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Circular Economy Practices by the Informal Sector: an Implementation of Green Manufacturing in Urban Area

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Abstract. A large amount of household e-waste and their recovery activities by the informal sector positively impact the economic, social, and environmental in the urban area because they strongly support sustainable and green manufacturing principles. This research aims to observe the household e-waste collecting model in Padang city, Indonesia. Furthermore, it also wants to find several retain values of the Circular Economy practices by the informal sector for household e-waste when recycled, reused, or remanufactured. The e-waste from the refrigerator, air conditioner, and washing machine is taken as sample cases in this research. The result shows at least two collecting models: the reverse e-waste flow with and without the repair or service shop's involvement. These models include some actors such as (1) end-users, (2) household collectors, (3) repair shops, (4) intermediary collectors, (5) final collectors, and (6) recycling plants. Most of the collectors and repair shops involved are in the informal sector. The result also shows that remanufacturing through rebuilding its functional status as a new performance by reusing e-waste obtains the highest recovery value. Such remanufactured products in the secondary market can reach up to 40% from their first price. Recycling of household e-waste products has the lowest recovery value. However, copper (Cu) from e-waste products has the highest market value, and it follows aluminum and ferrous metals, among other metals, when recycled or reused.

1. Introduction

Green manufacturing is a paradigm in manufacturing industries that want to transform to be more environmentally friendly or have a minimal impact on the environment [1, 2]. For this reason, it takes effort and even additional costs by the manufacturing industry to minimize this environmental impact at each stage of the product life cycle from the development, design, manufacture, usage, and the end of product life [3]. Indicators of green manufacturing implementation at each step of the product life cycle can be seen from producers' and consumers' points of view. They can reduce the environmental burden and streamline the limited resources like materials and energy. The last aspect is viewed as something more profitable for the product maker because it lowers production costs [4]. While efforts to reduce pollutants due to manufacturing activities still do not significantly impact the industrial world, especially in developing countries.

In the product life cycle, the implementation of green manufacturing is the responsibility of the manufacturing industry (as a producer), but when used, it is exchanged to the user's side. The final stages of the product life cycle have become an environmental burden [5]. It further contains an economic value if some items can still be reused, remanufactured, or existing parts as a new material

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recovered for another product. In developed countries, the role is often carried out by the government to overcome product wastes [6, 7, 8]. Some products that their components are relatively expensive and suitable, even though they have been used up or damaged, can still be rebuilt to the original product's specifications. They use a combination of repaired, reused, and new components into a new remanufactured product by Original Equipment Manufacturer. Some examples are the remanufacturing of medical imaging devices by the Centre for Remanufacturing & Reuse [9] and remanufacturing at the Xerox photocopier [10].

Circular Economy practices in this context are actions, technologies designed, and actors involved in recovering unused products or products that have reached the end of their life. In this study, e-waste comes from household appliances such as refrigerators, washing machines, etc. Activities carried out by several actors related to household electronic waste recovery can be reused, remanufacturing, or recycled [11, 12].Recovery of household e-waste directly impacts for reducing the environmental burden and pollution on the one hand and minimizing the use of material resources by utilizing materials derived from electronic waste, on the other side. The household appliances e-waste, because of their short economic life, will continually increase every year. Some of these electronic wastes still contain components that are eligible to use, or devices still have sensory functions. The material such as Fe, Cu, Zn, Mn, etc. can also be obtained from e-waste. It can be higher than the corresponding amount of material if mined naturally. On the other hand, electronic waste also contains dangerous waste such as Pb, Mg, PCB, arsenic, etc. and can damage the environment [13, 14]. The Circular Economy (CE), through the recovery of electronic waste from urban areas, has the potential to produce mining activities that are more ecologically appropriate and support the concept of green manufacturing.

Uniquely in Indonesia, the actors of Circular Economy practices are informal sectors, and formally they do not get permanent employment. Urban mining activities in Indonesia are like reverse logistics chains carried out by several actors. Some serve as seekers of the used or defective electronic product; some also play a role as sellers of repair services. Those that function to disassemble the product into smaller assemblies. This last activity ends with the recycling processes, which converting wastes into new materials. Urban mining is a circular economy chain [15], making a manufacturing activity model "circular" or forms a closed product life cycle.

Recovery and utilization of e-waste in Indonesia are made in several ways. Handling e-waste by directly reusing some components for the same benefits in other products, known as reuse, is the greenest and most profitable solution from an environmental perspective. Another option is remanufactured that utilizes parts or several e-waste by adding manufacturing operations to restore the performance level of products that have been used or damaged to function again or be equivalent to new products [16,17]. The advantage of this remanufacture process is to increase the efficiency of material use and energy consumption, thus contributing directly to energy saving and waste reduction efforts. Environmental and economic advantages make remanufacturing an essential strategy in various industries [18]. Another e-waste recovery is recycling, which offers opportunities to reduce the environmental impact of e-waste. If appropriately managed, the recycling process can be a source of new material to meet the needs in the industry or reducing raw materials extracted from nature.

