Identification of Electronic Waste (E-Waste) generation from the household and non-household sectors in Indonesia and its sustainable management system

I Made Wahyu Widyarsana, Dinda Annisa Nurdiani

1 Bandung Institute of Technology
Ganesha St. 10, Bandung 40132, Indonesia

Abstract. The rapid development of technology has spurred competition among electronics manufacturers to innovate. The resulting electronic waste (e-waste) has potential hazards due to its composition. The prediction of e-waste generation is carried out using the Delay Model method, modified by applying end-of-life (EoL) value to the lifespan to adjust Indonesian society’s treatment of e-waste. The calculations show that the prediction of hazardous material from Indonesia’s household sector will reach 16,653.73 tonnes in 2040, while the non-household sector comes to 25,391.72 tonnes in 2040. The most e-product produced from the household sector is TV with 3,763.74 tonnes, while the non-household sector is also dominated by TV with 23,380.52 tonnes in 2040. The composition of materials obtained from e-waste, in general, is 1% hazardous materials, 31% ferrous metal, then 27% glass and plastic materials, 6% non-ferrous metals, and 8% other materials. Thus, the total generation of e-waste will reach 4,204,545.43 tonnes, and the hazardous components in e-products only reach 42,045.45 tonnes or about 1% of the total e-product generation. In the future, it is necessary to integrate and formalize the handling of e-waste from the informal sector, which has been developing into the formal sector. This research is expected to be used as a reference by the government to make regulations, plans, and strategies related to hazardous waste management to prevent harm to the environment and human health.

1 Introduction

The rapid development of technology has spurred competition among electronic product (e-product) manufacturers to innovate. Updated innovations often replace old e-product. This rapid development is not balanced with managing e-product that become waste due to damage or disuse from expiration. Electronic waste (e-waste) continues to be generated in line with the changing trends in the use of e-product, especially electronic communication and information products. E-products can now be obtained at low prices and is accessible to young audiences. This additional number of consumers significantly affects the decline in service life and the increasing diversity of e-products [1].

* Corresponding author: imww.research@gmail.com
The resulting e-wastes have potential hazards due to their composition. The presence of heavy metals can cause systemic diseases in the body; additionally, persistent organic pollutants (POPs) can accumulate in the body; furthermore, there is also indium glass which makes up screens that can cause various respiratory diseases. In Indonesia, e-waste processing has not been given much attention.

This research aims to determine the generation of e-waste in the household and non-household sectors in Indonesia. In addition, a projection for e-waste generation will be carried out until 2040, followed by e-waste management plans, which is expected to be used as a reference by the government in making regulations, plans, and strategies related to hazardous waste management to prevent harm to the environment and human health.

2 Material and methods

Several methods can be used to estimate the generation of e-waste, such as the Time Step Model, Market Supply Model, Stock and Lifespan Model, Leaching Model, The Delay Model, etc. The Market Supply Model method and Stock and Lifespan Model require e-product data not available in Indonesia. In this research, the prediction of e-waste generation is carried out using The Delay Model method, which has been modified by applying the End of Life (EoL) value to the lifespan enabling the treatment to adjust to Indonesian society to e-waste, as can be seen in the following equation [2].

\[ \text{Outflow}(t) = \text{Inflow}(t - \text{EoL}) \]

Where:

\[ \text{Outflow} = \text{E-waste generation (tonnes/year)} \]
\[ \text{Inflow} = \text{Electronic purchase (tonnes/year)} \]
\[ t = \text{Year} \]
\[ \text{EoL} = \text{End-of-life} \]

The prediction of e-waste generation requires detailed sample data for every unit of e-products owned by the household and non-household sector. The sample data in the prediction uses 12 samples of schools and offices for the non-household sector. The sample data for the household sector are 412 households. The scope of e-products types for the household sector are cell phones, TVs, laptops, refrigerators, rice cookers, washing machines, ACs, irons, fans, blenders, DVD/VCD players, radios, tape recorders, and personal computers. The scope of e-products types for the non-household sector are laptops and TVs (including personal computer monitors). In this research, a prediction of the age of e-product ownership is carried out using the Weibull distribution with the following equations.

\[ F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^\beta\right] \]

\[ E(T) = \sum_{i=1}^{T} \cdot \left[F(t_{i+1}) - F(t_i)\right] \]

