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Entrepreneurship in electronic waste management: A design thinking approach

Jurry Hatammimi[1,2]*, Astri Ghina[1,2]

[1]School of Economics and Business, Telkom University, Bandung, West Java, Indonesia

[2]Center of Excellence for Key Digital Transformation Indonesia, Research Institute for Intelligent Business and Sustainable Economy, Telkom University, Bandung, West Java, Indonesia

Abstract

Electronic waste (e-waste) is becoming an increasingly significant problem, particularly due to its hazardous and toxic content. The paucity of business management research on technology-based e-waste disposal management exacerbates this issue. The novelty of this study lies in the application of design thinking not to prototype a solution, but to gain a deep understanding of stakeholder experiences and pain points, translating them into structured problem categories that support the development of an ecopreneurial information and communication technology-driven e-waste management system. Understanding the perspectives and experiences of these e-waste stakeholders helps us identify the real issues. In the empathise stage, we conducted interviews with 10 participants, who were chosen to represent the three main stakeholder categories: e-waste disposers, government institutions, and recycling institutions. In the define stage, an affinity diagram was used to analyse the gathered data and formulate the problem. We identified four primary issues with e-waste treatment: inadequate systems, a lack of socialization, low public awareness, and high processing costs. It can be concluded that developing an efficient e-waste disposal management system is a top priority. To realise the possibility of creating an ecopreneur business, further study is suggested to proceed to the ideation stage, where solutions to the four identified problems can be generated.

Keywords: Design thinking; Disposal management; Ecopreneurship; Electronic waste; Innovation management

***Corresponding author:**
Jurry Hatammimi
(jurryhatammimi@telkomuniversity.ac.id)

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1. Introduction

The United Nations (UN) 2020 Global E-Waste Monitor annual report estimated that 53 million tonnes of electronic waste (e-waste) were produced in 2019 (Forti *et al.*, 2020). This large quantity of e-waste is primarily due to the difficulties users face when attempting to repair damaged electronic goods, which encourages them to purchase new ones (Rahman, 2022). Electronics makers refer to this cycle as "planned obsolescence" or purposeful obsolescence. The overall volume of e-waste is expected to reach 74 million

tonnes by 2030, increasing to 120 million tonnes by 2050 (Forti *et al.*, 2020). The electronics sector is a significant industry, and e-waste is currently the fastest-growing waste stream (Harikaran *et al.*, 2023). Although e-waste contains a mixture of hazardous substances and valuable materials, only 17.4% of it can be collected, processed, and recycled properly (Fanthi *et al.*, 2021; Lu *et al.*, 2023; Wang & Anand, 2024). Ghana and China face severe air, water, and land contamination due to improper e-waste recycling (Parajuly *et al.*, 2019). According to the UN, Indonesia produced approximately 1.618 million tonnes of e-waste in 2019. Specifically, Java, as the most populous island, contributes to 56% of the total amount of Indonesian e-waste (Citarum Harum, 2021).

According to *Indonesian Government Regulation No. 27* (2020), e-waste is categorised as waste that contains hazardous and toxic materials, such as lead, chromium, mercury, cadmium, and arsenic. Therefore, e-waste should not be mixed with other types of waste. According to Khalid (2022), the Indonesian government has issued at least three other regulations regarding e-waste. There have been some efforts to manage e-waste in Indonesia. For instance, the company EwasteRJ provided e-waste drop boxes at 20 points in 12 districts (Defitri, 2022). Perkins *et al.* (2014) found that only 25% of e-waste gets recycled in formal recycling plants with worker protection. The Environmental and Sanitation Department in Bandung, Indonesia, set up 10 e-waste collection drop boxes; however, some have disappeared. In addition, according to Iqbal and Dyah (2022), public awareness of current waste management practices remains low. The population still relies heavily on traditional methods, as they find it difficult to dispose of e-waste (Wanderley & Bonacin, 2019). Recently, a new approach to gaining an understanding of e-waste among students has emerged, utilising interdisciplinary design-driven studios (Wang & Anand, 2024), as well as a novel concept of incorporating e-waste components into the electronic goods design process (Lu *et al.*, 2023).

Based on the amount of e-waste generated in 2020, it was estimated that Indonesia could make a profit of USD 1.8 billion if it were recycled (Puspa, 2023). The Ministry of Environment and Forestry estimates that every 1 tonne of e-waste from telecommunications equipment contains 1.44 kg of gold, silver, copper, and other high-value commodities (Dinnata, 2017). In addition, every 1 tonne of managed e-waste can also prevent the emission of 1,400 tonnes of CO_2 (Puspa, 2023). Nuryanto and Suzianti (2022) emphasised the need for e-waste collection facilities and information campaigns to raise awareness, as e-waste is often found in general waste bins (Wanderley & Bonacin, 2019). Jain *et al.* (2023) and Rive (2017) noted that e-waste is a complex problem that requires innovative solutions. Previous studies have focused on technical solutions or interface design prototypes for e-waste management; therefore, the current study focuses on mapping stakeholder pain points as the basis for an ecopreneurial business opportunity.

E-waste issues require new solutions. An innovative e-waste disposal method could be proposed. This field could have an ecopreneur enterprise. Design thinking can be used to construct this system, as Inegbedion (2022) found that it improves corporate success. Therefore, this research advances ecopreneurship entrepreneurial theory by applying design thinking to e-waste management. Understanding the perspectives and experiences of these e-waste stakeholders could help us identify their genuine concerns.

1.1. Literature Review

End-of-life electrical and electronic equipment (e-waste) is a rapidly expanding global problem. E-waste comprises both electronic equipment that is used but no longer functions and can still be repaired, and electronic equipment that is used but no longer functions and cannot be repaired (Basel Convention, 2013). Such waste generally contains valuable materials that are economically valuable when recycled. Unfortunately, most e-waste is recycled in the unregulated informal sector, posing a significant risk of toxic exposure to recyclers (Perkins *et al.*, 2014). E-waste can be categorised as (Jafar, 2015):

(i) Technology and communications: Laptops, PCs, earphones, headphones, scanners, data cables, cameras, chargers, power banks, loudspeakers, etc.
(ii) Electronic entertainment: Cameras, video recorders, radios, video players, audio players, remote controls, etc.
(iii) Electronic toys and sports equipment: Toy cars, toy musical instruments, etc.
(iv) Household: Rice cookers, irons, electronic kettles, toasters, stirrers, whisks, etc.
(v) Lighting: Light bulbs and light tubes
(vi) Electrical power cables, batteries, extension cables, etc.

According to Nnorom and Osibanjo (2008), changes in government attitudes, the enactment of laws specifically addressing e-waste, control over e-waste disposal, the implementation of Extended Producer Responsibility, and the transfer of technology for proper e-waste recycling are key criteria for effective e-waste management in some emerging economies. Sundar *et al.* (2023) suggested

that the government provide incentives to stakeholders involved in e-waste handling. Nowakowski and Pamuła (2020) proposed the design of an application that can identify e-waste types based on photos sent by people seeking to dispose of e-waste. There is also the idea of implementing mobile robots that identify e-waste during the collection process from households, thereby reducing the need for human labour (Shreyas Madhav *et al*., 2022).

Brindhadevi *et al*. (2023) discussed numerous present and emerging e-waste recycling systems; however, their primary focus was on the health effects of e-waste metal pollution. Yu *et al*. (2023) suggested optimising the e-waste recycling industry using legal, reasonable, and efficient methods. George and Michael (2023) proposed the idea of creating e-waste-based crafts and using a platform to sell them. Overall, e-waste studies conducted between 2008 and 2023 have shown that controlling e-waste disposal in emerging economies is hampered by several key issues.

Design thinking is a comprehensive thinking process that focuses on generating market possibilities and solutions, starting with a process of empathy for a specific human-centered need and progressing to sustainable innovation based on user demands (Brown, 2009). In this method, five stages/processes enable us to obtain innovative outcomes. These stages aim to explore user needs and determine optimal product specifications (Plattner, 2010). The five stages of design thinking are empathise, define, ideate, prototype, and test.

