Assessing materials from hoarded mobile phones: hidden e-waste subject for reverse logistics

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Abstract. The advancement of communication technology is shortening the lifetime of mobile phones (MP), resulting in a phenomenal increase in mobile phones waste (MPW). However, instead of recycling their obsolete devices, customers shelved MPW for the personal data stored inside. This study aims to estimate secondary minerals contained in MPW stockpiled by Indonesians. “Consumption and used” method was employed to assess the quantity of MPW generated in this country based on the data of mobile subscribers. Considering that MP life span was around 3 years, and about 38% of obsolete MP were hoarded by their owners, this study revealed that about 339.69 million units of MPW were waiting to enter the reversed logistics. This volume of MPW may generate economic intrinsic at approximately USD 508 million from valuable metals such as 80,949 Kg of silver, 8,873 Kg of gold, and 2,547 Kg of palladium. It implied that hoarding MPW impedes the noble goal of recycling; that is to promote sustainable materials management (SMM) since mining precious metals from e-waste will reduce the demand of virgin minerals directly extracted from nature and reduce the environmental impact. This paper highlighted that it is imperative to develop a sustainable system to support the mineral supply chain.

1. Introduction

When mobile phones (MP) were firstly introduced in Indonesia market, not many residents could afford to buy this particular technology. However, the purchasing power in this country has improved along with its economic growth. As a result, the demand of these equipments escalates persistently. In facts, the penetration of medium brands with affordable price has made smartphones popularity increases among lower-medium income residents. They are attracted to the multiple functions embedded in these devices. Having diverse features, smartphones can assist people in many ways, for example, maintaining social relationship, reading news and doing many other activities.

The number of cellular customers in this country experienced enormous growth since it was the third biggest market of MP in Asia. In 2001, there were only 3.6 million subscribers then it multiplied almost a hundred times within 15 years (see figure 1); at a point that outnumbered its population. In 2015, this country was populated by 255 million inhabitants [1] but mobile cellular subscriptions reached more than 338 million [2]. This mobidity (mobile connections per 100 citizens) of 132% was clear evidence that some residents possessed more than one active MP. It was supported by a survey conducted by Maheswari et al. [3] that there were 47.9% of Indonesians who had 2 or 3 active phones.
Figure 1. Mobile cellular subscriptions in Indonesia [2].

The increasing amount of MP ownership along with significant improvements in communication infrastructure explains how this country is in the period of a digital revolution [4]. It raises concerns because this proliferating number of MP demand has a positive correlation to the enormous number of MPW. The MPW quantity will continue to rise driven by technology enhancement that provokes people to replace their gadgets. Due to its short lifespan, literature shows that MPW dominated the number of e-waste in this country [5,6]. Recently, Santoso et al. [6] applied population balance method and estimated that in 2028, the amount of e-waste generated in Indonesia will be about 49.62 million units, including MPW of 40.78 million units or 82%. This number is alarming since the management of obsolete telecommunication devices in the country shows minimum progress. Besides, it is portraying that developing sustainable e-waste management is urgent.

Sustainable e-waste management needs a legal framework, collection mechanism, transportation scheme and processing infrastructure [7]. In this system, collection plays as a front gate, and it influences the whole process. The collection rate will be affected by consumer's willingness to recycle their old devices. However, for many reasons, users prefer to retain their end of used MP. Some people replace their old MP since they have been malfunctioned, and it is cheaper to buy a new one rather than bringing the broken handheld to service centres [8]. Others who are addicted to gadgets, change their MP merely because they are fascinated by the innovative features in the latest models [8, 9]. Moreover, people hesitate to recycle their MPW since their personal data are loaded inside. They are afraid of privacy disclosure [3]. As this type of e-waste is small enough, keeping them does not need much space in a room. Consequently, a large proportion of MPW are buried deep inside one’s drawers; stockpiled by their owners. This has become a barrier to mineral resources sustainability as shown in figure 2. Indonesians who show this kind of behaviour are about 38% [3]. To compare, residents in India, China, and Spain who have a similar habit are 59%, 62% and 73% respectively [8, 9, 10].

Figure 2. Minerals in stockpiled MPW outside the reverse logistics (modified from [11]).
Minerals recovery is imperative for MP since numerous metals including rare earth elements are embedded in them. Although in a tiny amount, they are indispensable. They make the device working. As MP production is increasing, so does demand for these minerals. However, natural reserves of some metals are reaching their scarcity level nowadays [12, 13]. It makes the supply vulnerable. Moreover, the market and regulation fail to support the mineral life cycle from MPW [14]. For this reason, promoting sustainable materials management through recycling is urgent because it can recover a lot of minerals. Effective recycling also supports reverse supply chain. It will lengthen the life cycle of critical metals. Secondary minerals extracted from e-waste can be used for manufacturing new products. The cost for processing metals from e-waste is also more effective than mining the virgin minerals [15]. Besides, having better life cycle can preserve virgin material extracted directly from nature and reduce destructive environmental impact [16]. A study by Szamalek and Galos [17] estimated that the quantity of MPW in the world hidden by their owners was around 14 billion units and half of them are smartphones. These hoarded telecommunication handhels may generate precious minerals such as 3,892,000 Kg of silver, 378,000 Kg of gold and 140,000 Kg of palladium [17].