In this study, several questions about the actual urban mining carried out by major cities in Indonesia, especially household electronic wastes, need to be explored further. Some of the research questions about the types of household e-wastes targeted for urban mining and the technical background. Who are the actors involved in this activity, and what kind of household e-waste collecting model happened in urban areas? What is the reuse, remanufacture, recycle (3R) policy carried out by urban mining actors, and how much is the retained value by different product recovery processes of the household e-wastes?

2. Materials and methods

2.1. Research Object

This research explores the practice of household e-waste product recovery in the city of Padang, which focuses on three household e-wastes: (1) Air Conditioner, (2) Refrigerator, (3) Washing machine. The product recovery here means regaining the possession of the lost value of a product by recycling, reusing, or remanufacturing. According to the initial survey, there are several actors involved in the urban mining process and Circular Economy practices:

a) End users,
b) Household collectors,
c) Repair shops,
d) Intermediary collectors,
e) Final collectors,
f) Recycling plants.

A household e-waste collecting model is based on the interaction between those six actors. The circular economy activities discussed in this study are limited to product recovery activities, such as remanufacturing, reuse, and recycling. Remanufacturing is an option in which the household e-waste will enter the reverse flow channel at a particular manufacturing stage. At this stage, household e-waste products would be disassembled, reassessed, replaced, remanufactured, and reassembled to bring the obsolete product to specific quality and reliability levels. Reuse is the activity to retrieve one or more valuable parts from the household e-waste and use it to repair other used products. Recycling is the activity to recover the material of e-waste by recycling plant into a new material that is lower in quality than the original one.

2.2. Method

The research was conducted with the following steps:

a) Survey to identify the household e-waste, which the urban miner often uses in the city of Padang, Indonesia, and some actors involved in this activity. The survey was conducted on eight household collectors using motorized rickshaws or pick-up cars to inquire about the availability of e-waste, eight informal repair shops, eight intermediate and final collectors that collect metals and plastics from e-waste for recycling. The research also identifies the household e-waste collecting patterns, which usually occurred in Padang.
b) Survey to know the product recovery values obtained by the respective urban mining actors by different product recovery scenarios. The amount of money still retained by some household e-waste when recycled, reused, or remanufactured. The survey is conducted by asking direct questions to the actors involved. For instance, the question about the average price of used or obsolete goods (AC, washing machine dan refrigerator) from the end-user. How to quickly evaluate the e-waste based on their conditions and determine the retained value? What is the e-waste selling price in the repair shop? Which items are still valuable to reuse from sample e-waste? What is the selling price of remanufactured e-waste (case: AC, washing machine, and refrigerator) in the secondary market? What is the market value of Cu, Al, Ferrous metal, or plastic for recycling?
c) Sampling and disassembling the e-waste in the laboratory and separating them based on material types. It then identifies the material composition of the samples and obtains the retained value by recycling. For this purpose, two samples are used for each e-waste (AC, refrigerator, and wash machine). Each e-waste should be disassembled into parts, and then they must be weighed and determined the material type (e.g., ferrous, non-ferrous, plastic, Al, Cu) and their retained value by recycling.

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3. Results and discussion

3.1. Household E-WasteCollecting Model

A household e-waste collecting model as an implementation of Circular Economy (CE) practices in the urban area in Padang is illustrated in figure 1. This collection model is similar for three different household e-wastes samples (air conditioner, washing machines, refrigerators). At least, there are two collecting models of household e-waste in Padang city, Indonesia: (1) the e-waste flows with the involvement of the repair shop, and (2) without the participation of the repair shop. If the reverse flow includes the repair shop, most e-waste (AC, washing machines, and refrigerators) still function or have slightly damaged. Most of the components can be reused or repaired or can be reassembled using a combination of reused, repaired, and new elements into a remanufacturing product. The second model without including the repair shop is characterized by heavy damaged or obsolete products. The e-waste is generally disassembled, and the components are separated and processed based on the material types. The parts are then utilized by recycling.