In the first stage, empathise, the design thinker must identify the user or intended user and then analyse the user's experience, emotions, and situation. Empathising is essential in design thinking because it ensures that the final product or service is user-centred and meets the needs of the target user. Regarding the empathy results, an empathy map is a commonly used tool to better understand the perspectives and experiences of a particular group of people. It is often employed in the fields of design and customer experience to help organisations better grasp their clients' or users' requirements and feelings. According to Bratsberg (2012), an empathy map is a human-centred tool that focuses on understanding individuals by seeing the world from the user's perspective. Four of the five stages (empathise, define, prototype, & test) are forecasters of business success (Inegbedion, 2022).

Several other studies on e-waste have applied design thinking. Nuryanto and Suzianti (2022) utilised design thinking to design and test the elements of an e-waste application, while Wanderley and Bonacin (2019) employed the Hackathon method to create a recycling bin prototype. Fanthi *et al*. (2021) used e-waste for home interior accessories. Rive (2017) highlighted the use of e-waste for installation and performance art, and Madrigal *et al*. (2024) utilised design thinking specifically for photovoltaic panels.

Other waste-related studies have also used design thinking. Specifically, Jimenez *et al*. (2021) described a sterilisation system; Rois *et al*. (2020) applied design thinking to organic waste management; Machado and Grilo (2020) focused on a general waste collection system; and Massari *et al*. (2022) used design thinking to examine food waste management.

2. Methods

As this study focused on the empathise stage of the design thinking method, it is considered a qualitative research and thus aims to present the results descriptively. According to Sekaran and Bougie (2016), descriptive research seeks to describe an interesting topic and explain the characteristics of relevant objects such as people, products, and brands. In this study, at the empathise stage, we seek to capture the characteristics of stakeholders in managing e-waste. The needs of these parties should be understood in the final phase. Based on this research strategy, this study was categorised as a case study. Case studies examine something in depth and provide a more precise explanation of the problem by examining real situations (Sekaran & Bougie, 2016).

A case study was conducted by selecting a city on Java Island, Indonesia, as the research object. Currently, this city has only six e-waste drop points (Citarum Harum, 2022). Next, we selected the parties to be interviewed using purposive sampling. Purposive sampling is based on certain criteria to support the information needed (Sekaran & Bougie, 2016). The participants were stakeholders in e-waste disposal management, comprising several parties, including e-waste disposers, government institutions, and recycling institutions. E-waste disposers were represented by a housewife, a father, a college student, a factory manager, a shopping mall manager, and a logistics manager of an educational institution. The government institutions were represented by a staff member and the manager of the Environmental and Sanitation Department. E-waste recycling organisations were represented by the director of a waste bank and the manager of a recycling company. In total, there were 10 participants.

The interview method was used to collect data. The interviews were conducted in a semi-structured manner, following verbal confirmation of informed consent from the participants. We compiled a list of interview questions for the three types of stakeholders. The questions consisted of three parts: the stage prior to e-waste disposal, the stage of e-waste disposal, and the stage after e-waste disposal.

The questions are presented below:

(i) Questions for the environmental agency

- Before disposal:

a. To what extent does the environmental agency understand electronic waste and its management?
b. Does the environmental agency have guidelines or regulations regarding the disposal, recycling, and processing of electronic waste?
c. What should be done with damaged electronic devices?
d. What kind of items are considered electronic waste?
e. How much electronic waste is generated in your work area per month?
f. What do you usually do with electronic waste in your area?
g. What are your feelings about electronic waste disposal?
h. Are there any campaigns or programs regarding electronic waste? What are they?
i. What are the obstacles facing in managing and educating about electronic waste?

- During disposal:

a. How does the environmental agency dispose of electronic waste?
b. What is the current process for people disposing of electronic waste?
c. Is there a specific time for you to dispose of electronic waste? When is that?
d. Where do you dispose of electronic waste?
e. Who should be responsible for managing electronic waste?
f. How should electronic waste be managed?

- After disposal:

a. How do you feel about the way people currently dispose of e-waste? Satisfied/dissatisfied? Explain.
b. Do you know what happens to discarded e-waste? Explain.
c. Are you aware of the dangers of improperly disposed of e-waste? Explain.
d. Does e-waste have economic value? Explain.
e. How do you measure the success of your e-waste recycling efforts?
f. What are the long-term and short-term goals of the environmental agency in managing e-waste?
g. Does the collected and processed e-waste comply with applicable environmental and safety standards?

(ii) Questions for e-waste disposers:

- Before disposal:

a. To what extent do you understand electronic waste?
b. What do you do with broken electronic devices?
c. What are the conditions of the items you dispose of as electronic waste?
d. How much electronic waste is there in your area per month?
e. What do you usually do with the electronic waste in your area?

- During disposal:

a. How do you dispose of e-waste?
b. Is there a specific time you dispose of e-waste? When is that?
c. Where do you dispose of e-waste?
d. Who should be responsible for managing e-waste?
e. How should e-waste be managed?

- After disposal:

a. How do you feel about the way you currently dispose of e-waste? Satisfied/unsatisfied? Explain.
b. Do you know what happens to the e-waste you dispose of? Explain.
c. Are you aware of the dangers of improperly disposed e-waste? Explain.
d. What do you expect to happen after disposing of e-waste?

(iii) Questions for recyclers:

- Before disposal:

a. How well do you understand electronic waste?
b. What should be done with damaged electronic devices?
c. What kind of items are considered electronic waste?
d. Are there any campaigns about electronic waste? How?
e. Are there any certifications or standards that recycling managers must meet to ensure proper recycling?

- During disposal:

a. What are the procedures for disposing of e-waste?
b. How is the community currently disposing of

e-waste?

c. Is there a specific time for people to dispose of e-waste? When is that?
d. Where do people dispose of e-waste?
e. Who should be responsible for managing e-waste?
f. How should e-waste be managed?

- After disposal:

a. Considering discarded electronic waste, how do you think it is managed? What do you think?
b. Do you know what happens to the electronic waste discarded by the public? Explain.
c. What happens to the electronic waste you manage? If it cannot be processed, what do you do?
d. What are the economic benefits of the electronic waste you manage?
e. What recycling process is considered feasible? Is it implemented by your team? What will you do if it fails?
f. What response does the recycler expect from the government and the public regarding e-waste recycling?
g. How long does it take the recycler to manage e-waste?
h. How is the success of e-waste management calculated?

Case studies often use three validity tests to verify study quality: external validity, internal validity, and construct validity (Yin, 2014). We examined the construct and external validity. Internal validity was examined only in explanatory or causal research; hence, we did not include it in our study. Three tactics can be used to increase the construct validity when conducting a case study. The first uses evidence from several sources (Yin, 2014). The data for this study were gathered from a number of sources, including physical artefacts, interviews, documentation, and archival documents. Creating a chain of evidence is the second strategy for construct validity. Most of the evidence in this study was cited and treated as a book or scientific article; therefore, it is also listed in the references. Finally, the third tactic is to have a draft report reviewed by key informants. The second test was external validity. The only way to increase external validity is through replication. This is reflected in the method used to select the sources for this study.

Yin (2014, p. 240) defines reliability as "the consistency and repeatability of research procedures used in case studies". Using a consistent approach ensures the trustworthiness of outcomes. When another researcher conducts the same case study using the same methodology as the previous researcher, they should obtain the same results and conclusions. Documentation of past study techniques is essential and can be accomplished using a case study protocol. In this study, the collected data were grouped according to their answers. The aim was to avoid errors during data collection. In qualitative research utilising interview transcripts, processes for validity (credibility) and reliability (dependability) are implemented to guarantee the trustworthiness and consistency of the findings derived from the data. These are the processes:

(i) Credibility (validity) protocol: The principal method employed in this analysis to ensure that the interpretations accurately represent the meanings expressed by interview participants is triangulation. Specifically, this study utilised source triangulation, which entails the comparison and contrast of information obtained from various, distinct sources. For example, the notion of inadequate infrastructure mentioned by household consumers was contrasted with reports from the Environmental and Sanitation Department indicating the presence of infrastructure. The triangulation indicates that although infrastructure is present in some locations, household awareness and accessibility continue to pose significant obstacles. Another example is analysing the financial perspective on e-waste: waste banks perceive e-waste as a cost/loss, while shopping malls regard e-waste disposal as a paid service. These views were then compared with the economic opportunity perspective, where factories transfer e-waste to generate value elsewhere, recycling organisations pursue repair/reuse, and the informal sector extracts gold/copper.

