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Generation estimation and metals recycling potentials evaluation of retired mobile phones in Philippines

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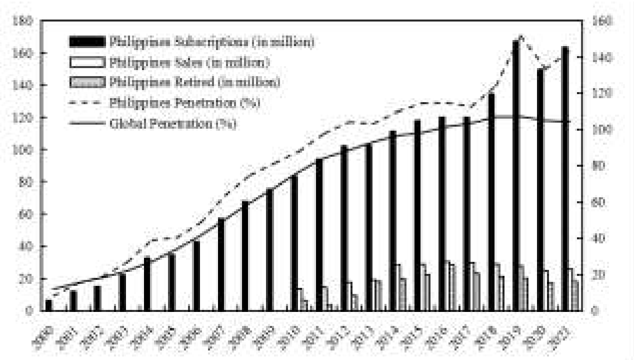
Graphical abstract



Abstract

The goal of this work is to evaluate generation estimation and metals recycling potential of retired mobile phones in Philippines. The generation estimation is conducted with the sales&new method and statistic data, such as sales of mobile phones and amount of the subscribers. The result shows that there are 18.11 million of mobile phones retired in 2021, compared 6.31 million in 2010. Accordingly, the deduced lifetime has minimum and maximum value in 2016 and 2011, which is 4.24 and 27.22 years, compared with 9.02 years in 2021. The crosscheck testifies to the veracity of the result in comparison with the actual condition. The metals recycling potentials and dynamic are also calculated with the content and amount of retired mobile phones. The result shows that the metals recycling potentials and dynamic increase with the increasing amount of retired mobile phones in Philippines.

Keywords: WEEE, e-waste, retired, mobile, phone, generation and estimation

1. Introduction

As the indispensable hardware equipment for mobile communication industry, mobile phones have flourished for decades. As a member of developing countries, Philippines have booming mobile communications industry. As showed in Figure 1, the penetration of mobile phone in Philippines increased from 8.28% in 2000 to 143.44% in 2021, with the relatively low penetration increased from 12.04% in 2000 to 104.30% in 2021 globally. There are 6.45 million mobile phone subscribers in Philippines at the end of 2000, while increased to 163.35 million at the end of 2021. At the same time, the amount of mobile phone subscribers globally increased from 738.60 million to 8648.00 million (ITU, 2022).

The huge number of subscribers and the frequent replacement of equipment lead to large quantities of retired mobile phones together (Marra et al., 2018b, Li et al., 2022a). The retired mobile phones are typical small waste electrical and electronic equipment (WEEE) for the characteristics such as tiny volume, huge generation, high recycling value and low take-back rate (Li et al., 2015).

WEEE is an important category of waste globally and classified as solid waste in many countries, not only for the huge generation and complicated composition with the potential negative consequences to the environment quality and public health, but also as the non-negligible sources of urban mines and critical metals (Cesaro et al., 2018, Lu et al., 2014, Diedler et al., 2018). The management system of solid waste usually includes both informal and formal sectors. The informal sector is common in developing countries with the low threshold of investment and technology (Lu et al., 2015, García-Madurga et al., 2022). The informal sector refers to individuals, families and enterprises without the governmental authorities such as taxed, contracted, financed, managed, organized, recognized, reported and sponsored (Johannes et al., 2012). The informal sector can recycle some resource in the waste and provide the opportunities of employment, while leading to the negative consequences to the environment quality and public health due to the lack of labor protection and safety standard (Galang and Ballesteros, 2018).

