Applying a stock-based model for estimating the amount of personal computer waste

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Abstract. The fourth industrial revolution has triggered an increase in the demand for information and communication technology equipment. Computers are useful in modern days and it is reflected in the ownership of these appliances which experienced steady growth in recent years. In 2017, about 20% of Indonesian households possess these devices. Undoubtedly, it will correspond to the escalating volume of computer waste. Furthermore, it raises concerns since valuable as well as toxic materials are embedded in e-waste. On the other hand, proper e-waste management is absent in the country. The current study aims to quantify the amount of computer waste generated in Indonesia by applying a stock-based model. The flow model is developed based on the secondary data of household ownership of computers, and the usage period is estimated using the lifetime distribution. The result indicates that computer lifespan in the country is 4.51 years. Besides, the 15 years prediction shows that in 2012 and 2026 the quantity of computer waste is about 1.16 million and 7.47 million respectively. It implies that the amount of e-waste will continue to increase. Therefore, it is imperative to design and implement sustainable e-waste management.

1. Introduction

In the last decade, the advancement of information communication technology (ICT) sector has stimulated the industrial era 4.0. The internet of things (IoT), big data and artificial intelligence are several noticeable characteristics that marked this age. It brings a considerable shift in how government, companies and education institutions running their routines. In fact, 39.8% of Indonesians are already using the internet [1], because there are more virtual interactions and digitized information. It proofs that ICT devices such as computers and tablets become more influential in everyday life. This technological equipment, however, has negative impact on sustainability [2].

Computer users in recent year experience an increase. From 2012 to 2016, Statistics Indonesia noticed a steady growth in household ownership of computers (Figure 1) [3]. This growth will continue in the future. It is affected by the improvement in ICT production combined with increasing obsolescence rates. Besides, with better purchasing power, their price becomes more affordable. Previously, some scholars discussed the correlation between e-waste generation and GDP at purchasing power parity (GDP PPP). For example, Mueller et al. correlated the ownership of computers with GDP PPP [4], while Singh et al. and Kusch investigated how GDP corresponds to e-waste generation [5,6].
Figure 1. Percentage of computer ownership in Indonesia [3].

It remains questionable whether the country is ready to face the strain of ICT waste as an impact of industry 4.0. Unlike developed countries that already instigate stringent regulation for e-waste, in Indonesia, such regulation is still absent. Implementing the extended producer responsibility (EPR) is not mandatory for companies and resellers. They do not take back the obsolete electronic products from their customers. Since most of the electronic equipment in the country are international brands that are imported from foreign countries, Hadi et al. argue that applying temporary import procedure is more effective to prevent the negative impact of e-waste [7]. One promising benefit of this policy is that it will lessen the environmental burden because after a certain period the product will be resent to its originated country. Before the authorities develop a proper system to handle this problem or establish a rigorous rule and policy, the informal sector will continue to dominate the role in processing the abundance of e-waste in this country.

Estimating the future flow of obsolete equipment is crucial as it helps the authorities to design an efficient e-waste management system. In Indonesia however, quantifying e-waste is rather challenging since there is limited reliable data. The sales data of new and secondhand electronic devices is not well administered and the number of discarded obsolete equipment is unrecorded. A similar situation also happened in other countries. Thus, some scholars were utilizing the stock data to predict the amount of e-waste. The stock-based method is one type of Input-Output Analysis (IOA), in which the stocks data is employed to estimate the e-waste quantity. For example, Muller et al. quantified the computer waste by using the data of computer penetration rate that can be easily obtained from open sources [4]. Furthermore, Zhang et al. employed the stock-based model to assess the amount of e-waste in Nanjing, China based on the ownership of household appliances that was published in the Statistical Yearbook of the city [8]. To sum up, stock data can be used as an alternative to assess the volume of e-waste, in circumstances where market supply data is not available. By understanding the e-waste flow and its quantity, the problem can be addressed properly.

The volume of computer waste correlates to the product’s popularity in the fourth industrial era. The market of this device is unsaturated. The rapid innovation drives the product demand and makes the product lifespan becomes shorter. As a result, the volume of computer waste increases to an alarming point. A study by Andarani and Goto stated that the lifetime of a portable computer in Indonesia is approximately 6 years, and in 2015, there were about 1.6-3.1 million units of computer waste [9]. While according to an online survey conducted by Sumasto et al., usually, users tend to store their old computers before deciding to discard them eventually. The paper stated that the dwelling period of laptop in this country is 4.79 years on average; it consists of 3.13 years in used and 1.66 years in storage [10]. To compare, the laptop average lifespan in India and Algeria are 3-4 years [11,12]. In addition, Sumasto et al. revealed that about 56% consumers sold their old laptops in the second-hand market, 29% donated them to families or friends while another 15% old computers were completely disposed of through scavenger, landfill or recycling facilities [10].
Computer waste is a significant problem related to industry 4.0. It needs to be managed in an environmentally friendly manner because it contains precious minerals and toxic substances that are destructive for the environment and human health [13-16]. However, in this country, this issue only has minor attention for years. The present study aims to estimate the volume of computer waste generated by Indonesian households by adopting the stock-based model. It highlights that the e-waste volume in the country is alarming and it is imperative to have sustainable e-waste management. The rest of the paper is structured as follows: Section 2 discusses the material and method; Section 3 presents the result and discussion and Section 4 consists of the final remarks which conclude the paper content.

2. Methods

The stock-based model is derived from the material flow analysis (MFA) method in which the stocks are related to the inflow and outflow of product. It applies the basic principle of conservation, where the difference between production and product disposal will cause a change in stock quantity (Figure 2). This study applies input-output analysis to forecast computer ownership in Indonesian households in the future. Therefore, to assess the quantity of computer waste, it is necessary to have the stock data and product lifespan.