(ii) Dependability and confirmability (reliability) procedures: To demonstrate that the analysis is coherent and based on the data, the following processes were employed:

a. Comprehensive documentation (audit trail): The analysis is only based on the supplied transcripts, ensuring a thorough record of the original data. The background information, encompassing the interviewers' identity, date, and the interviewees' unique function, provides a robust context for the data.

b. Systematic coding and categorisation: The method of categorising data into specific themes (definition, practices, and challenges)

through consistent comparison guarantees that the conclusions are produced systematically.

c. Direct quotation and citation: Each derived assertion is explicitly substantiated by citations utilising the source index. This commitment to source ensures confirmability, illustrating that the interpretations are based on the participants' own words and reducing researcher bias.

d. Thick description: Detailed accounts of the viewpoints of many roles—including students, fathers, the director of a waste bank, the manager of a factory, and the staff members of the Environmental and Sanitation Department—offer context for evaluating the applicability of the findings to analogous environments.

Lastly, according to Miles and Huberman (1994), qualitative data analysis has three stages: data reduction, data presentation, and conclusion.

3. Results

In the empathise stage, we used interviews for data collection to understand user needs in depth. The 10 stakeholders who were interviewed were classified into three categories. After all the interview audio clips were transcribed, the first step was to reduce the data. Unnecessary data were removed, and we retained only relevant and contextual data. The triangulation technique evaluated the viewpoints of home customers, institutional/corporate managers, and government/recycling organisations on certain essential themes as follows.

3.1. Definition and Comprehension of E-waste

All participants recognised e-waste as discarded or malfunctioning electronic devices; nevertheless, the understanding of its hazardous characteristics differs markedly by role, as presented in Table 1.

3.2. Practices for the Disposal and Management of E-waste

Practices vary significantly depending on the degree of institutional commitment and availability of regulated infrastructure, as shown in Table 2.

3.3. Obstacles and Systemic Deficiencies

The principal obstacles arise from insufficient public knowledge, inadequate infrastructure accessibility, and the absence of regulatory enforcement, notably the Extended Producer Responsibility policy. Details are as follows:

(i) Insufficient information and accessibility (household perspective): Consumers express confusion or apathy toward proper disposal due to a dearth of information. They observe an absence of designated e-waste drop-off sites in proximity to their residences. Their assertion indicates that the management system for home hazardous and toxic materials is suboptimal and necessitates individual effort.

(ii) Economic disincentives (waste bank/the Environmental and Sanitation Department perspective): The disposal of e-waste frequently constitutes a cost centre; in contrast to plastics

Table 1. Definition of E-waste by group

Stakeholder group	Key understanding
Household consumers	Define it as discarded or non-functional products (e.g., PCs, obsolete televisions, and damaged cables/earphones). They frequently combine minor e-waste components (batteries and tiny cables) with conventional refuse. They may be deficient in particular knowledge regarding hazardous content or its associated hazards. For example, the college student stated, "electronic waste as items that are no longer used, such as damaged goods, old computers, old televisions."
Institutional or corporate managers	Identifies e-waste as a category that necessitates specialized management due to its toxic characteristics. At the educational institution, e-waste is categorised as either non-organic (recyclable) or hazardous. The mall manager categorically classifies it as hazardous garbage, encompassing batteries and bulbs. The factory manager is aware that improper disposal constitutes hazardous waste. He said, "e-waste is trash that can be recycled by competent parties, and it is considered a hazardous waste if disposed of carelessly."
Government/Industry	Categorises e-waste as hazardous and toxic material garbage that must not be disposed of in standard household temporary disposal sites. The scope encompasses components, batteries, cables, and big appliances such as televisions, washing machines, and PCs. The waste bank director said, "E-waste is the residue from electronic goods that are no longer used."

Table 2. Disposal management of E-waste

Stakeholder group	Disposal technique
Household consumers	Primarily entails the accumulation of damaged things, the amalgamation of minor objects (such as cables, batteries, and mice) with ordinary refuse, or the transfer of substantial items to informal scavengers or hauliers. They frequently see the transfer to scavengers as a payment for disposal services. Disposal is unplanned and reactive. A housewife said, "Small items like used batteries are simply thrown into the regular waste bin." A father added, "If an item is beyond repair, large items (like old televisions or washing machines) are often given away to rag-and-bone men or the regular trash collector."
Institutional or corporate managers	Establishes a systematic internal procedure. The educational institution accumulates and retains e-waste (often for two years) before auctioning it to specialised collectors once the asset value has diminished to zero. The factory provides components to the cleaning personnel, who autonomously search for low-current electronic workshops for repair or reuse. The mall employs certified third-party suppliers for hazardous and toxic garbage collection, a fee-based service determined by volume and scheduled pickups. For example, the mall manager explained: We must operate a temporary storage site for hazardous and toxic waste and [be] registered with the Environmental and Sanitation Department. This storage requires specific infrastructure, safety procedures, and personnel. Later, the mall must then pay certified third-party vendors to collect and process the hazardous and toxic waste. The academic institutional official said, "We require a formal document to nullify the asset's value before disposal. Hence, we prioritise repair and cannibalisation (using parts from broken equipment)."
Government/Industry	Offers specialised infrastructure (drop box sites in public spaces). The Environmental and Sanitation Department provides complimentary online scheduling for the collection of large household items, excluding commercial zones. E-waste gathered by this department is dispatched to authorised transporters and processors for disposal. The manager of the Environmental and Sanitation Department said, "We established drop boxes in public areas like malls, schools, and transit stations. In Jakarta, there are 26 such locations. We also offer a free online e-waste pickup service for non-commercial residents who meet certain criteria (e.g., minimum weight)." A recycling company emphasises repair and reuse through service partners and deliberately refrains from collecting particularly hazardous goods such as batteries. The recycling company manager explained, "We accept electronics (televisions, fans) but refuse batteries and highly hazardous waste [as] they cannot safely process."

or cardboard, it lacks immediate economic value for the waste bank, necessitating a concentration only on collection and teaching. The department administers e-waste management as a public service, funded by the government.

(iii) Regulatory and policy deficiencies (government/industry perspective): Principal government agencies emphasise that adherence and enforcement are deficient. The implementation of the Extended Producer Responsibility policy, which mandates producers to reclaim their waste, is ineffective. The Environmental and Sanitation Department notes that 99% of the e-waste produced is not managed in accordance with regulations. A significant obstacle is the federal framework in which regional departments possess restricted jurisdiction over permits, which are governed by the national authority.

(iv) Informal sector risks: The informal sector significantly contributes to recycling, particularly for substantial commodities such as televisions. This frequently entails hazardous deconstruction processes to retrieve precious metals (e.g., gold, copper, and lead) without adherence to safety protocols, resulting in significant health and environmental repercussions (e.g., congenital anomalies in specific communities).

Furthermore, empathy maps were used as the framework to present the data. This tool helps understand the perspectives and experiences of the interviewed stakeholders. The following presents the empathy maps of all 10 participants:

(i) Housewife: The interview with the housewife revealed that she already had some awareness of e-waste, but only a little. She had heard that

e-waste could not be recycled in the same way as other waste types, and that developed countries have specialised e-waste disposal systems. She understood that e-waste must be disposed of specifically; however, she still disposed of small amounts of e-waste in the general waste bin. She acknowledged her limited awareness and actions in sorting waste due to a lack of information. She suggested that it is necessary to award points to individuals who properly handle e-waste. The highlights of the housewife's interview are presented in Figure 1.

(ii) Father: Based on the interview, the father had less knowledge than the housewife regarding e-waste. He still assumed that e-waste had some value that could benefit the waste collector or the junkman. He was unaware of the dangers associated with e-waste. The highlights of the father's interviews are presented in Figure 2.

(iii) College student: The college student observed that it was easy to produce e-waste. If she experienced a minor malfunction in an electronic item, she considered it e-waste. She had little knowledge about e-waste; for instance, she believed that e-waste could be disposed of in general rubbish containers. She thought that e-waste would be collected by waste collectors/junkmen. The highlights of the college students' interviews are presented in Figure 3.