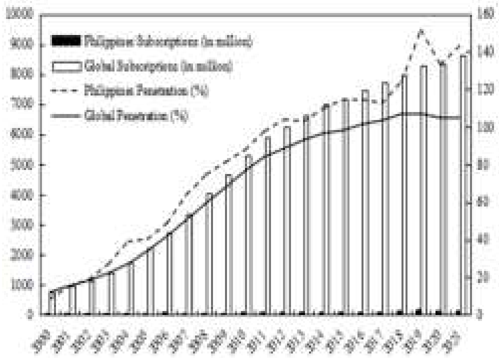


Figure 1. The amount and penetration of subscribers in Philippines and the world

The retired mobile phones make up a tiny part in the overall weight of WEEE. However, the contribution to the total environmental impacts can not be ignored while considering the large amount around the world. As a typical developing country in Southeast Asia, Philippines started to concern the challenge of retired mobile phones and WEEE in the past decades. The Republic Act 9003, which also with the title of Ecological Solid Waste Management Act, came into effect in January 2001. The Republic Act 9003 defined responsibilities of local governments as the primary institutions and encouraged the involvement of private sector. The Republic Act 9003, with mandatory targets, proposed the source reduction, as well as the recovery, recycling and reuse of wastes. The target was defined as a quarter of waste recovery by 2006 and increased in every 3 years thereafter. In order to achieve the target, every barangay need to constitute the Material Recovery Facility for the recyclables and biodegradables materials to be recovered. The Republic Act 9003 prohibited waste picking in segregation areas or disposal facilities without the permission from the owner or operator. However, the informal sector can participate the activities as a member of the Solid Waste Management committees of the barangays. At the same time, most of WEEE was collected and treated by informal sector, while the formal sector just treats few WEEE scrap wihch mixed in the industrial waste. The Republic Act 7160 stipulated the municipal governments need to guarantee fundamental rights and social welfare to all the citizens including waste pickers. Furthermore, the Republic Act 8425 established the National Anti-Poverty Commission to eliminate poverty and provide micro-finance services, which can also benefit the waste pickers (Yoshida et al., 2016).

The quantitative information of retired mobile phones and recycling potentials inside are fundamental for the sustainable management system of retired mobile phones and WEEE, while the valid data are difficult to obtain and verify. There are few generation estimations of retired mobile phones in Philippines (Galang and Ballesteros, 2018). However, the quantification of recycling potentials of retired mobile phones in Philippines is still not available. The goal of this work is to evaluate the generation and recycling potentials of retired mobile phones in Philippines, which can contribute to construct the sustainable management system of retired mobile phones and WEEE for Philippines and other countries.

2. Method and data

2.1. Method

There are several approaches can be used to estimate the generation of WEEE including retired mobile phones globally. These approaches can be classified as econometric analysis, factor model, direct waste analysis, time-series model and input-output model. There are few applications of econometric analysis and factor model, with no application on retired mobile phones.

Most generation estimations of retired mobile phones are conducted with various approaches which can be classified as input-output model. For instance, the classic market supply method was used to estimate the generation of retired mobile phones in China and U.S. (Martin Eugster et al., 2007); the market supply A method was used in Brazail (Abbondanza and Souza, 2019), China (Tan et al., 2017) and Czech Republic (Polak and Drapalova, 2012); the consumption and use approach was used in Australia (Golev et al., 2016b), China (Zeng et al., 2021), India (Pathak et al., 2017), Jordan (Saidan and Tarawneh, 2015) and Turkey (Öztürk, 2014); the MFA method was used in Australia (Golev et al., 2016a), Belgium (Forti et al., 2018), Brazil (Araujo et al., 2012), China (Yu et al., 2010), Greece (Kastanaki and Giannis, 2022), India (Kiran et al., 2021), Indonesia (Andarani and Goto, 2013), Italy (Forti, Bald´e, 2018), Korea (Jang and Kim, 2010) and U.S. (Althaf et al., 2020).

Based on the systematic and comparative research on the applications and data demand, the sales&new method has been selected to estimate the generation of mobile phones in Philippines. The sales&new method is based on the material flow analysis and principle of material conservation, so can be also described as MFA method (Li et al., 2020). The sales&new method can be described as:

$$\Delta M = \Sigma F_{in} - \Sigma F_{out}, \quad (1)$$

where: ΔM is the variation of stock, F_{in} is the flow into the stock, F_{out} is the flow leaving the stock.

