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Rethinking residential consumers' behavior in discarding obsolete mobile phones in China

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ABSTRACT

Significant progress has been achieved in China's electronic waste (e-waste) management, since a series of laws and regulations based on extended producer responsibility began to be enforced in 2011. In 2016, China's second batch of e-waste catalogue, which includes the mobile phone, was given priority. This study intended to propose potential approaches for addressing obsolete mobile phones management by examining residents' returning and recycling preferences and awareness in a typical city – Foshan, China, via face-to-face questionnaire surveys. The residents expressed their keen awareness of potential hazards caused by mobile phones and actively supported collection activities. However, 62.1% of residents stored their obsolete mobile phones at home, while only 4.7% of the mobile phones ended up in regulated treatment enterprises. The results indicated that most residents had much higher expectation on benefits from their obsolete mobile phones than their actual value, although only 1/3 of them declared the benefits would hindered their participation in collection activities. The formal collection channels, the convenience of collection facilities and guarantee of information security would also accelerate the collected amount. Additionally, this study investigated the structure of collection system and the relevant flow of mobile phones, and shed light on implications towards future studies and managerial implementation.

1. Introduction

Since 2011, China has been taking action to address issues related to improper management and treatment of electronic waste (e-waste) (Zeng et al., 2013), the fastest growing category in the waste stream (Baldé et al., 2015), and has achieved significant progress with the implementation of the *Administrative Regulation on Recycling and Treatment of Waste Electrical and Electronic Equipment* (the so-called *China WEEE*) and its subsidiary rules. Collection is the fundamental step to ensuring an adequate supply of 'raw materials' for further processing regardless of the methods selected – refurbishing, remanufacturing, or recycling (Golev et al., 2016; van Weelden et al., 2016). However, the environmentally sound management of e-waste in China has been severely hindered due to low resident participation and collection rates. Examining residents' behaviors, preferences, and awareness regarding the disposal, collection, and recycling of obsolete electronic products can be expected to provide suggestions for increasing the collection rate and the efficiency of e-waste processing. Mobile phones (MPs) present a relatively higher ownership per capita than any other category of electronic product (Li et al., 2012), and were listed as a priority for regulation in the second batch of e-waste catalogue in the *China WEEE*, in 2016. Consequently, MPs were selected as the case product for this study.

MPs are rapidly increasing in possession worldwide, including in China. According to officially released data, the global mobile-cellular subscription volume has already reached 7.38 billion units (ITU, 2017a), of which 1.32 billion units (MIIT, 2017b) were in China. Most consumers, furthermore, replace their used MPs in just 1–2 years (Huang et al., 2009; Ongondo and Williams, 2011b): a

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period much shorter than the technical service lifetime of these devices, because of better functionality and newer models, and falling prices of new MPs. Therefore, there is a considerable potential for valuable metal recovery from the waste generated from MPs. In China, for example, the quantity of waste mobile phones (WMPs) is estimated to be 0.35 billion units in 2025, containing about 9 tonnes (t) of gold, 15 t of silver, and 3107 t of copper, as well as other metals (Tan et al., 2017). Extensive studies have been carried out focusing on technologies for metal recycling from components in MPs (Szamalek and Galos, 2016), such as printed circuit boards (Ghosh et al., 2015; Li et al., 2017) and batteries (Guan et al., 2017; He et al., 2017; Meshram et al., 2014), and recovery technology is improving rapidly. As for the collection side of the problem, however, large amounts of MPs are simply retained by residents, rather than recycled, primarily because of their relatively small size (Li et al., 2012; Ylä-Mella et al., 2015). This hoarding of used MPs presents a significant barrier to implementing a circular stock and flow model for MPs, in China (Wilson et al., 2017).

Consumer participation appears to be the most important factor in achieving a good collection rate of e-waste. Regarding residents' e-waste disposal behavior, previous studies suggested that various factors are likely to affect their decisions towards different disposal options, including demographic factors such as age, gender, and educational level, as well as environmental knowledge (Chung and Poon, 1994; Liang and Sharp, 2016; Saphores et al., 2009; Wang et al., 2011). Nnorom et al. (2009) underlined the age as the determinant of willingness to take part in recycling programs, while Liang and Sharp (2016) referred to both gender and age as the significant factors. Bouvier and Wagner (2011) suggested that the amount of computers and televisions collected were negatively correlated with the recycling fees and stated that the distance for consumers' accessibility to collection facilities would not influence the collection rate these two types of e-waste. However, Saphores et al. (2012) decleared the farther the distance was, the less amount of e-waste collected in collection centers. In China, a study conducted by Yin et al. (2014) pointed out that the region of residence and educational level affected consumers' disposal behavior the most.