(iv) Factory manager: The factory manager seemed to treat e-waste as a source of company income. He had a policy of offering e-waste to other parties, such as electronic repair shops, so that some components could be sold and reused. However, he realised the dangers of e-waste and knew that it could not be disposed of carelessly. The highlights of the factory manager's interviews are presented in Figure 4.

(v) Shopping mall manager: Based on the interview, the manager was the interviewee with the most awareness in the e-waste disposal category. He was the only one who was convinced that e-waste created costs for businesses. He had already treated e-waste properly, including hiring a vendor to transport his mall's e-waste. The highlights of the shopping mall manager's interview are presented in Figure 5.

(vi) Logistics manager of an educational institution: The logistics manager lacked knowledge about e-waste. She had created a comprehensive procedure for waste management, but still mixed e-waste (lamps/bulbs) with other glass waste. The

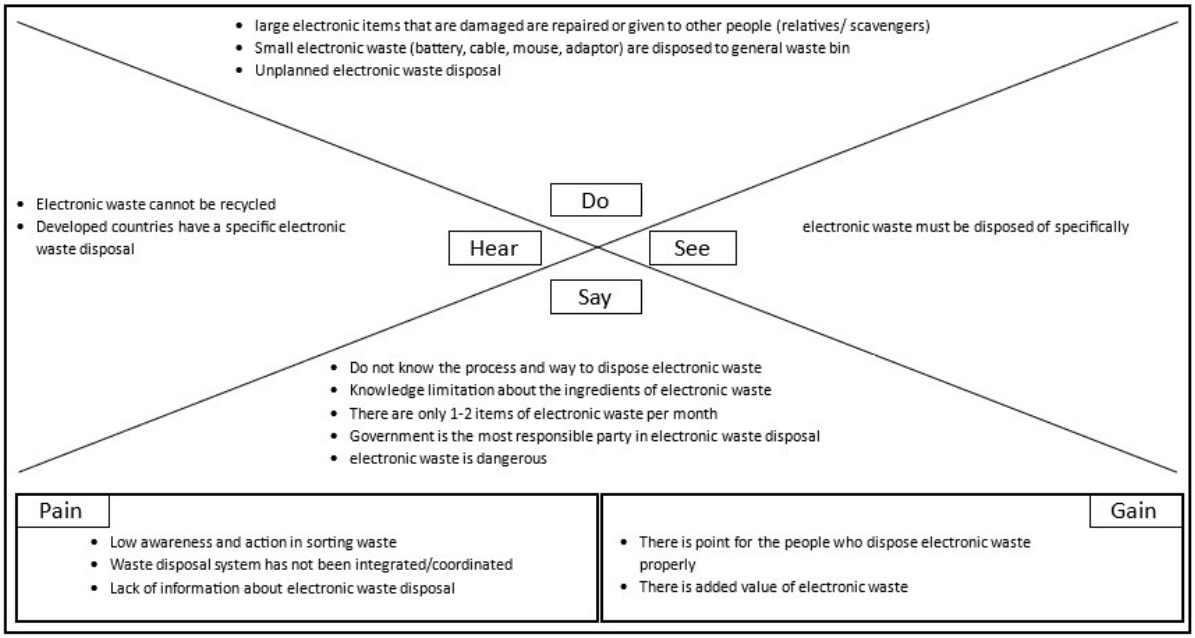

Figure 1. The empathy map of the housewife

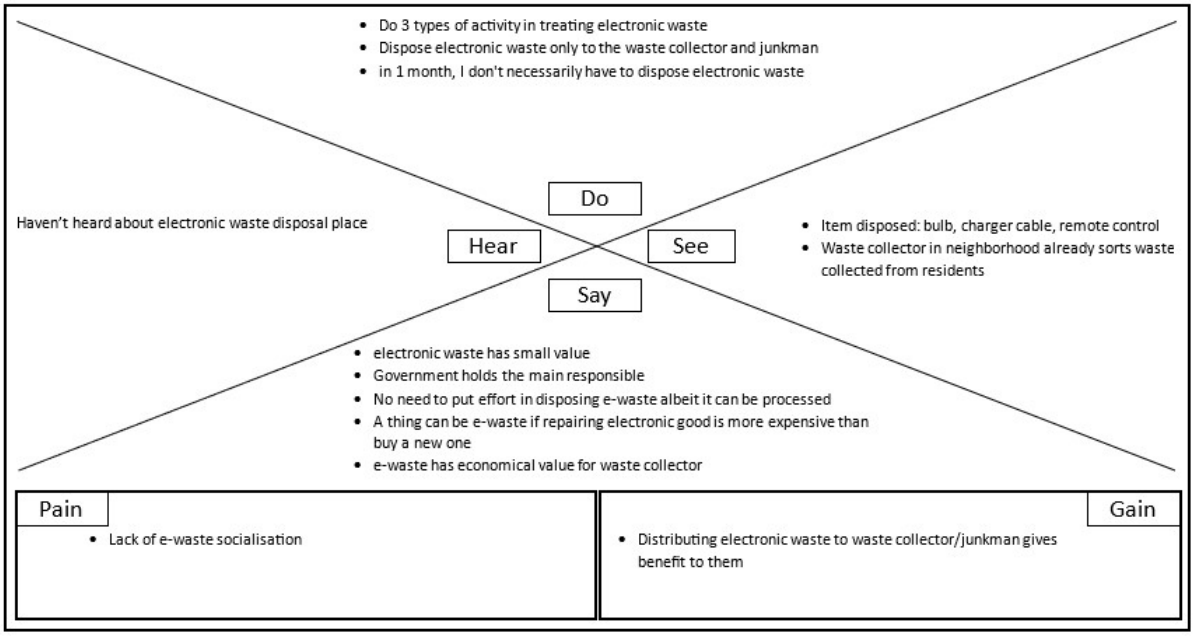

Figure 2. The empathy map of the father

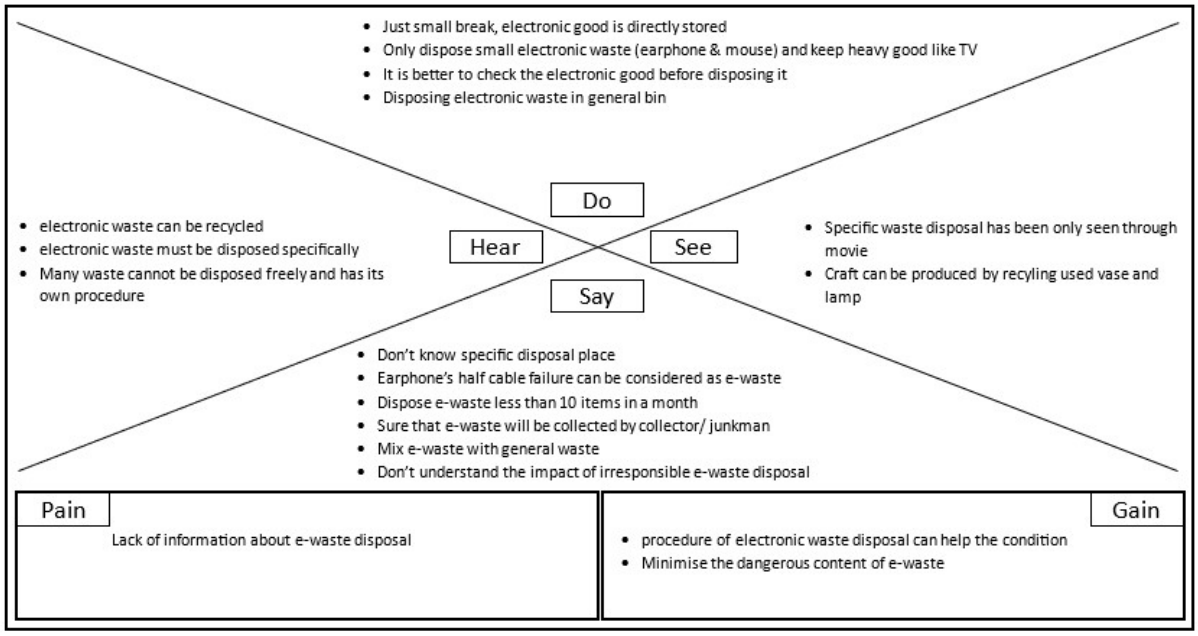

Figure 3. The empathy map of the college student

highlights of the logistics manager's interview are presented in Figure 6.