The amount of metals in MP is diverse for each model. In general, minerals in 4G models are different in comparison to their predecessor 2G models. It corresponds to their design and features. Material consumption in modern smartphones with their rich feature is dissimilar from nature and reducing destructive environmental impact [16]. A study by Szamalek and Galos [17] estimated that the quantity of MPW in the world hidden by their owners was around 14 billion units and half of them are smartphones. These hoarded telecommunication handhels may generate precious minerals such as 3,892,000 Kg of silver, 378,000 Kg of gold and 140,000 Kg of palladium [17].

The amount of metals in MP is diverse for each model. In general, minerals in 4G models are different in comparison to their predecessor 2G models. It corresponds to their design and features. Material consumption in modern smartphones with their rich feature is dissimilar from older models that only have basic functions. The type and amount of materials covered in a touch screen smartphone is in contrast with MP with QWERTY keyboard. For example, the usage of indium (In) is related to smartphones with LCD display [18]. Although MP models are varied, it should be noticed that valuable metals can be found in every model; from the outdated to a modern one. These precious metals undoubtedly are driving factors for the high economic value of e-waste [16]. The average content of precious metals inside MP which are produced in three distinct generations; 2001, 2005 and 2010 are listed in table 1 [18, 19].

Table 1. Precious metals in mobile phones [18, 19].

| Metals         | Mass (g) | 2001 | 2005 | 2010 |
|----------------|----------|------|------|------|
| Silver (Ag)    |          | 0.244| 0.150| 0.305|
| Gold (Au)      |          | 0.038| 0.018| 0.030|
| Palladium (Pd) |          | 0.015| 0.001| 0.011|

This study aims to assess the valuable metals that can be recovered from the end of life of MP, which passively lie in wait for entering reverse supply chain. It raises awareness among MP users that the recycling of materials embedded in MPW is related to preserving minerals in nature and extending the circular economy. It also portrays that stockpiling MPW will affect the supply chain and cost the environment dearly. Moreover, this research emphasized on how important for this country to have sustainable e-waste management with reliable collection systems. A trustworthy one so that it can motivate residents to recycle their MPW. The remainder of the paper structured as follows: the research method was presented in section 2, followed by result and discussion in Section 3 and conclusions in section 4.

2. Method

Two steps were employed to assess the valuable minerals from hoarded MPW. First, the number of MPW retired annually was calculated by adopting “consumption and used” method [20]. This method was also known as the approximation approach. It needed two input data; the number of active MP and their average lifetime. As the estimated proportion of stockpiled MPW, data presented by Maheswari et al. [3] in their research was utilized in this study. The calculation was conducted using the following equation:
where $Q_t$ (units/year) is the quantity of retired MPW in year $t$, $N$ (units) is the number of active MP which is equivalent to mobile phone subscriptions in a particular year, $l$ (years) is the average lifetime of MP, and $H$ (%) is the proportion of MP stockpiled by customers. Maheswari et al. in their survey revealed that average useful lifespan of MP in this country is about 2.57 year [3]. By applying the Weibull distribution, Santoso et al. [6] found that the average lifetime of MP in this country is around 3.42 years. Based on their research, in this study, 3 years is assumed as the average replacement time of MP. For example, if one bought his phone in 2005, he would replace it in 2008. Besides, in accordance with the previous study [3], 38% is adopted as a proportion of hoarded MPW.

Finally, the secondary minerals contained in hoarded MPW were estimated based on the information presented in table 1. The quantity of MPW was grouped in three according to their generation. It was because every generation of MP had its own characteristics and may include a distinct amount of metals. The average mass of metals for MP produced around 2001 was a key to assess minerals for MPW generated from 2001 to 2007. Mostly they were phones with basic functions; making phone calls and sending text messages. As for metals covered in MP produced around 2005 was used for MPW generated from 2008 to 2012. These were for MP with several additional functions. For example, they had an embedded camera and speaker. Besides, they also had bigger capacity to save data. Finally, materials embedded in MP manufactured around 2010, were useful to estimate the valuable metals contained in MPW generated from 2013 to 2016. These were smartphones generation with touch screen models. Usually they had rich features and able to connect to the internet.

3. Result and Discussion

3.1. Retired mobile phones hoarded by owners

The annual quantity of MPW generated in Indonesia was assessed by applying equation 1. The results are presented in table 2. It shows that by the end of 2016, the total MPW generated in this country had already reached 893 million units. It included 339 million MPW that were passively waiting outside the reverse supply chain. This extensive amount was an accumulation effect of low recycling rate. Besides, the vacancy of appropriate e-waste treatment and the lack of environmental awareness also played significant parts [3].