As for the economic factors affecting e-waste collection, Song et al. (2012), using the logistic regression method, tested residents' willingness to pay (WTP) for recycling in Macau Special Administration Region (Macau SAR), China, and suggested that an amount of 2.50 U.S. dollars (USD) per household per month was acceptable to the residents for their e-waste recycling. Tian et al. (2016) investigated residents' WTP for scrap fluorescent lamp disposal in Beijing, using the contingent value method, and determined an average value of 1.98 CNY (1 CNY = 0.1506 USD) per lamp, that residents would be willing to pay as a collection fee. However, in mainland China, it was stated in previous studies that economic benefit that the consumers could get from the waste was one of the key determinants of choosing disposal methods and channels (Chi et al., 2014; Gu et al., 2016; Li et al., 2012). It was also suggested by a study of the ministries of Economy, Trade and Industry, and of Environment, Japan, that incentives/rewards played an essential role in enhancing the collection rate (Mishima and Nishimura, 2016). However, the barriers to and incentives for residents' participation in collection activities are seldom analyzed when proposing potential measures for stimulating the MP collection rate, even though collection is an essential link in the recycling supply chain. It is necessary to study what steps can be taken to prevent consumers from hoarding their MPs and to determine what incentives and environmentally sound approaches could motivate them to bring their stored MPs to treatment facilities.

In this study, a questionnaire survey via face-to-face interview was adopted to investigate residents' behavior and preferences concerning MP disposal in Foshan city, China. The flow of used MPs in this area was tracked as well. We intended to explore the reasons residents are reluctant to turn in their out-of-use MPs, and the factors that may stimulate their participation in collection activities; to gather information about residents' preferred collection channels; to provide a perspective for MP management through analyzing the progress and effects of China's present e-waste recycling system; and to propose suggestions on current collection schemes and management systems for improving MP collection performance. Meanwhile, the results obtained from this case study of recycling MPs—the most commonly used small electronic device—might also be applied to promote the reclamation of other small e-waste products.

2. Methodology

Foshan city was chosen as a representative medium-sized city in China, from the viewpoint of both economic development and the income levels of its residents. Foshan city is located at the center of Guangdong Province, as presented in Supplementary Material (SM) Fig. S1, with a total area of 3797.72 square kilometers. By the end of 2015, Foshan city had a population of 7.43 million, the per-capita gross domestic product of Foshan city was about 107.7×10^3 CNY, and the per capita disposable income was around 38,000 CNY per year (FMBS, 2017).

The face-to-face interview method, using a pre-designed questionnaire, was adopted in this study. Small-scale pre-investigations were conducted in the campus and the community, for improving the questions, before we carried out the surveys. Residents' behavioral habits for the disposal of their out-of-use MPs and attitudes toward MP collection activities were considered; and their expectations of selling their waste MPs, and preferences in collection infrastructure setting and modes, were investigated. Identifying information, such as residents' demographic characteristics, and MP use and replacement habits, were also collected during the surveys. The details of the questionnaire used in the survey can be found in the SM.

A total of 300 interviews were administered in 2015, and 296 valid interviews were obtained, indicating that the valid proportion obtained was 98.67%. All the interviewers were well trained before we carried out this survey. Respondents were randomly selected in public places, such as supermarkets, parks, shopping centers, streets, and so on, in five districts of Foshan City: Chancheng, Nanhai, Shunde, Sanshui, and Gaoming. The sample size was determined by the method of simple random sampling without replacement, which was the most familiar sampling design had been widely employed in social surveys (Banning et al., 2012; Brewer and Gregoire, 2009). The formula of this method was presented in the SM Equation (1). For the survey on the market for used MPs, the snowball sampling method was adopted, if any of the respondents were willing to introduce other used-MP traders to the interviewers.

The nonparametric statistics method of Chi-square (χ^2) test of independence (or Fisher's exact test when necessary), the Wald-Wolfowitz test, and the Mann-Whitney test were employed to analyze the statistical correlations between variables (Richardson et al., 2015): i.e., factors that may affect residents' disposal behavior. The respondents were divided into groups according to their age, gender, occupation, educational level, and environmental knowledge of MPs. The responses to the questions concerning mainly residents' environmental awareness and behaviors were analyzed in order to investigate differences between the groups.

3. Results and discussion

3.1. Socioeconomic characteristics of residents

According to the socioeconomic characteristics of the respondents (SM Table S1), the mean age was 29.34, and 41.5% of the respondents were male. The majority (42.2%) of the respondents had an associate degree. The average individual income was 5000–7000 CNY/month. Business or services, student rights, and environmental protection were the top three areas of interest and activity that the respondents engaged in most, and these issues were the top priorities of 25.0%, 16.4%, and 14.1% of the respondents, respectively.

3.2. Residential ownership of mobile phones

MPs have a high penetration rate: only one out of the 296 valid respondents (0.3%) declared he/she did not have a mobile phone, and smart phones accounted for a very high proportion: 98.6%. Mobile phones have been shown to be the product with the highest per capita possession of all household appliances (Li et al., 2012). The survey results showed that most (42.6%) of the respondents had one mobile phone, while 39.5% had two, and 17.6% had more than two. The average number of mobile phones a Foshan respondent possessed was more than 1.74 units, which is slightly lower than the projected quantities (1.79 unit per capita) of MPs stockpiled by higher-education students in the U.K. in 2011 (Ongondo and Williams, 2011a). The residents' average ownership number of MPs in Foshan were 1.26, 1.82 and 1.76 times the average number of mobile-cellular subscriptions per capita of Guangdong province, China and the world, where the corresponding figures were 1.38 (GPBS, 2016; MIIT, 2016), 0.96 (MIIT, 2017a), and 0.98 (ITU, 2017b) units per capita, respectively, in 2015.