(vii) Staff member of the Environmental and Sanitation Department: The staff member mentioned that the Environmental and Sanitation Department has several e-waste management programmes and extensive knowledge of how to handle e-waste. However, there is no integrated data on e-waste processes. The highlights of the staff member's interview are presented in Figure 7.

(viii) The manager of the Environmental and Sanitation Department: The Environmental and Sanitation

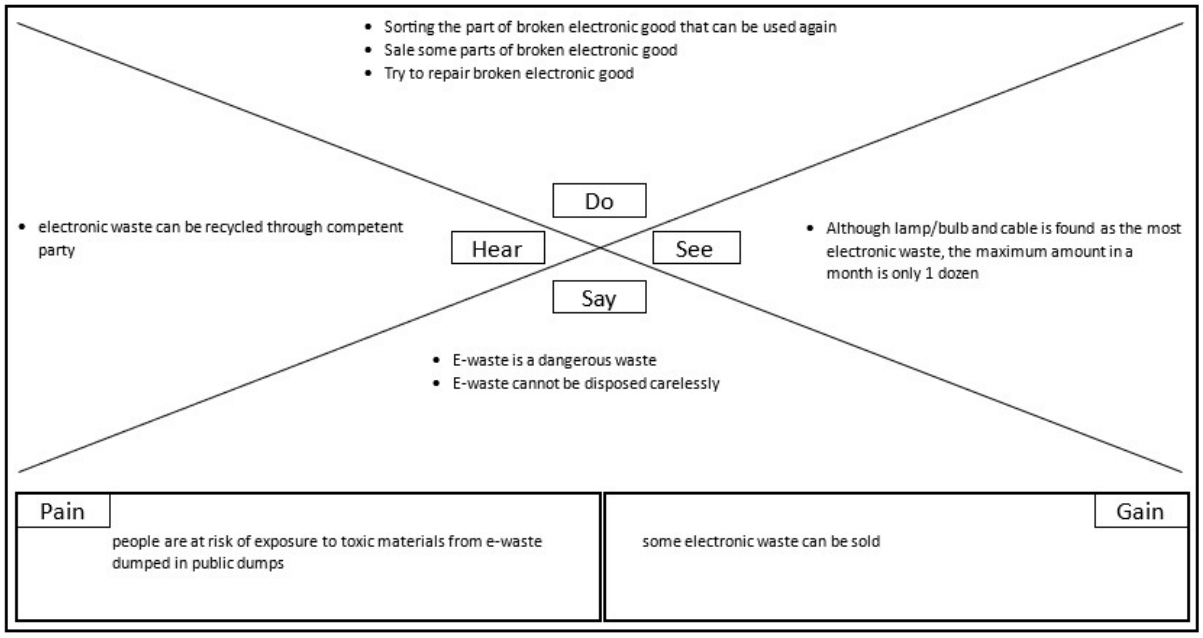

Figure 4. The empathy map of the factory manager

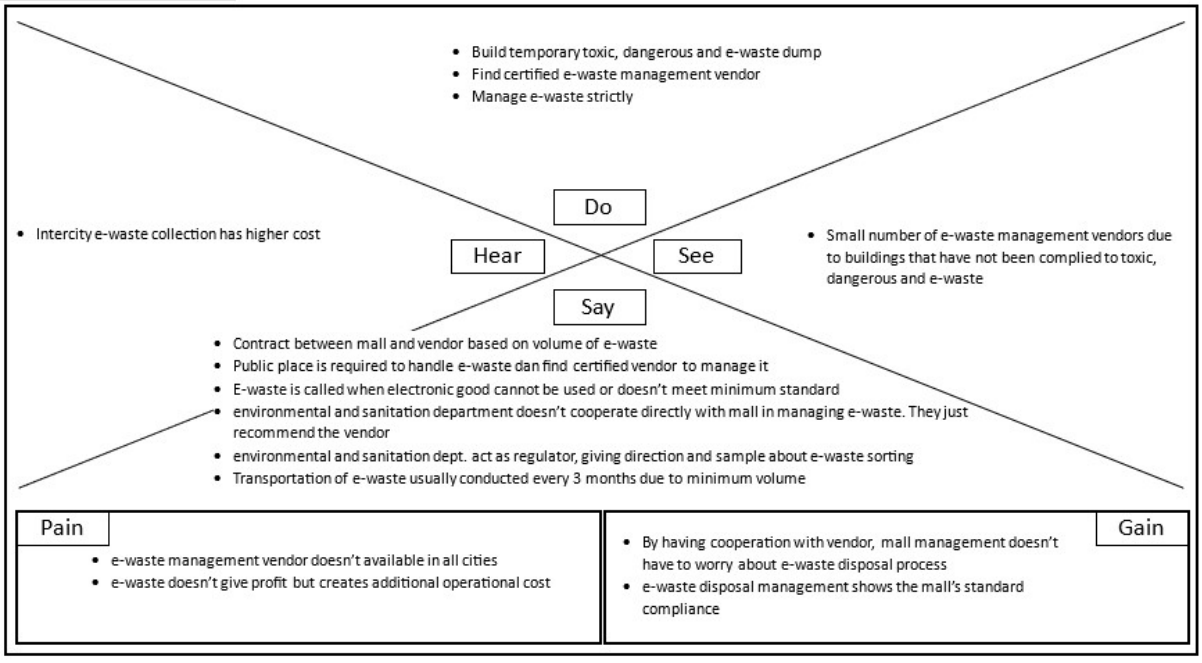

Figure 5. The empathy map of the shopping mall manager

Department of Bandung city has a more advanced e-waste treatment than other cities. However, it still depends on the private sector for the disposal of e-waste. The manager acknowledged the lack of a waste sorting process at the household level. The highlights of the interviews with the manager of the Environmental and Sanitation Department are presented in Figure 8.

(ix) Waste bank director: As the director of a waste bank, the participant confessed that the

