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Exploring "Internet+Recycling": Mass balance and life cycle assessment of a waste management system associated with a mobile application

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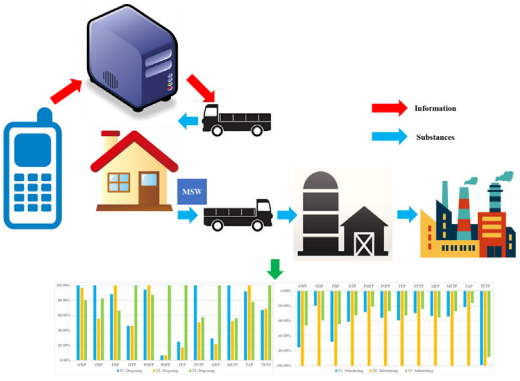
HIGHLIGHTS

- Environmental performance of "Internet+Recycling" is assessed via a case study.
- Environmental burdens are associated with the final disposal procedures.
- The recovery of metals gives the most significant environmental benefits.
- Remanufacturing is not necessarily ensuring a good environmental performance.
- Increasing the volume of collected waste mobile phones is highly beneficial.

GRAPHICAL ABSTRACT



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ABSTRACT

Individual users cannot readily access the collection channels is a persistent problem in municipal solid waste (MSW) management, resulting in low MSW collection rates. A new waste management model, "Internet +Recycling", has come into being; this model enables individuals to arrange collection appointment through various online platforms, then the collectors pick up the waste on-site. It is believed that "Internet+Recycling" can be a solution to mitigate the collection barrier in MSW management, as it provides individuals a convenient access to formal waste management systems. However, whether this emerging MSW collection model would bring environmental benefits is yet unknown. We here quantitatively examine the mass balance and environmental performance of MSW recycling associated with the use of such a "Internet+Recycling" mobile application - *Aibolv*. All transactions occurred on the mobile application within a period of six monthare included, and all related activities are modeled using the methodology that combines material flow analysis (MFA) and life cycle assessment (LCA). According to the extant MSW management legislation in China, we classify the collected MSW into three categories, subsidized waste electric and electronic equipment (WEEE) like television and refrigerator – T1, unsubsidized WEEE like mobile phone – T2, and other recyclables like paper and fabric – T3. The MFA results show that plastics and common metals are the dominate secondary material streams, and glass, precious metals and battery metals are mainly recovered from WEEE. The LCA results indicate that the disposal of the T2 waste has the highest environmental savings, due to the recovery of precious metals. Increased remanufacturing rates impart negative impacts, while increments in the quantity of spent mobile phones could significantly

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improve overall environmental performance. Based on the acquired results, recommendations are provided for facilitating the future development of "Internet+Recycling", and limitations of this work are identified as well.

1. Introduction

Recycling of municipal solid waste (MSW) promotes sustainability and long-term well-being, through closing material loops and reducing environmental pollutions and human hazards. Recognizing the importance and urgency, rigorous legislations have been proposed to propel recycling of MSW. For example, extended producer responsibility (EPR), "a policy measure that recognizes the producer's role in reducing the impacts of their product throughout its entire lifecycle, including Design for Environment (DfE) and waste management at end-of-life" (Mckerlie et al., 2006), has been implemented in Europe (Gottberg et al., 2006; Niza et al., 2014; Richter and Koppejan, 2016), North America (Mckerlie et al., 2006; Hickle, 2013), Asia (Awasthi and Li, 2017), and Pacific region (Lodhia et al., 2017). However, there is a persistent problem of low collection rate, compromising the effectiveness of these legislations (Gu et al., 2017a; Hahladakis et al., 2018a). Although people generally express their willingness towards recycling (Echegaray and Hansstein, 2017; Gu et al., 2017b; Sun et al., 2015), a great amount of MSW, particularly the waste electric and electronic equipment (WEEE), still remains in idle, endangering the sustainable development of relevant industries. For example, low recycling rate of lithium-ion batteries intensifies the supply and demand of lithium (Zeng and Li, 2013) and cobalt (Zeng and Li, 2015), and hence could hinder the future development of electric vehicle industry and consumer electronic industry.

According to the previous investigations (Yin et al., 2014; Sun et al., 2015; Gu et al., 2017b), one of the major causes in the collection problem is that there are only few recycling channels accessible to individual users, particularly for the waste that is not included in the official collection list, such as waste mobile phones (WMP). A possible route to provide accessible channels to individuals is to use information technology for the sake of facilitating the communication between recycling practitioners and general population (Gu et al., 2017a). From this perspective, "Internet+Recycling", a new business model for urban waste management has come into being. In essence, "Internet +Recycling" is based on some online platforms, where participants, both individuals and recycling practitioners, make appointments for on-site waste collection or trading. This model is gaining an increasing popularity due to its convenience and availability (Gu et al., 2017b; Tong et al., 2018; Zlamparet et al., 2018), for anyone can register an account on such platforms and then strike a bargain. Yet, apart from the descriptions regarding the operational models (Sun et al., 2018; Tong et al., 2018; Wang et al., 2018), there is little available knowledge about this emerging recycling model, especially in terms of its environmental performance.