Where:

\[ F(t) = \text{Cumulative distribution function for the Weibull distribution} \]
\[ t = \text{E-product age} \]
\[ \alpha = \text{Distribution parameter} \]
\[ \beta = \text{Distribution parameter} \]
\[ E(T) = \text{Expected average lifespan of e-products} \]
After obtaining the EoL value and the purchase value of each e-product each year, the generation of e-waste can be calculated using the Delay Model method using the following equation.

\[ T_{Indonesia\ Year\ i} = \frac{N}{n} \times T_{Sample\ Year\ i} \]

Where:
- \( T_{Indonesia\ Year\ i} \) = The prediction of Indonesia’s e-waste generation in Year i (unit/year)
- \( N \) = Population number
- \( n \) = Sample number
- \( T_{Sample\ Year\ i} \) = The predicted sample e-waste generation in Year i (unit/year)

3 Result and discussions

3.1 The prediction of E-Waste from the household and non-household sectors

The prediction of Indonesia’s e-waste generation is carried out using the Delay Model method by applying the EoL value to the lifespan to adjust the community’s treatment of e-products. The prediction concept of e-waste generation uses the Delay Model, namely the generation of waste in a year (outflow), a purchase (inflow) in a year, which is the difference between the predicted year of the e-waste generation and the EoL value. In this research, a predicted age of e-product ownership is also carried out using the Weibull Distribution. This prediction of e-waste generation as both consider the age of ownership under Indonesian people’s treatment of e-products’ lifespan is factored by corrosion and damage.

| Methods                  | Required Data | Used for            | Accuracy |
|--------------------------|---------------|---------------------|----------|
|                          | Purchase      | Ownership | Lifespan | Saturated Markets | Dynamic Markets |          |
| Time Step Model          | ✓             | ✓         |          | ✓                  | ✓                  | High     |
| Market Supply Model      | ✓             | ✓         |          | ✓                  | ✓                  | High     |
| Stock and Lifespan Model | ✓             | ✓         |          | ✓                  |             | Low      |
| Leaching Model           | ✓             | ✓         |          | ✓                  |             | Low      |
| Delay Model              | ✓             | ✓         |          | ✓                  |             | Intermediate |

The comparison of the projection methods is shown in Table 1 according to [2] where the compared static and dynamic model future emission/waste based on characteristic of stocks.
the age of ownership is limited to first hand (first user) to second hand (second user) users. The age of ownership (End of Life) of each e-product is a variable used to calculate e-waste generation using the Delay Model. The calculation shows the age of ownership for each type of e-product, as seen in Table 2.

The prediction results of the generation of e-waste for 412 respondents were projected to present all Indonesian residents for the household sector and present all schools and offices for the non-household sector. The prediction result of e-waste will then be multiplied by the generation of e-waste with the average weight per unit of each type of e-product.

Table 3 shows the average weight of each type of e-product consisting of cell phones, PCs, laptops, TVs, refrigerators, washing machines, radios, tape recorders, DVD/VCD players, air conditioners, rice cookers, irons, fans, and blenders. The calculations show that the prediction of e-waste in the household sector in Indonesia will reach 1,665,372.63 tonnes in 2040, while the non-household sector will come to 2,539,172.80 tonnes in 2040.

Table 2

| Types of E-products | Age of Ownership of New E-product (Year) | Age of Ownership of Second Hand E-product (Year) | Age of Ownership of E-product (Year) |
|---------------------|-----------------------------------------|-------------------------------------------------|-------------------------------------|
| Cell phones         | 2.88                                     | 2.95                                            | 5.83                                |
| PCs                 | 4.75                                     | 3.68                                            | 8.43                                |
| Laptops             | 4.16                                     | 3.9                                            | 8.05                                |
| TVs                 | 6.89                                     | 4.75                                            | 11.64                               |
| Refrigerators       | 7.78                                     | 5.55                                            | 13.33                               |
| Washing Machines    | 6.1                                      | 4.11                                            | 10.22                               |
| Radios              | 11.16                                    | 9.33                                            | 20.5                                |
| Tape Recorders      | 12.65                                    | 7.25                                            | 19.9                                |
| DVD/VCD Players     | 6.46                                     | 4.9                                            | 11.35                               |
| ACs                 | 5.92                                     | 4.39                                            | 10.31                               |
| Rice Cookers        | 5.21                                     | 3.46                                            | 8.67                                |
| Irons               | 5.83                                     | 4.59                                            | 10.42                               |
| Fans                | 5.48                                     | 4.39                                            | 9.87                                |
| Blenders            | 5.96                                     | 2.07                                            | 8.04                                |
| Non-Household Sector|                                        |                                                |                                     |
| Laptops             | 1.16                                     | 0.93                                            | 2.10                                |
| TVs and Screens     | 5.99                                     | 0.93                                            | 6.92                                |