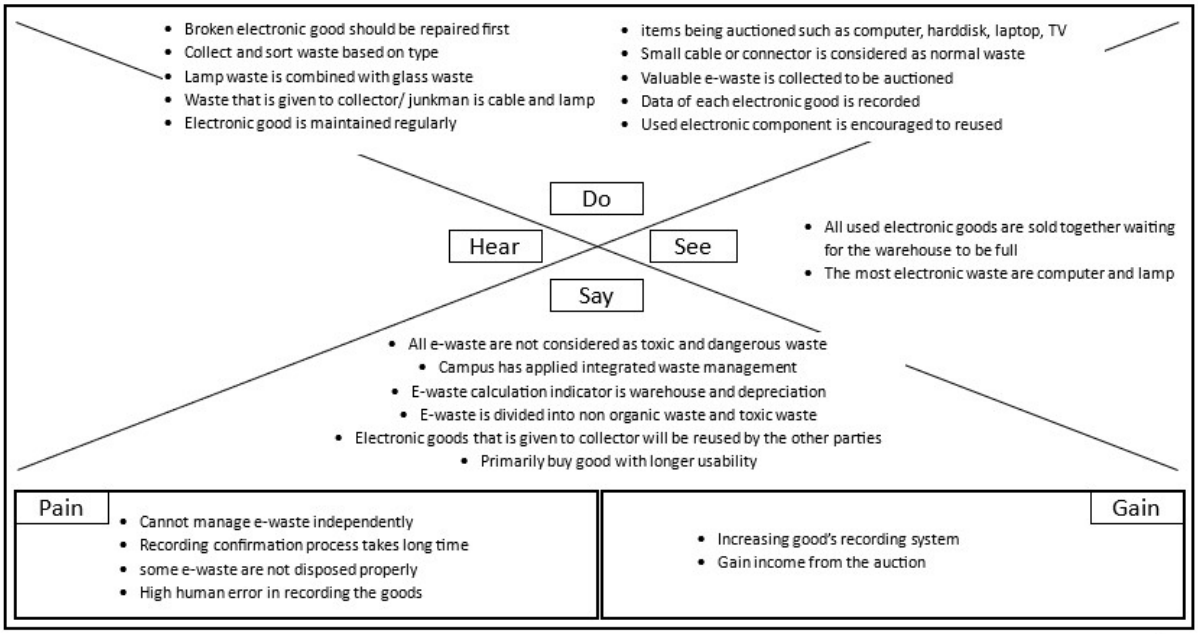

Figure 6. The empathy map of the logistics manager of an educational institution

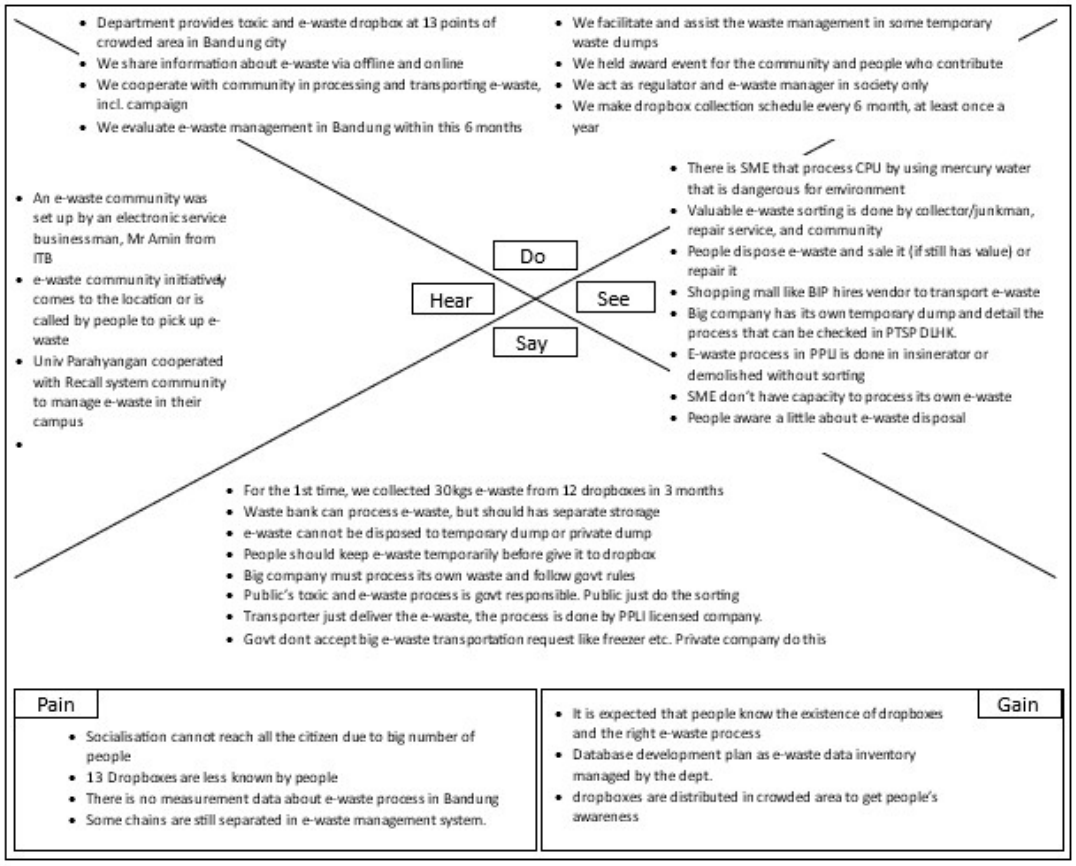

Figure 7. The empathy map of the staff member of the Environmental and Sanitation Department. Abbreviations: BIP: Bandung Indah Plaza, DLHK: Dinas Lingkungan Hidup dan Kebersihan, ITB: Institut Teknologi Bandung, PPLI: Prasadha Pamunah Limbah Industri, PTSP: Pelayanan Terpadu Satu Pintu; SME: Small- and medium-sized enterprise.

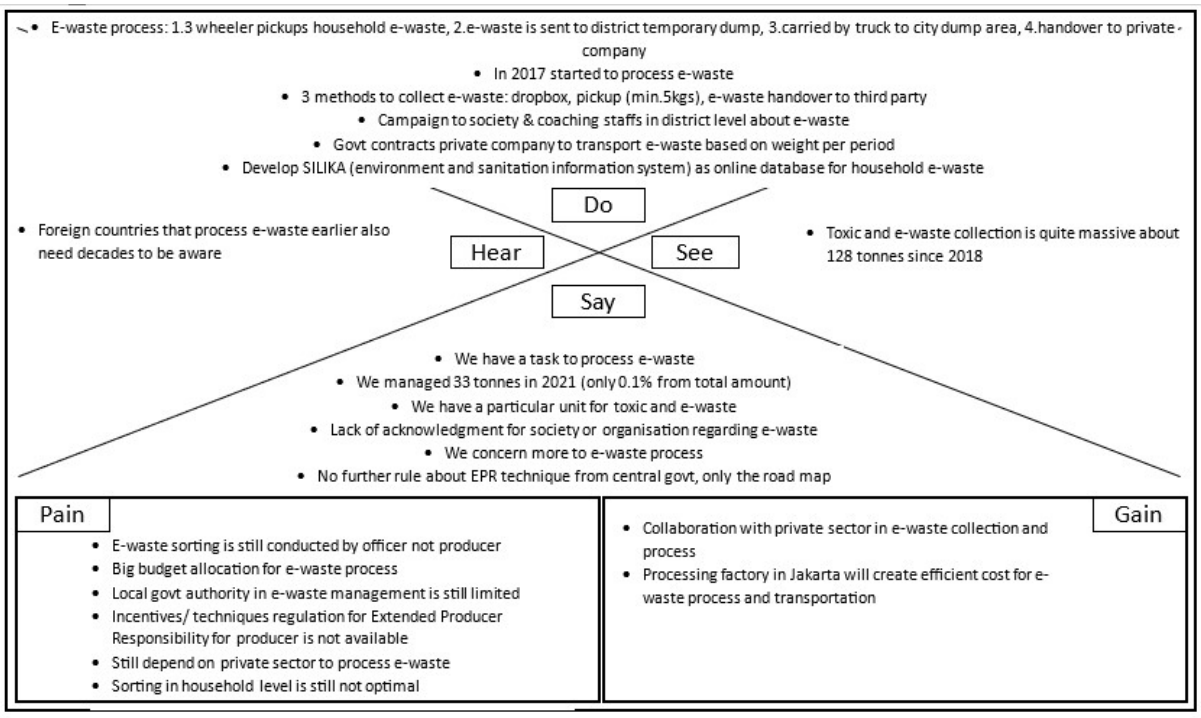

Figure 8. The empathy map of the manager of the Environmental and Sanitation Department. Abbreviation: EPR: Extended Producer Responsibility

