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How to recycle the small waste household appliances in China? A revenue-expenditure analysis

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ABSTRACT

Along with rising household incomes and living standards globally, quantities of high-value small waste household appliances (SWHAs) that generate highly detrimental e-waste are rapidly burgeoning each year. Currently, China's regulations and policies related to Waste Electrical and Electronic Equipment (WEEE) cover just five types of large-scale appliances. Thus, the country's resource recovery industry remains undeveloped, because of the lack of practical experience of SWHAs recycling and associated policies. For this study, we developed a revenue-expenditure analytical model using five illustrative types of SWHAs to calculate the total expenditures and revenues of SWHAs recycling. Subsequently, we analyzed the recycling potential of SWHAs under different collection scenarios after incorporating subsidies and tax reductions. The results indicated that in the absence of economic policies, recycling enterprises demonstrated a perpetual deficit regardless of who took the lead in e-waste collection. Tax reductions, alone, were insufficient for reducing the total expenditures. Consequently, alternative strategies introduced by recycling enterprises were considered necessary. Under different scenarios of producer-led, government-led, and recycling enterprise-led collection, the subsidies required for recycling industries ranged between 472 and 927 million dollars. Sensitivity analysis revealed that material prices and collection quantities were positively correlated with net profit (*NP*), indicating that the government should consider subsidizing enterprises from the outset to ensure their viability. When the scale of collection expanded sufficiently, government subsidies were no longer required and enterprises were able to operate autonomously.

1. Introduction

Waste Electrical and Electronic Equipment (WEEE) constitutes one of the most important waste streams globally (Li, 2017). Based on the composition, volume and socio-economic characteristics of e-waste, WEEE can be broadly categorized into the following two types (Tomása et al., 2017): (1) large waste household appliances (LWHAs), which is called high-load appliances. In line with the *WEEE Treatment Catalogue* (2011) issued by the Chinese government (The State Council, 2009), we assigned television sets, refrigerators, washing machines, air conditioners, and computers to the LWHAs category; (2) small waste household appliances (SWHAs), which is low-load appliances with complex components (Yin, 2014).

Along with rising household incomes and living standards, globally, the use of SWHAs is widespread, especially in China (Yin et al., 2014). Consequently, there has been an explosive growth in SWHAs. While the collection rate of SWHAs is extremely low. For example, by the end of 2016, there were up to 1.32 billion mobile phone users in China, with the penetration rate reaching 96.2% (MIIT, 2017). However, the service life of mobile phones is less than 3 years (Yin et al., 2014). Consequently, almost 77 million units of waste mobile phones are generated annually in China (Bian et al., 2016). Of these units, only 28.1% are recycled in various ways, with less than 9% being recycled by authorized enterprises (Yin et al., 2014). Improper landfill, burning, or disposal procedures applied to e-waste pose serious potential hazards to the ecological environment and to human health (Wang and Xu, 2015; Yadav et al., 2014; Hibbert and Ogunseitan, 2014; Tsydenova and Bengtsson, 2011). Conversely, WEEE is subject to "Urban Mining" due

Abbreviations: WEEE, Waste Electrical and Electronic Equipment; LWHAs, large waste household appliances; SWHAs, small waste household appliances; LCA, Life Cycle Assessment; MFA, Material Flow Analysis; MCA, Multi Criteria Analysis; EPR, Extended Producer Responsibility; EU, European Union; MP, mobile phone; TS, telephone set; MC, microcomputer; PT, printer; FM, fax machine; GLC, Government-led Collection; PLC, Producer-led Collection; RELC, Recycling Enterprise-led Collection; NP, net profit; ROI, return on investment

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to containing significant amounts of precious metals and non-metallic materials (Li, 2017), which is more cost-effective than virgin mining (Zeng et al., 2018).

In 2011, the Chinese government introduced *The Chinese Management Regulation for WEEE Recycling and Disposal* (The State Council, 2009), which can be viewed as a Chinese WEEE Directive. In March 2016, the government updated the *WEEE Treatment Catalogue* (NDRC, 2015), adding nine other types of WEEE to the catalogue. Consequently, appropriate recycling WEEE is thus of vital importance in the development of China's ecological civilization.

2. Literature review

With increasing e-waste tonnages, recycle and disposal are the effective ways to solve environmental problem. Numerous previous studies about WEEE have been conducted on the reverse logistics network design to optimize collection sites and transportation routes (Ayvaz et al., 2015; Kilic et al., 2015). Several scholars have conducted in-depth investigations of recycling technologies aimed at the efficient recovery of precious metals from e-waste (Yang et al., 2017; Lu and Xu, 2016; Wang et al., 2016; Ebin and Isik, 2016; Bachér et al., 2015; Bas et al., 2014; Natarajan and Ting, 2014; Yang et al., 2014; Lister et al., 2014; Matsumoto and Oshima, 2014; Gurung et al., 2013; Watling, 2013).