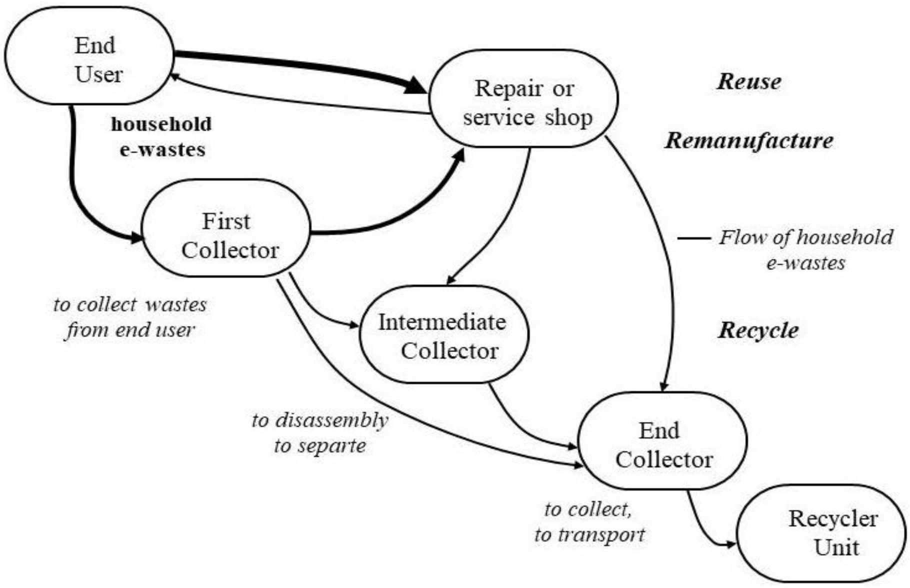

Figure 1. Household e-waste collecting model as a CE practice

There are six main actors involves in this model: (1) end-users, (2) household collectors, (3) repair shops, (4) intermediary collectors, (5) final collectors, and (6) Recycling units. End-users are household electronic product consumers where e-waste originates. Household or First collectors are the agents that collect e-waste from door to door. Usually, these informal collectors ride motorized rickshaws or pick-up cars, as shown in figure 2. Repair shops are those who receive e-waste from end-users or household collectors. Intermediary collectors are those who collect e-waste to be recycled. Final collectors act as material collectors and transport materials to recycling units.

The CE practices by the informal sector start with end users as the source of household e-waste products. Two scenarios can happen: either the end-user sold the e-waste to household collectors or directly to informal repair or service shops. Usually, the repair shops then conduct an assessment to determine whether the e-waste will be reused, remanufactured, or recycled. The choice to remanufacture or reuse is selected when e-waste (or at least their parts) are still in good condition. E-waste parts cannot be used as input to remanufacture or reuse process then sold to intermediary collectors. They disassemble and separate several obsolete parts based on their material type to be recycled. Those parts next sold to final collectors who subsequently transport them to recycling plants.

Figure 2. First collector transportation mode

3.2. Material Composition of E-Waste Products

The material composition of e-waste samples is identified by disassembling them in the laboratory. The type of material from each component is identified and weighed. The material composition in percentage is shown in figure 4. Based on observation, the air conditioner consists of approximately 63% ferrous metals, 20% plastic, 8% copper, 6% aluminum, and 3% of other materials. A similar case can also be seen in the refrigerator, where the most common material is also ferrous metals (58%), followed by plastics (26%), copper, and aluminum (roughly 2%), although the percentage is slightly different. A different result can be seen in the washing machine, where the highest rate is owned by plastics (69%), followed by ferrous metals (22%), copper (6%), and other non-ferrous metals (3%).

There is the market potential for copper, aluminum, and ferrous metals, and each of them has a different market value by CE actors. Copper has the most significant market value. It can be sold at roughly IDR 60-70K per kg by e-waste collectors. Aluminum is the second best (can be sold at roughly IDR 16K per kg), followed by ferrous metals (can only be sold at roughly IDR 2.5K per kg). Material compositions, along with their prices, are used to calculate product recovery value by recycling.

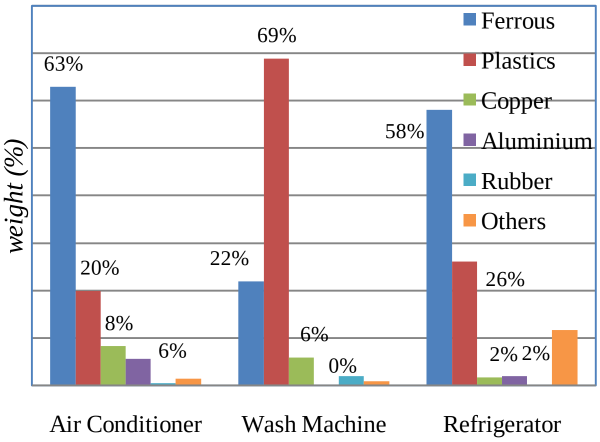

Figure 3 The material composition of e-waste samples

3.3. Product Recovery Value

Product recovery value is the price that still exists or retained at their end of life stage on the household e-waste products. Product recovery is related to the action of obtaining possession of the lost value again after product usage. The product recovery options included reuse, recycle, or remanufacture. A higher value can be expected if most of the used product parts are still in good condition, which means they can be used again through reuse or remanufacturing. Used products that have been damaged beyond repair can only be recycled; thus, it has less value. This product recovery value is highly dependent on the used product functionality and condition.