To address this knowledge gap, in this paper we present and discuss the results of a study that thoroughly investigated the life cycle environmental impacts associated with the activities of MSW disposal occurred on a "Internet+Recycling" mobile application, namely *Aibolv*. In essence, this mobile application is a WeChat applet, or mini program, a type of applications that developed inside WeChat, one of the world's most popular social networking application which has over 963 million monthly active users (Statista, 2018a). The application is designed specifically for MSW recycling, on the basis of a peer-to-peer (P2P) mechanism; individual users place requests of disposing their wastes on the mobile application, then the nearby dealers are dispatched to collect MSW onsite. The collected MSW is shipped to the warehouses (licensed dismantling sites) for a brief inspection and then dismantled; some of them are sold to second-hand good dealers for remanufacturing, while the majority are transported to licensed disposers in accordance to the nature of constituting materials of disassembled components, i.e., plastics for plastic disposers, metals for smelters. Formally launched on the early 2017, the *Aibolv* application now has over 7000 monthly active users, and every day there are about 75 new users registered. This mobile application not only provides individuals a convenient option for disposal of their MSW, but also offers informal recycling practitioners, e.g., peddlers, a chance of being integrated into the formal network of MSW management; for anyone can register an account in the application. According to the CEO and operation manager of *Aibolv* – Mr. Baitong Tang, most of the MSW collectors use the mobile application are originally peddlers and scrap dealers, the regulation of whom is supposed to be almost impossible (Orlins and Guan, 2016; Gu et al., 2017b). It has been speculated that integrating formal and informal sectors is a possible solution to the environmental, health and social problems that arise from informal recycling, where information systems are supposed to play a key role (Fei et al., 2016; Gu et al., 2017a). Currently, the "Internet+Recycling" activities that related to the use of the *Aibolv* application have taken places in over a dozen of cities in China, including major cities such as Shenzhen, Tianjing, Chongqing, Shenyang and Dalian. It worth noting that the transactions occurred on this application only represent a very tiny percentage of MSW, thus the waste management system based on the mobile application is not equivalent to the conventional MSW management systems (Rigamonti et al., 2010; Biganzoli et al., 2015; Ripa et al., 2017), which cover most of the MSW management activities the entire regions. Quantitatively examining the environmental performance of "Internet+Recycling", in this case, the operations of the *Aibolv* application, is a highly desirable task, which provides valuable insights to improve current MSW management.

On the basis of an exhaustive collection of primary data, we analyze material flows of the MSW recycling processes that linked to the use of this mobile application; the potential environmental benefits and burdens of relevant activities are then evaluated using a combined material flow analysis (MFA) and life cycle assessment (LCA) methodology. In China, some WEEE are subsidized to facilitate their collection, including television (TV, both cathode ray tube, CRT and liquid crystal display, LCD, 85 RMB per unit), refrigerator (RF, 80 RMB per unit), laundry machine (LM, 35 RMB per unit), air conditioner (AC, 35 RMB per unit), and personal computer (PC, mainly desktop PC, or DPC, 85 RMB per unit), and waste collectors tend to focus on these pieces of WEEE (Gu et al., 2017b). The government uses part of taxes from electric and electronic equipment (EEE) sales to subsidize the collection of this officially listed WEEE (Zeng et al., 2017a). Although the subsidy system is effective in promoting the collection rates of the WEEE on the list, the other types of WEEE are generally being neglected (Gu et al., 2017b). Besides, the subsidy system is not self-sustainable, as the expenditure outnumbers the income (Zeng et al., 2017a). To demonstrate the benefits of "Internet+Recycling", we hereby classify the collected MSW into three categories: (1) T1, subsidized WEEE, such as TV, RF, LM, AC and DPC[1], (2) T2, unsubsidized WEEE, such as laptop PC (LPC)[2], WMP, small appliances (SA) and batteries (B), and (3) T3, other MSW, such as plastic solid waste (PSW), wastepaper (WP), scrapped metals (SM), kitchen tools (KT) and spent textiles (ST). There are two goals proposed in this work:

[1] According to the transactions in *Aibolv*, only LCD DPCs are collected.
[2] In this study, tablets are also assigned to this category.