Many studies have shown that sustainable management on e-waste played one of the most important roles in e-waste recycling. Wang et al (2018) created an evaluation framework to analyze and evaluate the effects of the implementation of Fund policy for subsidizing WEEE dismantling in China. Awasthi and Li (2017) proposed that environmentally sound management of WEEE is a critical problem by comparing the current regulations and recycling practices electronic waste in China and India. Based on an analysis of the legislation and recycling practices of e-waste in India. Pathak et al (2017) put forward several steps towards sustainable management of WEEE in India. Yu et al (2014) reviewed the development of WEEE management in China and discussed the effectiveness of existing policies related to WEEE. In addition, several tools have been developed and applied to e-waste management including: Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA) and Extended Producer Responsibility (EPR) (Kiddee et al., 2013). Consequently, many scholars examined the sustainable management of e-waste from economic, social and environmental perspectives (González et al., 2017; Zubiani et al., 2017; De Oliveira Neto et al., 2017; Bian et al., 2016; Cucchiella et al., 2016; Biganzoli et al., 2015; Wäger and Hischier, 2015; Zink et al., 2014).

In order to support the development of e-waste recycling, many scholars pay great attention to economic matter, with using parametric and non-parametric methods (Simões and Marques, 2012). Awasthi et al. (2018) revealed a strong linear correlation among global e-waste generation and GDP. The conclusion proposed that a discounted cash flow analysis or a life cycle economic assessments would become fundamental for any kind of investment decision or market analysis. Using a television set as an illustrative example, Li et al. (2016) developed a comprehensive revenue-expenditure model (REM) for evaluating the costs and revenue possibilities associated with the WEEE recycling process. Cruz et al. (2014) applied an economic-financial model to Portugal, France and Romania to assess whether the net costs of the packaging waste recycling system were being covered by the industry and to find out who was paying for the incremental costs of recycling. Achillas et al. (2013) developed a cost-benefit model for analyzing the degree of disassembly of a specific product from an economic perspective aimed at maximizing profitability or minimizing end-of-life management costs. Blaser and Schluep (2012) examined the economic feasibility of the entire treatment process, including collection, recycling, and refurbishment at a WEEE treatment facility in Tanzania. Alwaeli (2011) proposed a research framework incorporating key economic factors affecting resource recycling, with the aim of analyzing the benefits of recycling enterprises and determining how to maximize them. Gregory and Kirchain (2008) developed a framework to assess the economic performance of recycling systems, using different operating models to pre-test the framework. Nakamura and Kondo (2006) applied life cycle costs to calculate the total costs of different processes for handling waste household appliances. Their results indicated that recycling entailed the highest cost, whereas the landfill cost was the lowest.

Researches on e-waste recycling are abundant and in-depth. However, more studies have investigated the recycling potential of WEEE from the perspective of resource and environment, less from the perspective of operators. There were very few analysis and research on SWHAs in China. Consequently, there is a necessity to evaluate the recycling potential of SWHAs given its high penetration rate and high elimination rate from the perspective of operators.

Therefore, this study developed an analytical framework to explore the recycling potential of SWHAs in China from the perspective of operators. A revenue-expenditure analytical model was developed to quantify the economic expenditures and revenues of the recycling process, and three different collection scenarios were formulated for analyzing recycling feasibility when subsidies and tax reductions were applied. Here we took the expenditures, including seven costs (material procurement, depreciation and amortization, equipment, waste disposal, logistics, fuel and power, taxes) and one fee (labor) and revenues (the sales of recycled materials, including metals and non-metallic materials) into the research framework. The results provide technical guidance for economic policymaking in China. Moreover, the study's framework and guidelines for recycling SWHAs within large-scale processes can benefit other developing countries.

3. Materials and methods

3.1. System boundaries

System boundaries were established, encompassing the entire process of SWHAs recycling, commencing with the first stage of collecting the SWHAs from consumers and culminating in the last stage of selling recycled materials and waste disposal. Generally, three main processes occur within the system boundaries: collection, transportation, and treatment. This study was designed from an economic policy oriented perspective. Hence, we excluded environmental and social benefits, focusing mainly on the direct economic expenditures and revenues of the entire process. We consulted existing international legislative frameworks used to classifying types of e-waste, namely *The Directive on waste electrical and electronic equipment (2012)* in the European Union (EU) and Japan's *Promotion of Recycling of Small Waste Electrical and Electronic Equipment Law (2012)*. In conjunction with SWHAs' usage frequencies in China, we considered five types of SWHAs: mobile phone (MP), telephone set (TS), microcomputer (MC), printer (PT), fax machine (FM). Fig. 1 depicts the system boundaries.

3.2. Scenario building

Responsibility for e-waste collection may lie with different parties. In Japan, consumers are required to deposit their large-sized e-waste at specific sites themselves and to bear all of the recycling costs (Lin et al., 2014). However, SWHAs are collected by the local government and subsequently sent to the recycling enterprise. Thus, consumers are not charged for recycling small-sized e-waste; they just need to send their e-waste to specific sites (Wang, 2015). In Germany, electronics producers are responsible for recycling 10 e-products listed in the EU Directive (Xiang et al., 2014). In China, with the advance of Internet technology, some recycling enterprises are spontaneously collecting e-waste online and offline (Song et al., 2017). Moreover, different parties have different recycling responsibilities. Based on the above information, three

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