Generally speaking, majority subscriber needs mobile phone as the equipment to realize communication function, so the number of subscribers in use can be treated as the amount of the mobile phone stock: the amount of new subscribers in certain period can be treated as ΔM; the sales of mobile phone can be treated as $\sum F_{in}$, the amount of retired mobile phones can be treated as $\sum F_{out}$ (Li et al., 2022b). So the sales&new method can be described as:

$$R_t = S_t - N_t, \quad (2)$$

where R_t is the amount of retired mobile phones generation in the year t; S_t is the sales of mobile phones in the year t; N_t is the number of new subscribers in the year t, which can be described as:

$$N_t = U_t - U_{t-1}, \qquad (3)$$

Where: U_t and U_{t-1} are the number of subscribers in the year t and t-1.

2.2. Data sources

2.2.1. Sales

There is no productive capacity of mobile phones in Philippines, all the mobile phones sold in Philippines are imported (Galang and Ballesteros, 2018). The continuous sales data of mobile phones are obtained from the third-party consulting company (Sellcell, 2023).

2.2.2. Possession and new

The number of subscribers is obtained from the official website of Department of Information and Communications Technology (DICT, 2023).

2.2.3. Composition and content

There are two categories of typical mobile phones, which can be called feature phone and smart phone. They are composed by same components but have visible difference such as physical keyboard, touchable screen and extensible operating system. The appearance of iPhone by Apple in 2007 marks the emergence of smart phones. The previous research shows that the amount of retired mobile phones increased by 10% every year from 2009 and reaches the maximum limitation of 90% in 2018 (Li et al., 2022b).

The quality of both categories of feature phone and smart phone are set to 80.00 g according to the previous research (Li et al., 2022b), which both excluding the batteries. The details of the content of both feature phone and smart phone are shown in Table 1.

Table 1. The contents of mobile phones

Materials	Feature(g)	Smart(g)	Materials	Feature(g)	Smart(g)	Materials	Feature(mg)	Smart(mg)
Total	80.00	80.00	Nickel	0.61	0.31	Silver	25.00	16.00
Plastics	33.99	34.73	Cadmium	0.49	0.97	Potassium	20.00	50.00
Ceramics	6.97	3.64	Lead	0.38	0.19	Bismuth	20.00	9.00
Epoxies	4.27	3.40	Zinc	0.24	0.16	Chromium	10.00	20.00
Rubbers	1.28	0.00	Strontium	0.17	0.36	Gold	6.80	4.00
Others	12.34	14.69	Tungsten	0.06	0.04	Titanium	5.80	3.30
Silicon	4.25	9.48	Antimony	0.06	0.03	Indium	4.20	1.70
Copper	10.08	5.61	Arsenic	0.05	0.18	Palladium	3.20	2.00
Ferrum	2.51	2.90	Manganese	0.04	0.02	Beryllium	2.80	1.50
Tin	0.99	0.51	Barium	0.04	0.19	Platinum	2.20	1.50
Aluminum	0.97	2.22	Gallium	0.03	0.01			

2.3. Data correction

The number of subscribers increased steadily from 6.45 million in 2000 to 167.32 million in 2019. However, the number of subscribers decreased to 149.58 million in 2020 and 163.35 million in 2021. The fluctuation can not change the tendency of continuous increase, instead of leading to the negative value of number of new subscribers. The fluctuation can be also found in Indonesia in 2018 and Thailand in 2020 because of the change in regulation. The new regulation requires all the owner of prepaid subscribers register with ID card (ITU, 2022).

In order to obtain the valid data, the number of subscribers was revised with the linear regression correction approach. The revised data instead the official data from 2017 to 2021 with the R-squared of 0.989.

3. Result and discussion

3.1. Generation estimation

The data and results of the generation estimation are showed in Table 2. The revised data and official data of the number of subscribers are both showed in Table 2, while the amount of new subscribers, generation results and deduced lifetime are based on the revised amount of subscribers.

The result shows there are 18.11 million of mobile phones retired in 2021, compares with 6.31 million in 2010. The minimum of retired mobile phones shows in 2011 with the value of 3.46 million, while the minimum of sales shows in 2010 with the value of 13.87 million. The maximum of retired mobile phones shows in 2016 with the value of 28.34 million, while the maximum of sales shows in 2016 with the value of 30.60 million. From 2010 to 2021, there are 291.21 million of mobile phones sold and 208.62 million of mobile phones retired, with the weight of 16689.60 tons in Philippines.