3.3. Frequency of, and reasons for, mobile phone replacement

According to the Consumer Technology Association, the shortest life expectancy of a mobile phone is 4.7 years (CEA, 2014). The average service lifetime of the respondents' mobile phones in our research, however, was 1.57 years (Fig. 1 (a)): only about 1/3 of a mobile phone's shortest life expectancy. Among the respondents, the majority (55.8%) kept their MPs for 1–2 years, and 19.7% of the respondents changed their spent MPs when the service life reached 2–3 years. A considerable number of residents discarded their MPs in just 0.5–1 year (13.3%), or even in less than 0.5 year (1.7%). It could be observed that there was a significant acceleration in the intervals of consumers replacing their MPs, over time. The average service lifetime of MPs during an investigation by Yin et al. (2014) was suggested to be 2.9 years, and 59.9% of the respondents changed their MPs after 2–3 years, while 57% of the MPs were changed within 2–3 years according to an investigation by Ylä-Mella et al. (2015). The MP is gradually being transformed from a durable consumer good to a fast-moving consumer good, due to rapid updating in functions and MP manufacturers' sales strategy of pushing new MPs to the market every year. In the study conducted by Bai et al. (2018), an average service time of 2.61 of the respondents' mobile phones was proven. The difference between their result and this study could be resulted from the income of residents, meanwhile, electronic and information products manufacturing is also one of the key components of Foshan industry, what would also make the replacement frequency higher than others.

As presented in Fig. 1 (b), there were a variety of reasons for residents' behavior in discarding their used MPs. These factors affected residents' decision either solely or in combination with other factors. The most frequently cited reasons for replacement related both to the functioning of the old MPs (such as frequent malfunctioning, outmoded design and limited functions), and to the capabilities of a new product. More than half (58.4%) of the respondents declared that frequent failures occurred during their daily use, before they replaced their MPs. The reasons "completely destroyed," "unit lost," and "service lifetime exceeded" were cited by 17.2%, 8.1%, and 5.1% of the respondents, respectively, as the reason for their decision to replace their MPs. The poor function was also stated as the reason by around half of consumers as the reason for replacing their MPs in the study by Bai et al. (2018), while

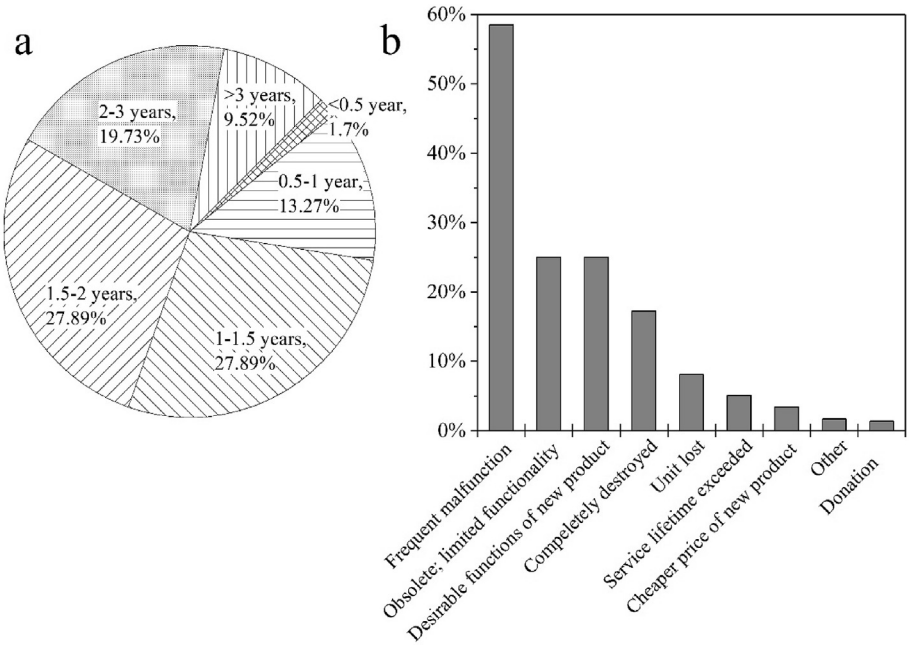

Fig. 1. Residents' MPs replacement behavior: a) replacement frequency, b) reason for replacement (multiple choices).

it was pointed out that 65% of the respondents would stop using their old MPs because of malfunctions and insufficient capabilities for the residents' needs in the study conducted by Li et al. (2012) in Baoding city, China. These proportions also agreed with the results obtained by Ylä-Mella et al. (2015) in the city of Oulu, Finland, where 72% of the respondents would change their old MP when it no longer worked properly, and the novel features of the latest models prompted 32% of respondents to change their MPs.

3.4. Residents' environmental awareness with regard to MPs

3.4.1. Disposal methods for out-of-use MPs

According to the surveys, most of the respondents (62.1%) were keeping their out-of-use MPs at home, unlike their behavior with regard to large household appliances like televisions, computers, and refrigerators: only about 13% of residents kept these large household appliances at home after they had stopped using them (Song et al., 2012). The relatively high storage rate of out-of-use MPs is likely due to a mobile phone's small size, taking up little space in the house. Furthermore, much private information is stored in a MP, especially in smart phones, making the residents more cautious about discarding their out-of-use MPs, and there is limited easily accessible information about where out-of-use MPs can dropped off without concern for the safety of this private information.