The prediction results exposed that the e-waste for the whole household sector in Indonesia will reach 1,665,372.63 tonnes in 2040, with the TV being the most produced e-product from the household sector with 376,374.23 tonnes, followed by PCs with 315,454.34 tonnes and ACs with 309,210.39 tonnes in 2040. The EoL analysis in the household sector demonstrated that tape recorders are predicted to no longer be traded in 2037, and DVD/VCD players are predicted to no longer be traded in 2039.
VCD players are also considered to be no longer traded starting in 2030. Those two e-products will become obsolete and be replaced by modern e-products such as laptops, televisions, and PCs that have similar functions as tape recorders and DVD/VCD players.

The prediction of e-waste generation from the non-household sector is limited to 2 (two) e-products: laptops and TVs as they are considered to be mostly owned by offices and schools; furthermore, this scope is applied due to limitations in the survey. The non-household sector is also dominated by TVs amounting to 2,338,051.58 tonnes in 2040. This dominating e-product (TV) may be due to TV’s significantly heavier weight than other e-products. The intact e-waste is not completely categorized as hazardous waste. If the hazardous materials in e-waste are separated during the dismantling process, other economic value materials will become non-hazardous waste. The composition of e-waste depends on the type and age of the unit. For example, computer equipment contains more metals, while household appliances such as refrigerators predominantly contain plastic components.

Table 3. Average weight of each type of e-product

| Types of E-products      | Average Weight (kg) | Source |
|--------------------------|---------------------|--------|
| Cell phones              | 0.1                 | [3]    |
| PCs                      | 27.2                | [4]    |
| Laptops                  | 2.9                 | [4]    |
| TVs                      | 24                  | [4]    |
| Refrigerators            | 30                  | [4]    |
| Washing Machines         | 23                  | [4]    |
| Radios                   | 2                   | [3]    |
| Tape Recorders           | 0.181               | [5]    |
| DVD/VDC Players          | 5                   | [6]    |
| ACs                      | 55                  | [3]    |
| Rice Cookers             | 4                   | [7]    |
| Irons                    | 1                   | [3]    |
| Fans                     | 7                   | [8]    |
| Blenders                 | 1                   | [3]    |

The composition of materials obtained from e-waste, in general, is 1% hazardous materials, 31% ferrous metal, then 27% glass and plastic materials, 6% non-ferrous metals, and 8% other materials [9].

In 2040, the total generation of e-waste will reach 4,204,545.43 tonnes; the hazardous components in e-products only reach 42,045.45 tonnes or about 1% of the total e-product generation in 2040. The dominating material in the e-product generation is ferrous metal by 31% or around 1,303,409.08 tonnes in 2040. The next largest component is plastic and glass, each weighing 1,135,227.27 tonnes, followed by non-ferrous metals and other materials at 6% and 8% or 252,272.73 tonnes 336,363.63 tonnes, respectively, as seen in Fig. 1.
Therefore, the content of hazardous materials from e-products in Indonesia from 2020 to 2040 will increase. In 2020, hazardous materials in Indonesia reached 8,486.79 tonnes. The prediction results show a 395.42% increase of 33,558.66 tonnes, resulting in a total of 42,045.45 tonnes in 2040—a very significant increase.

It is known that the distribution of e-waste in Indonesia is not evenly distributed. The generation of e-waste is dominated in Java, which had 15,000 to 86,000 tonnes of e-waste in 2019. This is due to the majority of Indonesia’s population being located in Java and having the dominant center of government activities. Meanwhile, the smallest generation of e-waste is in Maluku, North Maluku, Papua, and West Papua Provinces, which are in the range of 1,000 to 3,000 tonnes of e-waste. This is due to the small population and limited internet and electricity supply in those areas.