| Year | MPW retired | MPW hoarded |
|------|-------------|-------------|
| 2001 | 2,173,649   | 825,987     |
| 2002 | 3,900,000   | 1,482,000   |
| 2003 | 6,165,084   | 2,342,732   |
| 2004 | 10,112,202  | 3,842,637   |
| 2005 | 15,636,657  | 5,941,930   |
| 2006 | 21,267,672  | 8,081,715   |
| 2007 | 31,128,960  | 11,829,005  |
| 2008 | 46,859,414  | 17,806,577  |
| 2009 | 54,558,987  | 20,732,415  |
| 2010 | 70,430,078  | 26,763,430  |
| 2011 | 83,268,540  | 31,642,045  |
| 2012 | 93,987,888  | 35,715,398  |
| 2013 | 104,408,971 | 39,675,409  |
| 2014 | 108,527,606 | 41,240,490  |
As shown in table 2, MPW that was retired in 2001 but still in stored by their owners was about 825,987 units or 82.59 ton. It increased consistently every year. In 2016 the number reached 48,839,297 units or in terms of weight it was 4,883 ton. This number will grow persistently in the future as people will maintain their behaviour before trustworthy system to collect e-waste is available. The current finding had a small contrast with previous research performed by Santoso et al. [6] in which they estimated that the number of MPW in 2028 was about 40.78 million units or 4,078 ton. In total, the quantity of hidden MPW in the country was about 339 million units.

To answer the objective of this research, it was imperative to group the quantity of hoarded MPW in table 2 in three. The first one was for MPW generated from 2001 to 2007. Because in this period, the number of cellular subscribers was only about 93 million, this group had the lowest quantity; that was 34,346,005 units in total. The next group was for MPW generated from 2008 to 2012. The number of hoarded MPW from this generation was 132,659,865 units. The last group was MPW generated from 2013 to 2016 or smartphones models. With 172,688,653 units, the last group had the highest number compared to another two; almost half of the total quantity. Having megabytes capacity to save data, users found their smartphones bursting with personal data. It made them have a stronger emotional attachment. Consequently, they hesitated to recycle their old gadgets and preferred to retain them for a longer period instead. The result was in agreement with Szamalek and Galos [17], that half of the hoarded phones were smartphones.

3.2. Valuable minerals lie in wait for reverse supply chain

This section discussed the estimated amount of valuable materials contained in three distinct generations of hidden MPW and their economic value. To determine the amount of valuable metals contained in hoarded MPW, metals weight in each MP as listed in table 1 was multiplied by the MPW quantity in each group. The result is presented in table 3. It shows that in total, silver, gold, and palladium that can be recovered from hoarded MPW in this country were about 80,949 kg, 8,873 kg, and 2,547 kg respectively.

| Metals          | 2001-2004 | 2005-2009 | 2010-2015 | Total      |
|-----------------|-----------|-----------|-----------|------------|
| Ag (Silver)     | 8,380.43  | 19,898.98 | 52,670.04 | 80,949.44  |
| Au (Gold)       | 1,305.15  | 2,387.88  | 5,180.66  | 8,873.69   |
| Pd (Palladium)  | 515.19    | 132.66    | 1,899.58  | 2,547.43   |

When this study was conducted, the average price index for Ag, Au, and Pd in the global market were (in USD/t oz) 14.50, 1,280 and 1,290 respectively [21]. The monetary values of precious metals in table 3 were determined based on those prices. The potential economic value for each identified metal was approximately USD 37.7 million for silver, 365.2 million for gold, and 105.6 million for palladium. Those three metals worth USD 508.5 million in total or in local currency they were worth IDR 7.3 trillion. However, this study was assessing the value of three precious minerals only. It should be noted that the number would be higher if all the types of minerals including the rare earths covered in MPW was also considered. On the other hand, the cost for reverse logistics, including processing secondary minerals, even though a lot more effective compared to traditional mining [15], will reduce the monetary benefit. This issue was not discussed in detail in this manuscript though.
4. Conclusion and Recommendation

This study assessed the quantity of precious minerals inside hoarded MPW and its economic value. Every MP contains various materials, which makes recycling imperative. Because sustainable mineral management has a positive correlation to sustainable e-waste management, consumer's awareness and behaviour play an essential role. Most people hesitate to bring their MPW to collection points; they hide these small devices in their home instead. The quantity of hoarded MPW in Indonesia was estimated at around 339.69 million units, and half of them were smartphones. Economic intrinsic in the form of valuable metals contained in this volume of MPW was approximately 80,949 Kg of silver, 8,873 Kg of gold and 2,547 Kg of palladium. One disheartening fact was that these metals worth of USD 508.5 million was waiting outside the reverse supply chain. Therefore, sustainable e-waste management need to be developed to save these mineral.

By reliable collection system, secondary minerals extracted from e-waste will find their way back in the manufacturing cycle. Some measures can be applied to collect MPW from the society. Government can provide a formal and permanent collection facility as part of sustainable e-waste management. It is useful for the country for long terms period. However, asking residents to donate their MPW in a campaign to solve a specific issue may show effective result. It helps the reverse supply chain. For example, when Australian zoos campaigned for gorilla conservation, they successfully collected 115,369 MPW from their visitors from 2009 to 2014 [22]. Recently, Japan’s Olympic Committee is asking e-waste donation from society in order to create the entire medals for 2020 Tokyo Olympic. Those are some evidences that organized missions can influence people and raise their awareness.

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