In addition to simply keeping their out-of-use MPs at home, 12.7% of the residents donated them to relatives, friends, and charities, where the service lifetime of the MPs could be effectively extended. Another a considerable proportion—8.9% of the respondents—discarded their out-of-use MPs into the regular municipal solid waste trash. The proportion of MPs that were delivered into recycling channels operated by MP producers or treatment enterprises came to only 1.4% and 0.8%, respectively, according to our survey.

There were also significant differences in the storage proportions of out-of-use MPs by country, and even by city. The percentage of users who kept their out-of-use MPs at home reached 85% (Ylä-Mella et al., 2015) in the city of Oulu, Finland, while surveys conducted by Li et al. (2012) in Baoding City, China and by Yin et al. (2014) across all of China found the proportions to be 31% and 47.1%, respectively. A ratio of as high as 79% for consumers' obsolete MPs storage at home was observed by the Bai et al. (2018). These differences may be partially attributed to the different income levels of the residents in the investigated regions. Keeping used MPs at home, however, will to some extent hinder reuse, recycling, and recovery activities, since a certain minimal number of MPs are required for the economical operation of treatment facilities. Hence, changing residents' attitudes toward WMP disposal options is a fundamental requirement for solving the WMP-related environmental issues.

3.4.2. Recognition of used/waste MP hazards, and attitudes toward collection

Encouraging results were obtained in the survey of residents' awareness of environmental hazards related to MPs, and of their attitudes toward collection. The results indicated that around 75% of the respondents knew that WMPs could cause environmental hazards, and also indicated that among this group only 5.1% knew what the specific hazards were, while the remaining 69.7% did not know. The rest of the respondents (25.2%) had no knowledge about whether WMPs could cause environmental hazards.

As for residents' attitudes toward WMP collection activities, around 85% of the respondents expressed support: 41.6% simply supported these activities and 43.2% strongly supported them; 10.8% were neutral to the idea, and 4.4% were opposed.

3.4.3. Differences in levels of environmental awareness, between different groups of residents

We used the Chi-square test to analyze how factors affected attitudes toward WMP recycling and reuse. Since the results of the Chi-square test will be not reliable when more than 20% of the expected values are less than five, some categories of variables were combined to improve the results (Richardson et al., 2015). The reorganized groups are shown in SM Table S2.

Table 1 shows the results of the Chi-square test of independence between demographic factors and other environmental awareness variables, including knowledge of MPs, attitudes toward MP collection activities, and methods of discarding out-of-use MPs. Respondents' knowledge about waste MPs was used as a variable to investigate its impact on residents' attitudes toward collection and their MP disposal behavior.

As can be observed in Table 1, all p-values were higher than 0.05 when the respondents were grouped by gender and age. Clearly, there is no significant difference in environmental awareness among residents of different age groups nor genders, which was different from the results obtained by Liang and Sharp (2016). Both educational level and occupational area, however, did show positive influences on residents' recognition of environmental issues related to waste MPs. Moreover, residents' knowledge about waste MP environmental issues also improved their attitudes toward WMP collection activities, as did educational level: respondents with higher educational levels showed a higher percentage in favor of collection activities. Occupational area, however, showed no statistically significant differences among respondents' collection attitudes.

As for residents' responses to the question concerning methods of discarding their out-of-use MPs, the results suggested that their selection of drop-off methods was independent of any other variables except for occupational area. Those residents who were engaged in environmental protection activities exhibited a statistically significant higher participation percentage in collection activities conducted by producers, maintenance providers, treatment enterprises, and individual collectors, as opposed to storing WMPs at home (Fig. 2). The situation for students fell between these two categories of respondents.

However, although 85% of the respondents expressed their support of MP collection activities, with 41.6% strongly supporting them, it was discouraging to find that only 2.2% of out-of-use MPs were sent into collection channels set by producers and treatment

Table 1
Chi-square test of independence contrast between variables.

Variable A	Variable B	χ^2	*p*-value	Interpretation
Gender	KMH	3.588	0.166	Independent
	ACA	4.923	0.276	Independent
	DWNM	12.678	0.216	Independent
Age	KMH	5.112	0.531	Independent
	ACA	12.194	0.368	Independent
	DWNM	23.206	0.793	Independent
Educational level	KMH	21.785	0	Dependent
	ACA	19.635	0.005	Dependent
	DWNM	24.152	0.172	Independent
Occupational area	KMH	12.237	0.016	Dependent
	ACA	7.678	0.406	Independent
	DWNM	30.186	0.031	Dependent
KMH	ACA	18.266	0.009	Dependent
	DWNM	23.163	0.205	Independent

Note: KMH refers to knowledge about MP hazards; ACA refers to the attitude toward collection activities; DWNM refers to disposal methods for out-of-use MPs. Confidence level is 95% and significance *p* value is 0.05.