### 3.2 The characteristics of E-Waste generation from household and non-household sector

The obtained data shows that e-products in the form of TVs and laptops are one of the most dominant e-products from both the household and the non-household sectors. So, from these 2 (two) e-products, the characteristics of the e-waste generation generated from household and non-household sectors can be analyzed through statistical analysis.

The normality test (Table 4) shows that the significance value of household e-product generation is greater than 0.05, which means the e-product generation data is normally distributed. Meanwhile, the significance value of non-household e-product generation is less than 0.05, which means the e-product generation data is not normally distributed.

#### Table 4. E-waste normality test results for household and non-household sectors

| E-waste Generating Sectors | Types of E-product | Significancy (Shapiro-Wilk) |
|----------------------------|--------------------|-----------------------------|
| Household Sectors          | TVs                | 0.118                       |
|                            | Laptops            | 0.707                       |
| Non-Household Sectors      | TVs                | 0.014                       |
|                            | Laptops            | 0.003                       |

Furthermore, the method chosen for this correlation test is the Mann-Whitney, where the tested data are unpaired and are not normally distributed. The first correlation test will be...
conducted on television waste from the household sector and the non-household sector. The initial hypothesis (H0) in this analysis assumes that there is no difference in the average generation of television e-waste in the household and non-household sectors. On the other hand, the alternative hypothesis (Ha) assumes that there is a difference in the average generation of television waste from household and non-household sectors. The results of the Mann-Whitney correlation test for TV from both sectors can be seen in Table 5 below.

Table 5. Mann-Whitney test results on television e-products

| No. | Parameters | Results |
|-----|------------|---------|
| 1   | Mann-Whitney U | 85      |
| 2   | Wilcoxon W    | 316     |
| 3   | Asymp. Sig. (2-tailed) | 0.001  |

The Mann-Whitney correlation test in Table 5 shows Asymp. Sig (2-tailed) of 0.001, which means that the value of the alternative hypothesis (Ha) is accepted and the initial hypothesis (H0) is rejected [11]; in other words, there is a significant difference in the average generation of television e-waste between the household and non-household sectors. This can be caused by the considerable difference between the household and non-household sectors from using television, considering that the non-household sector’s data is taken from the office and school activities that require more e-product units due to the large number of activities in schools and offices.

The next correlation test was conducted on laptop waste from the household sector and the non-household sector. The initial hypothesis (H0) assumes that there is no difference in the average generation of laptop e-waste in the household and non-household sectors. Alternatively, the alternative hypothesis (Ha) assumes that there is a difference in the average generation of laptop waste from the household and non-household sectors. The Mann-Whitney correlation test results for laptops from both sectors can be seen in Table 6 below.

Table 6. Mann-Whitney test results on laptop e-products

| No. | Parameters | Results |
|-----|------------|---------|
| 1   | Mann-Whitney U | 0       |
| 2   | Wilcoxon W    | 231     |
| 3   | Asymp. Sig. (2-tailed) | 0.000  |

The Mann-Whitney correlation test in Table 6 shows the Asymp. Sig (2-tailed) of 0.000, meaning the value of the alternative hypothesis (Ha) is accepted, and the initial hypothesis (H0) is rejected [11]. In other words, there is a significant difference in the average generation of laptop e-waste between the household and non-household sectors. This can be caused by the considerable difference between the household and non-household sectors from using television, considering that the non-household sector’s data is taken from the office and school activities that require more e-product units due to the large number of activities in schools and offices. Thus, the e-products generated by the household and non-household sectors have significant differences. This difference may lie from the use of e-products, usually more in the non-household sector such as offices and schools, as the main facilities that support activities, compared to e-products in the household sector.
3.3 Electronic Waste Management

Electronic waste, especially cell phones, televisions, and laptops, has a huge potential for recycling. The recovery rate for electronic waste is very high, reaching 37.5% - 80% [12]. E-waste can be reused because it contains materials of economic value such as e-plastic, glass, iron, aluminum, copper, precious metals such as silver, gold, and others. The recycling process design in this study is limited to e-product such as TVs and LCD screens. The recycling process begins with the cutting process. The important first step is decontamination by separating hazardous materials in electronic and electrical waste. Hazardous materials must be handled carefully, separated, packed, and closed so that they do not leak, have a label attached to the packaging, and have a hazardous waste symbol according to Governmental Decree Number 22 of 2021. The packaged hazardous materials will be stored at the hazardous waste transfer depots for transportation to the hazardous waste processor (third party). After separating the electronic and electric waste from the hazardous material, separation and sorting are done based on the type of e-waste material.