![Flow diagram of basic model](image)

Figure 2. Flow diagram of basic model [4].

To apply the model, the time-series of active computer stock in the country is needed. This paper focuses only on household computers and excludes the one in use by companies and government. The stock is generated by multiplying the number of urban and rural households by the percentage of households that possess computers in every province. Those data are already published by Statistic Indonesia [3]. It is time-series data from 2012 to 2016. Then, it will be extrapolated to the next ten years using linear regression as the forecasting tool with GDP PPP [17] as the independent variable. The forecasting will show the spread and adoption of this technological device. After having the stock data, these following two basic formulas in stock-based model are used to calculate the product flow [8].

\[
F_{n}^{in} = (S_{n} - S_{n-1}) + F_{n}^{out} \\
F_{n}^{out} = \sum_{k=1}^{M} F_{n-k}^{in} \times d_{k}
\]

where \(S_{n}\) and \(S_{n-1}\) are computer stock; the quantity of computer in use in year \(n\) and \(n-1\) respectively, \(F_{n}^{in}\) and \(F_{n-k}^{in}\) are the amount of computers inflow in year \(n\) and \(n-k\); \(F_{n}^{out}\) is the output or old product to be disposed in year \(n\); \(M\) is the maximum usage period of computer, and \(d_{k}\) is the density value in lifetime distribution.

Because quantifying e-waste also needs the data of product lifetime, thus, after having the time series data, it is necessary to estimate the usage period of computers. Two assumptions can be made for product lifespan; it can be constant or follow a lifetime distribution. In this study, the obsolescence rate of computer is assumed to follow the probability density function (pdf) in Weibull distribution. This distribution is commonly used in studies about product failure. To model the product lifespan, this study uses the excel spreadsheet and employs two constant parameters; the scale parameter \(\alpha\) is 4 and the shape parameter \(\beta\) is 2. The waste estimation is then calculated by using the above equation 2.
3. Results and discussion

By applying the method described in the previous section, the stock data is presented in Figure 3. The graph shows that in 2012 the number of computers dwelled in Indonesia households is 11.3 million. This number experiences a stable escalation and becomes double after ten years. This study indicates that in 2026 there will be about 28 million stocks. In general, the proportion of computer users in an urban and rural area is 80% and 20% respectively. According to ITU, in 2017, only 19% of Indonesian using the computer [18]. It is much lower than Singapore, Malaysia, and Thailand; three countries in south-east Asian. In contrast, since Indonesia is the most populous country in the region, the volume of e-waste in this country is the highest amongst others [19].

The stock forecasting model using the regression analysis indicates the $R^2$ value is 0.99. Thus, this study argues that GDP PPP has a strong correlation to computer ownership in the country. This is in agreement with previous studies conducted by Mueller et al., Singh et al. and Kusch [4-6]. Therefore, it can be concluded that computer ownership, as well as computer waste, will increase in correspondence to the improvement of income per capita.

![Figure 3. The computer used by Indonesian households.](image)

This study also estimates the product lifespan. Figure 4 presents the Weibull distribution model of computer lifetime in the country. It assumes that the usage period of the computer is approximately 4.51 years. This number is quite different from previous studies. According to Andarani and Goto [9] and Sumasto et al. [10], in this country, the average lifetime of this particular product is 4 years and 3.13 years respectively. However, the number is almost similar to computer lifespan in India and Algeria [11,12].

![Figure 4. The lifetime distribution of computer.](image)
The estimated amount of PC waste can be calculated using the proposed model presented in the previous section. The result is presented in Figure 5, and it indicates that in 2012 and 2026, Indonesia will generate computer waste of about 1.16 million and 7.47 million respectively. In other words, the quantity will be six-time higher after fifteen years. However, Sumasto et al. [10] stated that obsolete laptops mostly will be resold as second-hand product. In fact, this circular economy has lengthened the product lifetime and postponed the flow of e-waste. Though, it will not reduce the total quantity.

![Figure 5. Estimated computer waste in Indonesia.](image)

The result indicates that the fourth industrial revolution brings significant impact on the quantity of ICT waste in the country. Nowadays, computers dwell is only in 20% households but in the future, dependency on these technological devices will increase. The importance of this equipment is steered by the popularity of digital information and internet of things. As a result, more residents will adopt this ICT product in their home. Consequently, more obsolete computers will flow into the waste stream.

4. Conclusion
One challenge for sustainability in industry 4.0 is the increasing amount of ICT waste. This waste should not be abandoned because it contains valuable resources. Instead, it should be treated carefully since hazardous components inhibit the product. Although the e-waste problem is significant, in Indonesia, it is still improperly managed. This study estimates the volume of computer waste in the country in order to support the authorities to design a proper e-waste management system. Even though market data is not available, e-waste generated in this country can be quantified by using the stock-based model. Thus, computer waste can be assessed by utilizing the penetration rate of computers in households. Moreover, this study finds a strong positive correlation between GDP PPP and computer stock. Therefore, the GDP PPP can be used to forecast the ownership of computers in the future. The result shows that in 2012, the computer stock is estimated at around 11.4 million and after fifteen years it will reach 27.6 million units.

Quantity measurement is a necessary step in waste management. Besides the stock, the volume of computer waste also corresponds to the product lifetime. Recently, computer lifespan becomes shortened, driven by the fast innovation in this particular product. By using the chosen method, the present study reveals that the PC lifespan in the country nowadays is about 4.51 years on average. Besides, the amount of computer waste in 2012 is estimated at around 1.16 million and in 2026 it is expected to become 7.47 million units. By understanding the issue of e-waste quantity, this article encourages every actor to address the issue properly. In conclusion, an integrated sustainable system for e-waste management is imperative in order to manage the negative impact of the fourth industrial revolution.
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