3.2. Limitations and crosscheck

According to the essence of consumption and use approach, it can be speculated that the lifetime can be deduced by dividing the number of subscribers by the amount of retired mobile phones (Li et al., 2022b). The deduced lifetime with the results is also shown in Table 2 as L_R. The minimum value of L_R, which means the shortest lifetime, shows in 2016 with the value of 4.24 years. While the maximum value of L_R, which means the longest lifetime, shows in 2011 with the value of 27.22 years. The deduced lifetime of retired mobile phones in Philippines are longer than many countries reported in the previous research and other countries in Association of Southeast Asian Nations, such as 2.68 and 3.10 years before 2013 and 2016 in Thailand (Borrirukwisitsak et al, 2021, Budnard and Khaodhiar, 2022), 1.60 and 2.57 years before 2013 and 2017 in Indonesia (Maheswari et al., 2017, Panambunan-Ferse and Breiter, 2013).

Table 2. The data and results of the generation estimation in Philippines (million units).

Year	S_t	U_t	U_t^R	N_t	R_t	L_R
2009		75.59	75.59			
2010	13.87	83.15	83.15	7.56	6.31	13.18
2011	14.50	94.19	94.19	11.04	3.46	27.22
2012	17.55	101.98	101.98	7.79	9.76	10.45
2013	19.09	102.82	102.82	0.84	18.25	5.64
2014	28.40	111.33	111.33	8.51	19.89	5.59
2015	29.10	117.84	117.84	6.51	22.59	5.27
2016	30.60	120.10	120.10	2.26	28.34	4.24
2017	30.10	119.97	127.02	6.92	23.18	5.48
2018	29.30	134.60	134.81	7.79	21.51	6.26
2019	27.90	167.32	142.60	7.79	20.11	8.32
2020	24.90	149.58	150.39	7.79	17.11	8.74
2021	25.90	163.35	158.18	7.79	18.11	9.02
Total	291.21	-	-	82.59	208.62	-

Note: U_t^R *is the revised amount of subscribers in the year t.*

3.3. Recycling potential evaluation

As showed in Figure 2, the recycling potentials of precious metals such as silver, gold, palladium and platinum are 306.06, 77.51, 38.39 and 28.43 kilogram in 2021, comparing 152.07, 41.14, 19.43 and 13.44 kilogram in 2010, respectively. The maximum values are 529.96, 137.17, 66.88 and 48.46 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 80.27, 21.59, 10.24 and 7.12 kilogram in 2011 with the minimum values of retired mobile phones.

The static state is used to describe the constant content of retired mobile phones without the replacements of feature phones by smart phones (Li et al., 2022b). The recycling potentials of silver, gold, palladium and platinum in static state are 452.75, 123.49, 57.95 and 39.84 kilogram in 2021, comparing 152.07, 41.14, 19.43 and 13.44 kilogram in 2010, respectively. The maximum values are 708.50, 192.71, 90.68 and 62.35 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 86.50, 23.53, 11.07 and 7.61 kilogram in 2011 with the minimum values of retired mobile phones.

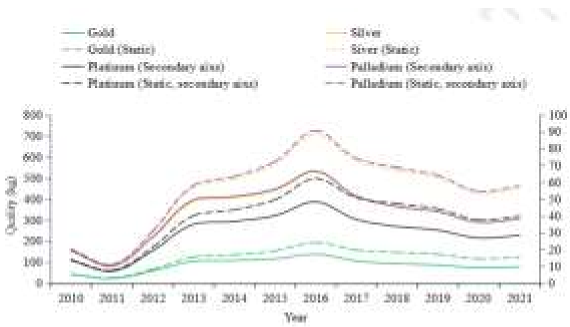


Figure 2. The recycling potentials of precious metals in Philippines

The accumulative recycling potentials of silver, gold, palladium and platinum are 3921.21, 1019.37, 496.48 and 359.15 kilogram from 2010 to 2021, while the accumulative recycling potentials of silver, gold, palladium and platinum in static state are 5215.50, 1418.62, 667.58 and 458.96 kilogram at the same time, respectively.