The LCD Television will be stripped down semi-automatically, resulting in the separation of different fractions. The LCD is then manually sorted and crushed using a shredding unit and a cutting mill, reducing the size of the waste. Afterward, the LCD particles are screened to separate the glass (containing indium) with e-plastic. The glass containing indium will be sold to the ceramic producing industry, while the e-plastic particles will be mixed with e-plastic particles separated from other components and then further processed.

The e-plastic mixture will be processed with a granulator unit and pelletizer, which produces e-plastic pellets that can be sold to the industry as a substitute for raw materials. Workers manually strip CRT televisions, then the CRT tubes are processed in a Hot Wire CRT unit to separate panel glass, funnel glass, electron gun, metal scrap, and lead dust. Panel glass and funnel glass will be processed in a glass crusher unit and can be used as a substitute for raw materials. Metal scrap will be further processed with metal scrap from other components to be used as metal ingots. The lead dust will be transported to a third party for storage in the hazardous waste landfill.

Technologies designed to recycle e-plastic include reducing the size of e-plastic and making plastic pellets by melting and printing. Plastic pellets are small pieces of plastic that can be further processed in the plastic processing industry to shape them into various everyday plastic objects. Plastic producers covet this product because it is ready to be processed into new plastic, thus the wider market. The examples of recycling diagrams of several types of electronic waste can be seen in Fig. 2. below.
Recycling schemes of cell phones, laptops, and televisions

To deliver e-waste to a recycling facility, an integrated e-waste collection concept is needed. The informal sector dominates recyclers as the recycling and e-waste utilization activities are quite dangerous. In the future, it is necessary to integrate and formalize the handling of e-waste from the informal sector, which has been developing into the formal sector, as shown in Fig 3.

The integration of computer e-waste handling is carried out, especially at collectors and processors (recyclers) from the informal to the formal sectors. Any reduction of informal recyclers is proportional to the increase of formal recyclers. The e-waste generated at the source will be collected by the formal collectors at the collection station and then brought to the processing station before ending at the final processing facility. E-waste collection stations can take advantage of the existing informal sector, which has been fostered, facilitated, and verified to meet the requirements (efforts to formalize the informal system of...
The proposed scenario of formalization for e-waste management can be seen in Fig 4. Fig 4. Concept of an integrated e-waste management

The application of the above concepts can be implemented by integrating the informal sector’s transition—which currently dominates the handling of e-waste—into a formal sector that is more familiar with hazardous waste management (in this case, e-waste management). The submission of this concept does not mean eliminating the informal sector, but rather empowering them by fostering, giving sufficient training and insight, and if necessary, facilitating and providing capital assistance; these activities should be, of course, verified by the relevant government.

The proposed concept may not necessarily integrate the informal sector into a formal sector. The proposal is planned in stages, with a target transition period of approximately 5 (five) years after being stipulated in a regulation. For the transition period and its implementation, both soft skills and financial support from related parties, like the government and producers, will be needed. Operational implementation should be handled by the private sector, which the government and producers control.

Maintaining the informal sector will go hand in hand with the formal sector. In this scenario, the collection will be regionally centralized, where the informal sector (scavengers and flea sellers) still play a role in collecting e-waste at the source as a mobile collector. In scenario 2, a local collection system (LCS) enables the e-waste from flea sellers and scavengers to go directly to the Regional Collection Station (RCS) located in each area. Then, the e-waste from RCS will go to the Intermediate Handling Station (IHS), Handling and Recycling Centre (HRC), and finally, the Final Disposal Facility (FDF).
4 Conclusion