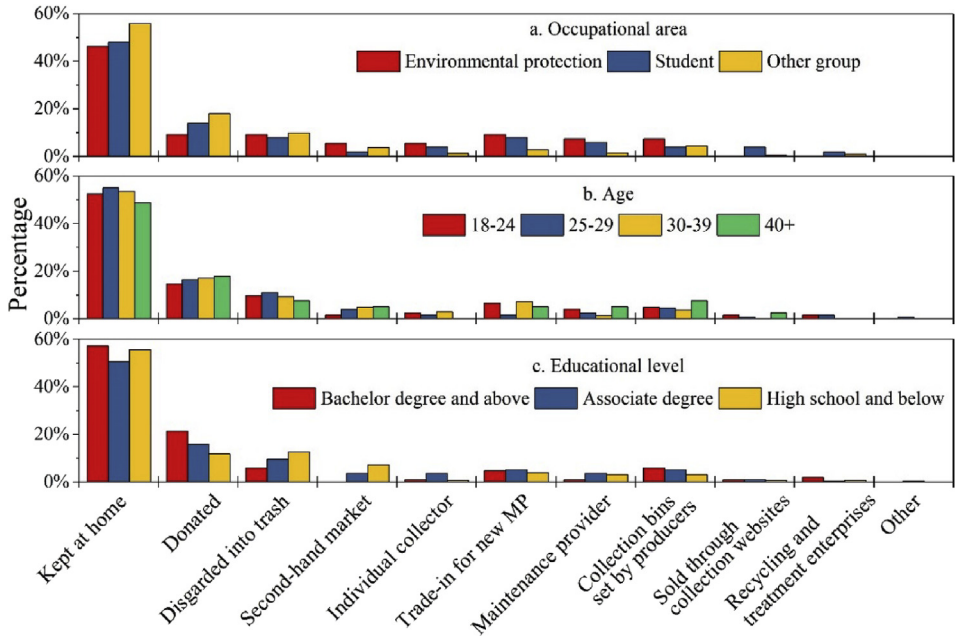

Fig. 2. Differences in disposal methods of out-of-use MPs, by categories of residents: a) occupational area, b) age, c) educational level.

enterprises. Residents' high awareness did not translate effectively into collection behavior.

3.5. Residents' preferences for collection modes

Fig. 3 shows the results of the survey concerning (a) the respondents' expectations of revenue they could collect by selling their broken MPs and (b) their preferences for various collection modes for out-of-use MPs. Regarding the expectations of revenue for selling MPs that were completely non-functional, 52.7% of the respondents expected 30–50 CNY per unit for such MPs—more than ten times the actual average price provided by individual collectors of waste MPs, generally less than 3 CNY per unit. Moreover, 9.5% of the respondents had even requested a price of more than 50 CNY, while only 6.8% of them showed an expectation of less than 10 CNY. The difference between the high expectations of obsolete MPs and the actual collection price was also an important factor leading to a high ratio of MPs stored at home. Regarding the location of collection points, 56.1% of the respondents preferred the 'assigned collection spot' option, followed by 'door-to-door collection' (30.1%) and 'itinerant collectors' (19.9%). The convenience of collection facilities and services were one of the key determinants of residents' willingness to engage in e-waste collection (Chi et al., 2014; Tian et al., 2016): it was pointed out by some respondents that their selection behavior would actually change based on the distance to collection sites. Therefore,

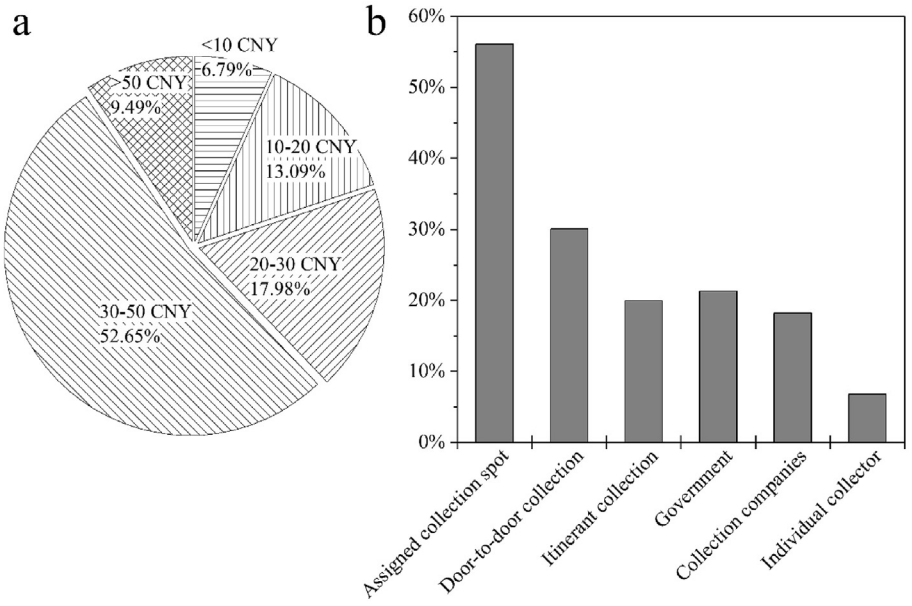

Fig. 3. Residents' preferences for: a) fees for selling non-functional MPs, b) collection mode (multiple choices).

surveys or studies on these related issues, such as the distance from community to collection facility and the frequency of opening, are necessary for collection facilities planning, to improve residents' participation in MP collection. Government-operated facilities were most preferred by residents (21.3%), although 18.2% and 6.8% of the respondents showed their acceptance of facilities run by private enterprises. Therefore, integrating the collection networks for MPs with the existing government-led municipal solid waste collection systems will effectively fulfill residents' expectation and eliminate their concerns. The trade-in method (a discount offered on a new MP) was the residents' favorite mode (53.3%) for their return of out-of-use MPs. The purchase-in and point-redemption methods also showed high acceptance rates: 46.6% and 20.3%, respectively. But the value of these awards is also concerned by the respondents.