As showed in Figure 3, the recycling potentials of rare metals such as beryllium, gallium, indium, titanium and tungsten are 29.52, 217.32, 71.53, 64.29 and 760.62 kilogram in 2021, comparing 16.85, 176.68, 12.30, 35.02 and 365.98 kilogram in 2010, respectively. The maximum values are 53.56, 453.44, 97.77, 114.77 and 1303.64 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 8.79, 89.96, 7.61, 18.34 and 193.76 kilogram in 2011 with the minimum values of retired mobile phones.

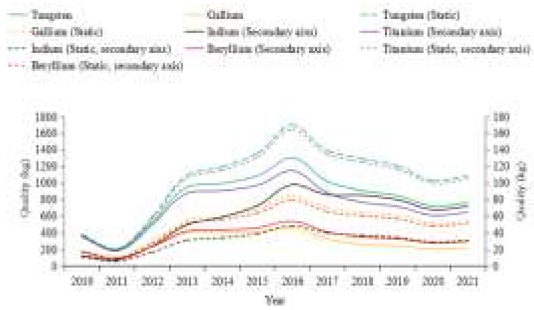


Figure 3. The recycling potentials of rare metals in Philippines

The recycling potentials of rare metals such as beryllium, gallium, indium, titanium and tungsten in static state are 50.71, 543.30, 30.79, 105.04 and 1086.60 kilogram in 2021, comparing 17.67, 189.30, 10.73, 36.60 and 378.60 kilogram in 2010, respectively. The maximum values are 79.35, 850.20, 48.18, 164.37 and 1700.40 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 9.69, 103.80, 5.88, 20.07 and 107.60 kilogram in 2011 with the minimum values of retired mobile phones.

The accumulative recycling potentials of rare metals such as beryllium, gallium, indium, titanium and tungsten are 398.77, 3406.84, 711.12, 853.53 and 9665.44 kilogram from 2010 to 2021, while the accumulative recycling potentials of rare metals such as beryllium, gallium, indium, titanium and tungsten in static state are 584.14, 6258.60, 354.65, 1209.99 and 12517.20 kilogram at the same time, respectively.

Figure 4. The recycling potentials of heavy metals in Philippines

As showed in Figure 4, the recycling potentials of heavy metals such as antimony, arsenic, barium, bismuth, chromium and manganese are 597.63, 3024.37, 3169.25, 1503.13, 344.09 and 398.42 kilogram in 2021, comparing 359.67, 397.53, 347.05, 170.37, 69.41 and 239.78 kilogram in 2010, respectively. The maximum values are 1105.26, 3995.94, 4109.30, 1955.46, 481.78 and 736.84 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 186.84, 262.96, 242.20, 117.64, 41.52 and 124.56 kilogram in 2011 with the minimum values of retired mobile phones.

The recycling potentials of antimony, arsenic, barium, bismuth, chromium and manganese in static state are 1086.60, 905.50, 724.40, 362.20, 181.10 and 724.40 kilogram in 2021, comparing 378.60, 315.50, 252.40, 126.20, 63.10 and 252.40 kilogram in 2010, respectively. The maximum values are 1700.40, 1417.00, 1133.60, 566.80, 283.40 and 1133.60 kilogram in 2016 with the maximum values of retired mobile phones. The minimum values are 207.60, 173.00, 138.40, 69.20, 34.60 and 138.40 kilogram in 2011 with the minimum values of retired mobile phones.

The accumulative recycling potentials of antimony, arsenic, barium, bismuth, chromium and manganese are 8.24, 28.97, 29.73, 14.15, 3.51 and 5.49 ton from 2010 to 2021, while the accumulative recycling potentials of antimony, arsenic, barium, bismuth, chromium and manganese in static state are 12.52, 10.43, 8.34, 4.17, 2.09 and 8.35 ton at the same time, respectively.