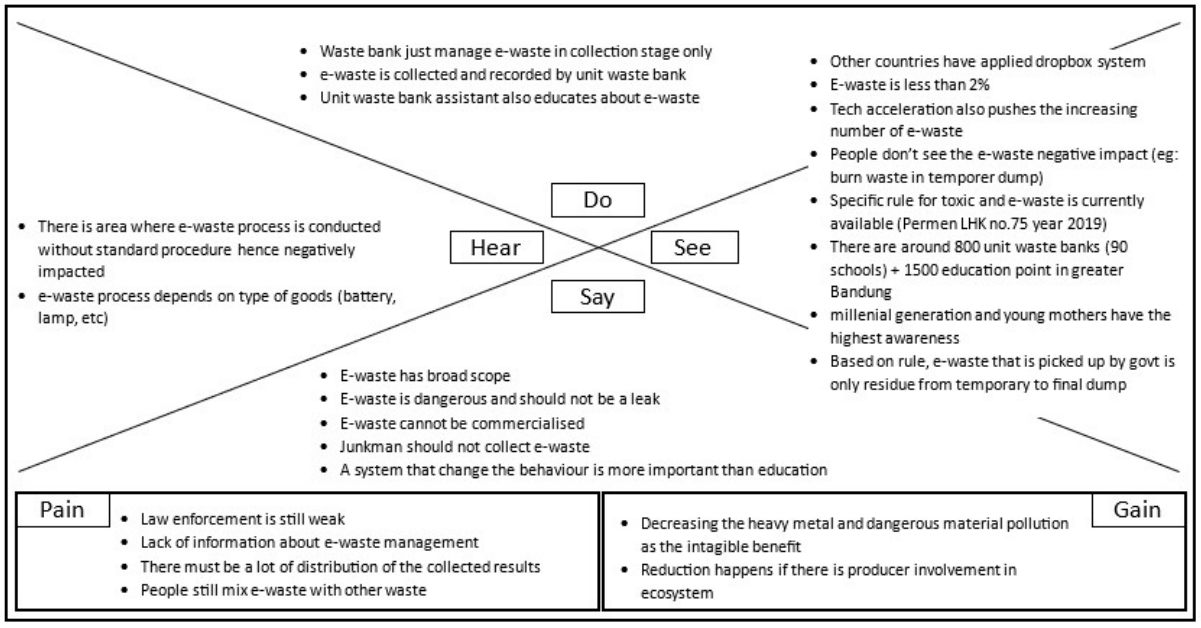

Figure 9. The empathy map of the waste bank director

bank did not wield considerable authority in e-waste disposal management. E-waste must be transferred to a certified e-waste processing facility. She understood the lack of knowledge and legal enforcement experience in the city. The highlights of the director's interview are presented in Figure 9.

(x) Recycling company manager: As the leader of an active recycling company, the manager often finds it challenging to determine the next steps for the

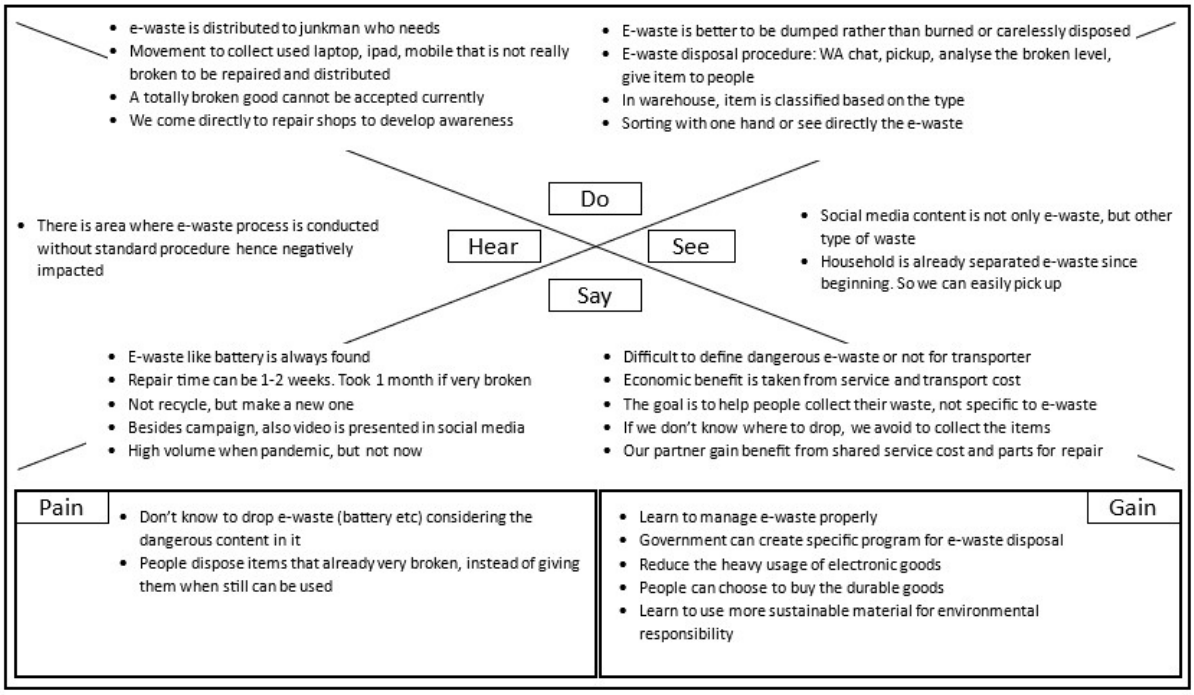

Figure 10. The empathy map of the recycling company manager

collected e-waste. Although their goal is to assist people with proper waste disposal, they still lack information about the suitable drop-off locations for e-waste. The highlights of the recycling company manager's interview are presented in Figure 10.

4. Discussion

This study used a formal opportunity recognition method, systematically transforming complex, "wicked problems" such as e-waste into actionable opportunities (Jain *et al.*, 2023; Rive, 2017; Wanderley & Bonacin, 2019). After developing the empathy maps based on the 10 interviews, the design thinking process progressed to the "define" step. We identified the challenges experienced by participants by grouping their pain points. Consequently, we focused on the pain section of the empathy maps, compiling a list of difficulties experienced by participants through the identification and categorisation of specific problems. An affinity diagram was used to organise and analyse the data obtained during the empathise stage, as shown in Table 3.

As shown in Table 3, the 25 pain statements were divided into four categories. The category "System is not good" contains 11 statements. As this category has the most pain statements, it is considered the priority category (marked with number 1). The category "Less socialisation/ information" consists of seven pain statements. As this category has the second-most statements, it is considered the second-priority category. The category "Low awareness of the community" consists of five pain statements. This category is considered the third-priority category. Finally, the category "Expensive processing cost" consists of two pain statements. This category is regarded as the fourth-priority category. These are the four main challenges in e-waste disposal management. The first three categories align with the management process issues and public knowledge identified by Nuryanto and Suzianti (2022). However, they focused directly on the design elements of the application and tested the interface prototype. By contrast, this study focuses on assessing the challenges faced by e-waste stakeholders and generating ideas to address these problems.

The "System is not good" category is the primary e-waste problem, confirming findings by Jain *et al.* (2023), Nnorom and Osibanjo (2008), and Parajuly *et al.* (2019). The global lack of effective e-waste management, including insufficient e-waste processing centres, is particularly pronounced in developing countries. Recognising this structural failing as the main pain point drives future ecopreneurial activity toward large-scale infrastructure solutions rather than superficial tweaks, revealing where investment and innovation are required most (Nuryanto & Suzianti, 2022). To develop an improved system for e-waste management, inspiration can be drawn from the works by

Table 3. Affinity diagram from the pain section in empathy maps

Category	Housewife	Father	College student	Factory manager	Shopping mall manager	Logistic manager	Staff at the government office	Manager at the government office	Recycling company manager	Waste bank director
Low awareness of community (3)	Low awareness and action to sort e-waste	-	-	-	-	Some e-waste is not disposed of properly	-	E-waste sorting is still carried out by officers and not by waste producers	Electronic goods that are still functional are not being utilised by those who need them	People still mix e-waste with other types of waste
System is not good (1)	The waste management system is not yet integrated (coordination)	-	-	-	Not all cities have vendors who manage e-waste	- Not yet able to manage e-waste independently - High level of human error in recording goods - Long recording confirmation process	-	- The authority of local governments in managing B3 waste is still limited - Still rely on third parties as management institutions - There are currently no incentive mechanisms or technical regulatory systems for producers under EPR	There is uncertainty about where to distribute e-waste containing hazardous materials	- The collected results need to be widely distributed - Enforcement of regulations is still weak
Less socialisation/ information (2)	Information on e-waste disposal is still lacking	Lack of socialisation of e-waste	Lack of information about e-waste disposal	E-waste thrown into public dumps will endanger people	-	-	Socialisation has not reached all communities due to their large number	-	People do not know much about e-waste disposal	Lack of information about e-waste management
Expensive processing costs (4)	-	-	-	-	E-waste does not provide income but instead adds to operational costs	-	-	The need for a large budget allocation for processing services	-	-

Note: Numbers in brackets under "category" refer to the priority level.
Abbreviations: E-waste: electronic waste; EPR: Extended Producer Responsibility.