Regarding the barriers towards their participation in collection activities, the majority of the respondents (71%) declared that the lack of formal collection channels was the biggest obstacle to returning their out-of-use MPs to collection channels, since there was few collection facility built by government specifically for MPs or e-waste in China and the information security in MPs were highly concerned when the residents drop their obsolete MPs. The 'low public awareness of collection responsibility' and 'insufficient promotion of formal collection' were pointed out by 48% and 42% of the residents, respectively, to be other main factors influence the collection activities. Only about 1/3 of the respondents claimed that the low prices obtainable for their out-of-use MPs were a barrier for their participation in collection activities. However, this was in contradiction with the price they charged and indicated that the residents commonly consider that their out-of-use MPs were still high value goods.

3.6. Collection channels and flow of waste MPs

Presently, a collection system composed of multiple channels and types of collection operators is being encouraged by the *China WEEE*, which aimed to improve the collection efficiency by adopting diversified collection modes. Characteristics of the different types of MP collection operators are summarized in Table 2.

Note: * Most of the MPs from special suppliers were from Hong Kong SAR, and a few of them were from Shenzhen City; other details were not available.

Based on the resident questionnaire survey and the investigation of the various collection operators, a flow chart of used and waste mobile phones in Foshan City was designed and is shown in Fig. 4. It can be easily seen that there were various channels available for residents' MP disposal. Used/waste MPs flowed from small-scale collectors to medium or large-scale collectors. For example, an itinerant peddler usually had a relatively fixed link with a specific large-scale individual collector, who could assure the peddlers' profits from the sale of their collected MPs. There was competition among different collectors; they could send their wares on into different tiers along the MP flow. The peddler, maintenance shop, retailer, communication operator, collection enterprise, and waste collection station could be classified as the first tier, who generally collect MPs directly from residents. The others, including the producer, stationary collection shop, second-hand store, and regulated treatment enterprises could be classified as the second tier, since they collect MPs not only from residents, but also from the first–tier operators. Meanwhile, the regulated treatment enterprises, some of the producers, and the centralized dismantling workshops could also be the final destination of MPs entering the disposal channels.

From the viewpoint of accessibility of the different channels, selling MPs to a peddler was the most convenient option for residents to drop off their MPs into the collection flow, because the peddler posed the most extensive regional coverage among all the collection operators, and even came door-to-door to collect MPs. In addition to the approximately 4% of the MPs directly entered into the collection channel via peddler, almost all the MPs collected by scavengers (9%) would be sold to peddlers. Yin et al. (2014) presented the percentage of MPs thrown away as 7%, similar to the result in this study, while 12% of MPs were collected by peddlers, or went into the second-hand market when a peddler was not available.

An investigation of the second-hand market suggested that the majority of the MPs that entered into the channels via peddlers, maintenance shops, second-hand stores, and collection enterprises would be repaired or refurbished, and they preferred to collect MPs in better functional states, and newer models. The repaired and refurbished MPs were resold to consumers in regions and countries less developed than China, and to consumers in China through second-hand stores, and a small portion were even resold through formal chain stores.

Table 2
Description of key collection operators for MPs.

Collection operator type	Collection method	Advantage
Peddler	Wandering in the street and directly purchasing from residents and scavengers	Convenient for residents; extensive coverage
Maintenance shop; stationary collection shop; second-hand store	Direct purchase from consumers and individual itinerant collectors (or peddlers); acquisition from smaller shops; some special suppliers*	Fixed location to access; relatively extensive coverage
Retailer; communication operator	Direct purchase from residents; collecting from residents through various collection and sales promotion activities	Fixed location to access; choice of methods for dropping off; subsequent flow relatively formal
Producer	Collection from consumers through self-built collection networks and reverse logistics; collaboration with collection enterprises	Security of private information in mobile phone guaranteed to some extent;
Collection enterprise	Website collection; collection from self-built collection facilities; purchase from smaller collection enterprises	Convenient to access; wide range of module types can be collected
Treatment enterprises	Collaboration with producers and collection enterprises; purchase from large-scale collectors; collection from self-built collection network	Guaranteed security of private information in the mobile phone; all categories of MPs included in the collection system; environmentally sound treatment of MPs
Other (Waste collection station)	Collection of MPs along with other waste; extracting MPs from general trash	Fixed location to access