As showed in Figure 5, the recycling potentials of bulk metals such as aluminum, copper, ferrum, lead, nickel, tin and zinc are 37.94, 109.69, 51.81, 3.78, 6.16, 10.11 and 3.04 ton in 2021, comparing 6.91, 60.78, 16.08, 2.28, 3.66, 5.94 and 1.46 ton in 2010, respectively. The maximum values are 52.29, 196.99, 78.87, 7.00, 11.34, 18.53 and 5.21 ton in 2016 with the maximum values of retired mobile phones. The minimum values are 4.22, 31.78, 8.95, 1.18, 1.90, 3.09 and 0.78 ton in 2011 with the minimum values of retired mobile phones.

The recycling potentials of aluminum, copper, ferrum, lead, nickel, tin and zinc in static state are 17.57, 182.55, 45.46, 6.88, 11.05, 4.35 and 17.93 ton in 2021, comparing 6.12, 63.60, 15.84, 2.40, 3.85, 6.25 and 1.51 ton in 2010, respectively. The maximum values are 27.49, 285.67, 71.13, 10.77, 17.29, 28.06 and 6.80 ton in 2016 with the maximum values of retired mobile phones. The minimum values are 3.36, 34.88, 8.68, 1.31, 2.11, 3.43 and 0.83 ton in 2011 with the minimum values of retired mobile phones.

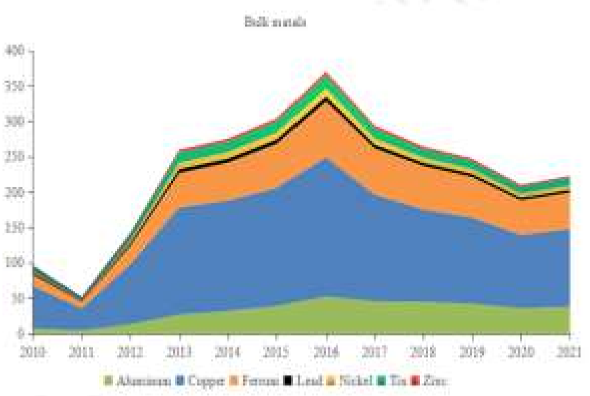


Figure 5. The recycling potentials of bulk metals in Philippines

The accumulative recycling potentials of aluminum, copper, ferrum, lead, nickel, tin and zinc are 380.60, 1465.52, 579.25, 52.18, 84.18, 138.09 and 38.66 ton from 2010 to 2021, while the accumulative recycling potentials of aluminum, copper, ferrum, lead, nickel, tin and zinc in static state are 202.36, 2102.89, 523.64, 79.28, 127.26, 206.53 and 50.07 ton at the same time, respectively.

4. Conclusion and policy implications

The goal of this work is to evaluate the generation estimation and metals recycling potential of retired mobile phones in Philippines.

The generation estimation is conducted with the sales&new method and statistic data, such as sales of mobile phones and amount of the subscribers. The result shows that there are 18.11 million of mobile phones retired in 2021, compared 6.31 million in 2010. From 2010 to 2021, there are 291.21 million of mobile phones sold and 208.62 million of mobile phones retired, with the weight of 16689.60 tons in Philippines.

Accordingly, the deduced lifetime has minimum and maximum value in 2016 and 2011, which is 4.24 and 27.22 years, compared with 9.02 years in 2021. The crosscheck testifies to the veracity of the result in comparison with the actual condition. The metals recycling potentials and dynamic are also calculated with the content and amount of retired mobile phones.

Based on the results, several policy implications can be made to establish the sustainable management system of retired mobile phones and small WEEE in Philiipines: from the bussniess perspective, the recycling capacity should merge with other WEEE and have no necessary to be independent; from the consumption perspective, the awareness and engagement of the customers should be enhanced.

Data availability

The data presented in this work come from free sources, they are available from the corresponding author on reasonable request.

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Competing Interests

The authors declare no competing interests.

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