Nowakowski and Pamuła (2020), Shreyas Madhav *et al.* (2022), and Wanderley and Bonacin (2019), who utilised the latest technology in e-waste management. This aligns with our intention to incorporate technology into e-waste management. Technology-based educational and logistical tools, such as mobile applications and smart recycling bins, can address the issues of "less socialisation/information" and "low awareness of the community" as confirmed by external research (Nuryanto & Suzianti, 2022; Wanderley & Bonacin, 2019). Moreover, the "Low awareness of community" issue has been acknowledged by Iqbal and Dyah (2022), Khalid (2022), and research conducted by the United Nations Institute for Training and Research (Widodo, 2023).

The issue of "expensive processing cost" in e-waste management confirms the findings by George and Michael (2023) and Yu *et al.* (2023), which highlight that the e-waste recycling industry is still inefficient. Moreover, a lack of returns and profits is mentioned as a barrier to e-waste management in the United Kingdom (Sundar *et al.*, 2023). These high processing costs can be compared with the potential economic advantages of e-waste, as calculated by doctoral candidates specialising in e-waste recycling (Dinnata, 2017; Puspa, 2023). Recently, the recycling process has been enhanced by a tool that enables electronic designers to incorporate recycled components into their designs for electronic appliances (Lu *et al.*, 2023). In addition to its economic advantages, e-waste recycling has the potential to reduce carbon emissions. Realising this potential and raising awareness within broader communities could help address the problem of "less socialisation/information." To tackle this, we applied the interdisciplinary learning approach proposed by Wang and Anand (2024). In summary, this study confirms the findings of previous studies from 2008 to 2024, demonstrating that the disposal of e-waste in developing countries continues to face several challenges.

The contribution of this research lies in applying design thinking specifically to e-waste disposal management from an ecopreneurial perspective. Design thinking was employed throughout this research, validating its effectiveness in addressing complex sustainability concerns related to human behavior. Design thinking excels at solving unknown challenges (Design Foundation, 2018; Fontichiaro, 2015; Schallmo, 2018). This study also confirms previous research showing the utility of design thinking in e-waste contexts, such as designing application interfaces or conceptualising material reuse, solidifying design thinking as a framework for managing technology, human behaviour, and disposal (Fanthi *et al.*, 2021; Madrigal *et al.*, 2024; Nuryanto & Suzianti, 2022; Rive, 2017; Wanderley & Bonacin, 2019).

The novelty of this study lies in utilising design thinking exclusively during the "empathise" and "define" phases to delineate and classify stakeholders' pain points. Although the results of this study are descriptive and do not introduce a framework, model, or actionable system for practitioners, they focus on mapping stakeholder pain points as the basis for an ecopreneurial business opportunity, differing from other studies that employ design thinking primarily to prototype and test user interface designs. For example, earlier research used design thinking to rapidly design and test user interface prototypes for e-waste applications (Nuryanto & Suzianti, 2022) or to create physical prototypes such as smart recycling bins (Wanderley & Bonacin, 2019). In contrast, this study evaluated the actual challenges encountered by stakeholders prior to the formulation of solutions.

Moreover, this study aims to enhance entrepreneurship theory within the ecopreneurship domain by addressing the existing research gap on effective, technology-driven e-waste disposal management from a business management perspective (Inegbedion, 2022). The principal finding identifies four fundamental issues that constitute the foundation for developing a future ecopreneurial, information and communication technology (ICT)-driven e-waste management system.

Design thinking is particularly important in developing economies, where management often has trouble with basic methods, weak enforcement, and low public awareness (Nnorom & Osibanjo, 2008; Parajuly *et al.*, 2019). This study establishes the fundamental framework necessary to address this intricate, globally acknowledged issue by affirming the principal challenges (such as the deficient system and limited awareness) within this context. This methodological framing is relatively unique compared to typical e-waste studies that focus on technical solutions or environmental impacts (Nowakowski & Pamuła, 2020; Shreyas Madhav *et al.*, 2022; Wanderley & Bonacin, 2019).

This study develops a systematic framework for ICT-based e-waste management solutions, advancing ecopreneurship. Ecopreneurship integrates sustainability and profit (Parajuly *et al.*, 2019; Rive, 2017). The findings identify market failures and outline the criteria that a viable entrepreneurial firm must address:

(i) Addressing market failure (the system gap): The "system is not effective" category suggests that e-waste is a rapidly growing, unmanaged stream. This gap presents a huge market opportunity for sustainable businesses (Forti *et al.*, 2020). Only 17.4% of e-waste is collected and recycled,

leaving a massive opportunity for entrepreneurs (Harikaran *et al*., 2023).

(ii) Monetising environmental value (economic gain): E-waste's revenue potential boosts ecopreneurship's financial side, dispelling "expensive processing costs." It has been estimated that recycling e-waste might earn Indonesia a total of USD 1.8 billion by 2020 (Puspa, 2023). E-waste from telecommunications contains valuable elements such as gold, silver, and copper, and managing one tonne of it can prevent 1,400 tonnes of CO_2 emissions (Dinnata, 2017). Ecopreneurial efforts are motivated by financial incentives and environmental benefits.

The limitation of this study is its coverage. This study only focused on the early stages of design thinking: empathise and define. Therefore, future research is advised to progress to the "ideate stage," utilising the four primary issues identified as a framework. Considering the objective is an ICT-driven system, the solution created in the "prototype stage" would presumably be digital and logistical in nature. Then, the prototype will be evaluated in the "test stage" with representatives from the three primary stakeholder categories: disposers, government, and recyclers. Another limitation is in its location. The study focused on a singular metropolitan context, implying that the recognised issues and subsequent challenges—such as the deficient system, insufficient social interaction, and minimal public awareness—are explicitly linked to the local regulatory, logistical, and social milieu of that city. Therefore, it is also suggested to study a broader context to gain different perspectives.

5. Conclusion

This study classified 25 pain statements into four core challenges to lay the groundwork for an ecopreneurial ICT-driven e-waste management system:

(i) System is not good (Priority 1);
(ii) Less socialisation/information (Priority 2);
(iii) Low awareness of the community (Priority 3); and
(iv) Expensive processing costs (Priority 4).

The application of design thinking in ecopreneurship-focused e-waste disposal management is the main contribution of this research. The uniqueness lies in using design thinking primarily through the "empathise" and "define" phases to identify and classify stakeholder pain issues. This deliberate approach transforms the complex, "wicked problem" of e-waste into business potential. While earlier design thinking research often focused on designing and testing user interface prototypes for e-waste applications, this study evaluates the real challenges faced by diverse stakeholders before proposing technical solutions. Rather than developing solutions directly, this study provides a diagnostic basis—the affinity map and four primary problem categories—upon which effective solutions can be built.

It is recommended that ecopreneurs invest in large-scale infrastructure rather than superficial modifications to capture this unregulated waste stream. Startups should actively capitalise on e-waste's economic potential to counter the perception of "expensive processing costs." Recycling is financially motivated by recovering valuable materials, such as gold, silver, and copper, and highlighting the environmental value—managing one tonne of e-waste can reduce 1,400 tonnes of CO_2 emissions. E-waste recycling could generate a total of USD 1.8 billion for Indonesia by 2030, underscoring its financial potential. Furthermore, startups can develop technological, educational, and logistical tools to address issues of "less socialisation/information" and "low awareness of community." Mobile applications or smart recycling bins that reward appropriate disposal can bridge knowledge gaps and influence customer behaviour. Given the current system's lack of integrated information, government departments should improve e-waste data integration. Additionally, waste management institutions should reduce human error and cumbersome confirmation processes that delay the formal disposal system.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualisation: Jurry Hatammimi
Formal analysis: All authors
Investigation: Jurry Hatammimi
Methodology: All authors
Writing–original draft: All authors
Writing–review & editing: Jurry Hatammimi

Ethics approval and consent to participate

The study was approved by the Institutional Review Board

(or Ethics Committee) of The Social Humanities Research Ethics Committee, Universitas Islam Bandung (protocol code 008/B.004/KEPSOSHUM/VI/2025; date of approval: April 9, 2025). Verbal consent was obtained from each subject to participate in this study.

Consent for publication

Verbal consent was obtained from each of the subjects to publish their data and/or images by anonymising their identities.

Availability of data

Data derived from the interviews and transcripts are available upon reasonable request to the corresponding author.

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