, including respiratory dysfunction, nerve damage, endocrine disruption, liver and kidney dysfunction, and increased cancer risks (Abedin et al., 2025).

Research across various countries shows that informal-sector urban mining activities have proven harmful to the environment and human health. Case studies in Iran, Bangladesh, China, and Ghana demonstrate that urban mining practices conducted without adequate personal protective equipment result in severe environmental degradation and significant health risks. Ecologically, these activities

contaminate air, soil, and water sources with toxic heavy metals (such as Pb, Cr, As, Ni, and Hg) and persistent organic pollutants (POPs and PFAS), often at concentrations exceeding international safety standards. Chronic exposure to these contaminants has direct impacts on human health, indicated by significantly elevated blood lead concentrations among workers, increased carcinogenic risks, reduced lung function, as well as long-term effects such as impaired child development and pregnancy-related complications among communities living near processing sites (Abedin et al., 2025; Amankwaa et al., 2016; Jorfi et al., 2023; Li et al., 2024).

The various impacts of informal-sector urban mining activities highlight the need for strict regulations on electronic waste management to mitigate environmental and public health risks. With policy intervention, not only can oversight be established, but the informal sector can also operate within a more structured and safer framework, ensuring that the economic potential of urban mining is maximized without harming the environment and public health.

4. CONCLUSION

The estimated generation of non-battery household electronic waste in Gunung Anyar District is 303,957.35 kg per year. The overall flow of electronic waste in this district reveals that the majority is either stored in households or sold to collectors, with only a small fraction directed to waste banks and TPSS B3 facilities. Collectors, including both dismantlers and non-dismantlers, play a central role in informal urban mining by channeling valuable metal fractions to industries and other collectors, while generating significant amounts of residue that ultimately end up at transfer stations (TPS) and landfills. Meanwhile, donation and repair practices help extend the lifespan of some electronic products. However, despite these efforts, much of the e-waste remains underutilized and continues to pose environmental risks, as it primarily ends up in storage, informal recycling, or disposal. While urban mining practices hold substantial economic potential, only a portion of the materials are effectively reused. Therefore, strict regulations are essential to minimize the environmental and health impacts associated with these practices.

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