Table 1 shows some used components that are normally reused as spare parts for remanufacturing in CE practices in Padang. Most of these items obtained from urban mining activities and used to rebuild the second-hand product, either by using them to replace the broken part(s) in used product or taking the valuable parts (parts that still in good condition and can function properly) and remanufactured them with other useful parts from another used products and or new parts. An essential item for the remanufacturing process is the product or unit body. This item serves as the base of assembly operations in remanufacturing. Repair shop conducted a remanufacturing process only if the product or unit body is available.

Table 1. Items are frequently reused or remanufactured in CE practices by informal sectors

Part or Assembly	e-Wastes
Thermostat, evaporator, compressor, overload relay	Refrigerator
Motor unit, compressor, copper pipe, run capacitor, fan unit, thermistor, evaporator unit	AC
Wash motor, spin motor, timer control	Washing Machine
Body	Most of e-wastes *)

*) main assembly for remanufacturing

As an example, the illustration of remanufacturing by the informal sector is explained as follows. Used or damaged refrigerators are obtained from household collectors or directly from the end-user. The used refrigerator was dismantled and cleared. Based on the identification of damage and a comprehensive valuation, the repair shop party can make repairs and or replacements with new components or other components from other refrigerators. In this process, several manufacturing operations are also carried out, such as cutting, forming, or connecting parts or materials so that the refrigerator can operate functionally again. Then do the assembly again and put forward the performance of the "new refrigerator" performance. This remanufactured product is sold with certain guarantees.

The main requirement for this remanufacturing is the main body of the product that is still in good condition. Some components or units in a used refrigerator are often reused by the repair shops, such as thermostats, evaporators, compressors, or overload relays. The retained value of all reuse components can reach 18% of new refrigerators' prices with the same type and brand. The selling price of remanufactured refrigerators in the secondary market can get 40% of the new refrigerators' purchase price. This remanufacturing process also leaves less unused material to be recycled.

The product recovery values from the remanufacturing of used refrigerators and washing machines are obtained from these products' selling prices in the secondary market. They can reach up to 40% to the initial price. Product recovery value from direct reuse of some valuable parts that can function appropriately from the waste of the refrigerators and washing machines can reach up to 18%. While recycling the ferrous metal, plastic, or copper from that e-waste still has its retained value up to 5% to the product's initial price. Used air conditioners (AC) produced lower recovery value than the refrigerator and washing machine if they are remanufactured and recycled as well by the informal sector. From the survey, the remanufactured AC reassembled by AC service/repair shop is sold up to 30% of their initial price, while recycling only 3%. The interesting thing here is although the air conditioner has a lower recovery value by remanufacturing and recycling, it has the highest recovery value from the reuse process. This may be related to the lower middle class's sparse use of air conditioners because the largest market for remanufactured and reuse products is the lower middle class. Table 2 shows product recovery values obtained from each reuse, remanufacture, and recycling process of CE practices by informal sector. The product recovery value obtained from the remanufacturing process is equivalent to the corresponding second-hand product selling price.

Table 2. Product recovery values of CE practices by informal sectors

e-waste	Recycle	Reuse	Remanufacture
Air conditioner	≤ 3%	≤ 22%	≤30%
Refrigerator	≤ 5%	≤ 18%	≤40%
Washing machine	2.5 - 5%	13 - 18%	≤40%

These results indicate two main points: First, there is considerable economic potential in household e-waste products. This potential can be utilized to improve social welfare. Second, remanufacture is a process that can obtain the highest product recovery value, followed by reuse and recycle. This is because the remanufacturing methods involve more value-added production activities than the reuse and recycle process. The implication is that greater economic benefits are obtained by actors who carry out remanufacturing processes or, in this case, the informal repair shop.

4. Conclusion

The Circular Economy (CE) practices for recovery of household electronic waste in urban areas in Padang is unique because many actors are involved in this activity. These activities provide economic benefits, as well as employing the low-income informal sector in Indonesia. For green manufacturing in the final stages of the product life cycle, it will have an excellent effect on the environment and a very sustainable circular economy activity carried out by the community and the informal sector. The practice and the potential of this recovery of e-waste are clearly shown in this article. This work aims to discover the informal remanufacturing potential carried out by the informal repair shops or other urban mining agents in Padang. Besides, extending product life is also outlook research that will be carried out to find environmentally and friendly Circular Economy practices in the urban areas.

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