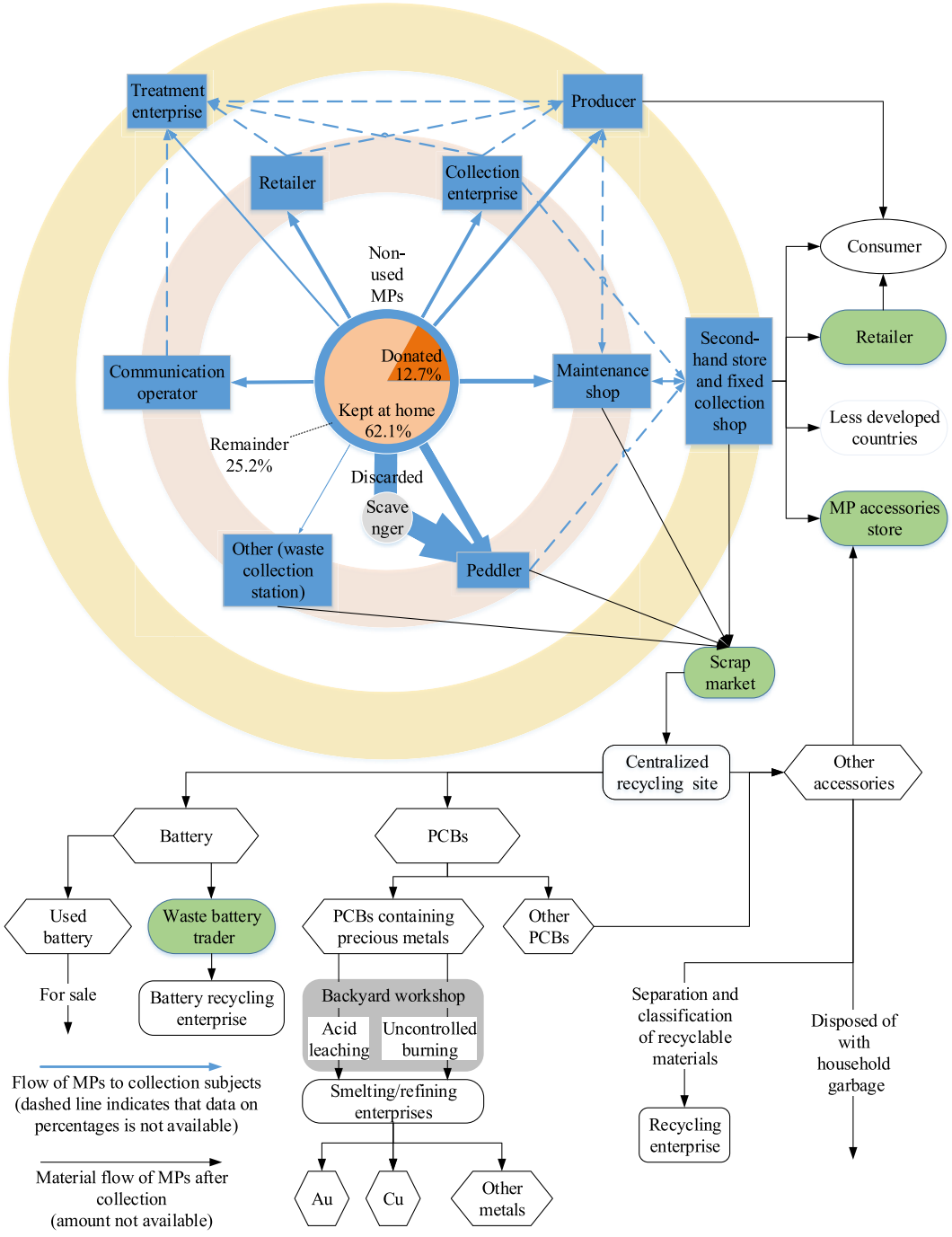

Fig. 4. Flow of out-of-use mobile MPs in Foshan City.

As for MPs that could not be restored to functionality or were completely outdated, the trading market for used/waste electronics played an essential role for the collectors in the first and second tiers, and the dismantling workshops. These MPs would be dismantled manually, and the obtained components would be categorized based on whether they could be reused. Components that could be reused would be sold to MP accessories stores. Plastic casings, metal shells, and waste batteries would be sold to specialized recycling companies. Waste printed circuit boards (PCBs) that contained precious metals such as gold (Au), silver (Ag), palladium (Pd), and platinum (Pt) were sold to recyclers in surrounding cities. The waste PCBs were subjected to uncontrolled burning to obtain the gold-containing residue, or to chemical leaching to produce a gold-containing solution, in concealed areas where monitoring and administrating were difficult, and the residue and solution would be sold to specialized smelting and refining enterprises. Uncontrolled burning and leaching for precious metals causes the most pollution to the environment during the end-of-life stage of MPs.

The amount of MPs ending up in regulated dismantling enterprises was estimated to reach 4.7% if the MPs were collected by retailers, communication operators, maintenance shops, or producers, and these generally flowed into the relevant output channels.

E-waste management policies in China, such as the *China WEEE*, including the subsidiary fund and administrative measures, have significantly accelerated the collection and treatment of regulated e-waste: televisions, refrigerators, washing machines, air conditioners, and personal computers (TRWAC). As presented in Fig. 5, the amount of TRWAC ending up in regulated enterprises had reached 71.4 million units in 2015—about 44% of the TRWAC generated in mainland China in the same year, whereas the dismantled amount and dismantling rate of TRWAC in 2012 were only 0.99 million units and 6.97%, respectively. By comparison, according to the data released by Eurostat (2017) and the United Nations University (Baldé et al., 2015), e-waste officially collected and processed in the 28 member states of the European Union accounted for about 32% of its generation in 2014.

It can be noted in Fig. 5 that the dismantling rate of television peaked at 203.4% in 2014. The amount of waste televisions dismantled in regulated enterprises was more than two times its generation, indicating that the implementation of the *China WEEE* effectively prompted residents to send their out-of-use electronic products that they had stored at home into the official collection channels. At present, MPs have already been included in the second batch of WEEE categories, and an increase in the percentage of MPs processed in regulated enterprises can be expected when the financial subsidies for standardized processing are issued.