The rapid development of technology has created competition among electronic product (e-product) manufacturers to innovate. The resulting e-wastes have potential hazards due to their composition. The presence of heavy metals can cause systemic diseases in the body, persistent organic pollutants (POPs) that can accumulate in the body, and indium glass, which makes up screens that can cause various respiratory diseases. This research aims to determine the generation of e-waste in the household and non-household sectors in Indonesia. In addition, a projection of the generation of e-waste will be carried out until 2040, followed by e-waste management plans. The prediction of e-waste generation is carried out using The Delay Model method, which has been modified by applying the end of life (EoL) value to the lifespan to adjust Indonesian society’s treatment of e-waste. Based on these calculations, it is known that the prediction of hazardous material from the household sector in Indonesia will reach 16,653.73 tonnes in 2040. In comparison, the non-household sector’s hazardous material from e-waste will accumulate to 25,391.72 tonnes in 2040. The most produced e-product from the household sector is TV with 3,763.74 tonnes, while the non-household sector is also dominated by TV with 23,380.52 tonnes in 2040. The composition of materials obtained from e-waste, in general, is 1% hazardous materials, 31% ferrous metal, then 27% glass and plastic materials, 6% non-ferrous metals, and 8% other materials. Thus, in 2040, the total generation of e-waste will reach 4,204,545.43 tonnes, and the hazardous components in e-products only reach 42,045.45 tonnes, or about 1% of the total e-product generation. Based on the statistical analysis, the e-product generated by the household and non-household sectors have significant differences. The use of e-products can cause this, usually more in the non-household sector, including offices and schools, as the main facilities that support activities, compared to e-products in the household sector. This follows the research results, which show that the generation of e-waste in the non-household sector is greater than the generation of e-waste in the household sector. The recycling process design in this study is limited to e-product such as TVs and LCD screens. The important first step is decontamination by separating hazardous materials in electronic and electrical waste. Hazardous materials must be handled carefully, separated, packed, and closed so that they do not leak, have a label attached to the packaging, and have a hazardous waste symbol.
According to Governmental Decree Number 22 of 2021, to deliver e-waste to a recycling facility, an integrated e-waste collection concept is needed. The informal sector dominates recyclers as the recycling and e-waste utilization activities fall into the dangerous category. In the future, it is necessary to integrate and formalize the handling of e-waste from the informal sector, which has been developing into the formal sector. The prediction can be referenced to design hazardous waste management systems that can reduce the harm of hazardous waste content on human health and the environment.

References

1. M. Dwivedy, and R.K. Mittal. Future trends in computer waste generation in India. J. W. M. 30. 2265–2277 (2004)
2. Van Der Voet, E., et al. (2002). Predicting future emissions based on characteristics of stocks. Ecological Economics.
3. Cobbing M. Toxic Tech: Not in Our Backyard. Uncovering the Hidden Flows of e-waste. Report from Greenpeace International. http://www.greenpeace.org/raw/content/belgium/fr/press/reports/toxic-tech.pdf, Amsterdam, (2008)
4. Kumar P, Shrihari S, Estimation and material flow analysis of waste electrical and electronic equipment (WEEE) - a case study of Mangalore City, Karnataka, India. In: Proceedings of the International Conference on Sustainable Solid Waste Management, 5-7 September 2007, Chennai, 48-154 (2007)
5. B&H. Data Berat Rata-Tape Recorder. Diperoleh dari situs: bhphotovideo.com, (2020)
6. Robinson, Brett H, E-waste: An assessment of global production and environmental impacts. Science of The Total Environment Volume 408 Pages 183-191, (2009)
7. Rimantho, D., & Nasution, S, The Current Status of E-waste Management Practices in DKI Jakarta. International Journal of Applied Environmental Sciences, 11(6), 1451–1468, (2016).
8. Chi, Xinwen, Mark, Yaoling W., Markus, A. Reuter. E-waste Collection Channels and Household Recycling Behaviors in Taizhou of China. Journal of Cleaner Production 80:87–95, (2014)
9. Chatterjee, S, Sustainable Electronic Waste Management and Recycling Process, American Journal of Environmental Engineering 2012, 2(1): 23–33. (2012)
10. Singgih Santoso. Panduan Lengkap SPSS Versi 20 Edisi Revisi. Jakarta: Elex Media Komputindo, (2014)
11. Graventter and Wallnau. Statistics for the Behavioral Sciences. Amerika: Wadsworth, Cengage Learning, (2013)
12. Friege, Henning. Review of Material Recovery from Used Electric and Electronic Equipment - Alternative Option for Resource Conservation. Waste Management and Research: England, (2012)