The frequency with which MP functions have been upgraded has been accelerating in the last few years, and this functional upgrading was one of the main reasons consumers gave for replacing their MPs, increasing the growth of end-of-life MP generation. It is not surprising, then, that financial compensation has proved to be an effective incentive for turning in out-of-use MPs. One disincentive, however, is the amount of private information stored in an MP. The amount of reported fraud due to the disclosure of private information from the sales of spent MPs has increased in recent years, making residents more cautious about the handling of their out-of-use MPs. Therefore, educating consumers about the safety of private information in used phones processed in regulated enterprises could also promote residents' willingness to send their MPs to the formal processing sector.

Actually, after the implementation of the *China WEEE*, the management of E-waste in China has shown significant progress. In fact, the survey in this study showed that the security of private information in MPs is a significant concern for residents, when they chose a method for MP disposal. The percentage of computers—which are similar to the MP in terms of the character of private information—ending up in regulated enterprises, increased from 0.8% in 2012 to 21.7% in 2015. Clearly, there is a huge potential for processing MPs currently stored in private homes. Propaganda and publicity on MP treatment in regulated facilities in China, especially in regard to private information safety and environmental protection during the treatment process, could be expected to improve the rate of MP recycling. Further, adjustments to the current e-waste management system to reward consumers for returning e-waste, and improvements in municipal infrastructure and departments to facilitate the collection of small WEEE, could help to foster residents' recycling habits and contribute to achieving a more sustainable society.

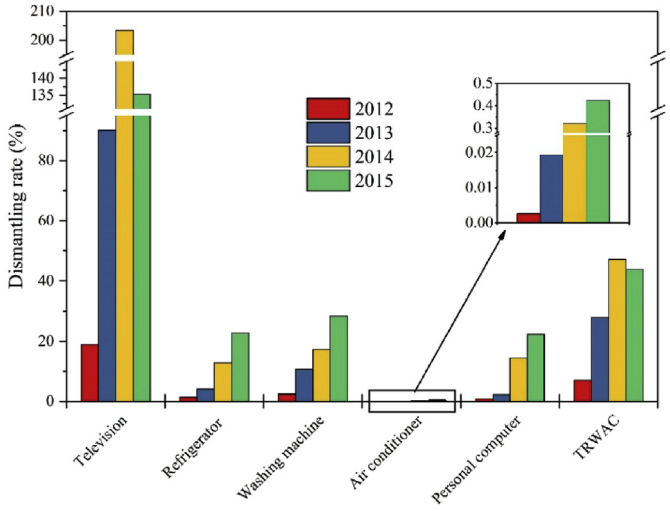

Fig. 5. Progress of e-waste dismantling in China. Note: source for dismantled amounts – MEP; sources for e-waste generation: (Duan et al., 2016; Li et al., 2015; Zeng et al., 2016).

4. Conclusion

Many e-waste issues have arisen with the rapid growth in economic and technological development, and the amount of obsolete MPs, especially, has increased explosively. MPs have a high per-capita ownership of 1.74 units in Foshan city, and the average service lifetime of an MP is short: only 1.57 years. Residents' environmental awareness about WMPs sound management has been accelerated significantly with the implementation of legislations and the progress that China has achieved on e-waste collection and recycling. There is no statistically significant difference observed on their environmental awareness among different age group and gender. However, residents' high awareness did not translate effectively into collection behavior. Less than 5% of WMPs end up in regulated treatment enterprises, in spite of residents' relatively high recognition of the hazards of obsolete MPs and their support of MP collection activities, while the majority (62%) of MPs were shown to be stored at home—a significant barrier to their efficient recovery and the circular supply chain.

Admittedly, the lack of formal collection channels was the most frequently cited barrier for residents to returning MPs, largely because of the information-safety issue. The operator that shows the highest ability to guarantee information-safety will gain the most trust from residents and have an advantage in conducting collection activities. Whereas residents showed the highest preference for assigned collection spots and the government as the operator, integration of MPs collection networks with the existing government-led municipal solid waste collection systems will effectively fulfill residents' expectation and eliminate their concerns. Improving the convenience and accessibility of collection facilities, especially the assigned collection spots, is a promising approach to increase the collection amount.

Although the low price provided by collectors is claimed thirdly after the low public awareness of collection responsibility and the insufficient promotion of formal collection as a barrier hindering residents' participation in collection activity. The majority of them (>90%) have posed times much higher expectation than the actual price for their out-of-use MPs, meanwhile the trade-in by cash is their most favorite method. Therefore, the design of incentives, and credits and value of awards should be combined into the study on collection scheme and network planning and establishment.

In summary, the establishment of convenient and diverse take-back locations by the government, with incentives to residents, is expected to translate their awareness into actual collection practice. Such a system could also be used for the collection of small-sized e-waste similar to MPs, and an acceleration in the collection rate could be achieved by reforming residents' turn-in habits. The methods for characterizing consumers' behavior and the findings in this study could be beneficial to promote the collection rate and

support an extended producer responsibility policy implementation in China and beyond.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2018.05.244.

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