Life Cycle Assessment of Waste Mobile Phone Recycling–A Case Study in China

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Abstract. With the rapid pace of technological development, electronic waste (e-waste) has become one of the fastest growing waste streams in the world. The exponential growth of e-waste, which is disposed of in landfills, incinerated, or dismantled, now significantly contributes to the massive increase in overall waste. This paper assesses the waste produced from recycling mobile phones in China and examines the influence of the waste that is released into the environment. The mobile phone recycling process at formal recycling facilities in China is investigated as a case study. The results highlight the toxicity of the waste and the influence such waste has had on the environment. Life cycle assessment (LCA) was employed to analyze the mobile phone recycling process and Gabi was used to quantitatively indicate the flows and environmental impacts. The results showed that resources recovery, human health, and ecosystem quality are the main effects of the mobile phone recycling waste produced. Based on this quantitative analysis, to reduce the environmental impact of mobile phone recycling, the demand for recycled materials, environmental awareness, law enforcement, and the e-waste recycling system were found to be significant drivers.

Keywords: Waste mobile phone · Life cycle assessment · Recycling

1 Introduction

Electronic waste, also known as e-waste, has been one of the major contributors to the waste stream since the rapid growth of advanced technological products [6]. E-waste includes waste electrical and electronic products such as televisions, desktop computers, microwaves and mobile phones. In recent years, economic and technological development in China has seen as massive growth in mobile phone penetration and a consequent rise in mobile phone waste.

Currently over 40 million tonnes of e-waste is generated annually in the world and is growing every year. Of all the kinds of e-waste, the growth in mobile phone waste has been three times faster than total annual waste [19]. Current mobile phone using data indicates that there are 7.2 billion active mobile phones in 2016, with over 1.305 billion of these being in China, a penetration rate of 93.1%

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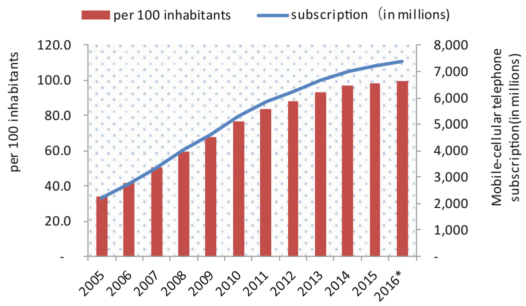

Fig. 1. Global mobile-cellular subscriptions, total and per 100 inhabitants, 2005–2016. Note: * Estimate

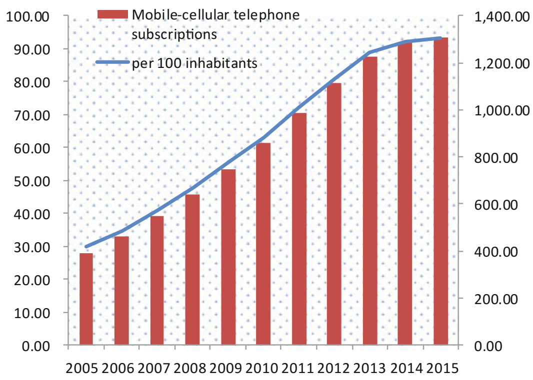

Fig. 2. China mobile-cellular subscriptions, total and per 100 inhabitants, 2005–2015

(see Figs. 1 and 2) [25]. About 77 million mobile phones are discarded every year in China, a figure the United Nations environmental program has predicted to be 7 times higher by 2020 [11].

The growing quantity of e-waste has begun to have a severe impact on the environment; especially in developing countries. As the leading manufacturing country of the world, China has become an "electronic waste treatment plant", with informal mobile phone recycling having become a major source of toxic pollution [13]. With rising climate change and water and land pollution concerns, mobile phone recycling waste has attracted increasing attention, forcing the mobile phone production industry to find solutions to decrease the environmental impact. In addition, various methods have been developed for mobile phone recycling to reduce the environmental damage. There has been a growing body of research into the recycling of waste mobile phones in China and the inherent problems. Wang et al. evaluated the potential yield of indium recycled from waste mobile phones in China [21], and Yi-Bo et al. and several others have examined the recovery and recycling of old mobile phones in China [23], and the other scholars did [4].

The main methods that have been applied to waste management analysis are data envelopment analysis(DEA) [2], the index decomposition analysis method(IDA) [12], and the structure decomposition analysis method (SDA) [1]. Life Cycle Assessment (LCA) was first used in 1969 when the Midwest Research Institute tracked and quantitatively analyzed the complete process of beverage containers from raw materials extraction to final disposal [3]. With development, the LCA has been included in the ISO14000 series of environmental management standards and has become an important support tool for international environmental management and product design [8]. LCA has been widely used in environmental assessments in such areas as food waste management [14], waste water [18], and plastic production as well as in waste electrical and electronic equipment (WEEE) management [10].

As an environmental management tool, LCA has expanded the boundaries of research systems, as it encompasses the entire life cycle of resource use, energy consumption and waste discharge and provides an evaluation of the potential environmental impact at each stage. This paper assesses the recycling of waste mobile phones in China using LCA. To date, analyses of the environmental impact of recycling waste mobile phones has lacked a systematic and scientific focus and has tended to ignore the management of discarded mobile phones [15]. In this paper, the life cycle assessment of the discarded mobile phone recycling process is quantitatively evaluated to identify the main factors influencing the environment and provide decision support for the waste management of other small electronic devices.

The remainder of this paper is structured as follows. In Sect. 2, the current recycling process in China is outlined, an abandoned mobile phone path analysis is conducted, and the latest recycling process explained. Section 3 applies the LCA to the mobile phone recycling process and gives the results. Section 4 gives suggestions and recommendations based on the analyses.

2 Mobile Phone Recycling in China

2.1 Recycling Status

China has had a rapid growth in e-waste streams over the past ten years [11], with mobile phone waste being the most rapidly growing. Because there has not been a regimented recycling system established in China, most waste mobile phones are kept, donated to others or discarded with other house-hold waste; the formal recovery rate has been only about 1% [25]. The recycling of batteries and other waste mobile phones parts has mainly been conducted through nonprofessional channels such as street vendors or small electronics shops or through recycling platforms on the internet. After recovery, refurbished mobile phones are generally sold in a second-hand market or sold at a low price in remote towns and villages. Mobile phones that cannot be refurbished often end up in illegal dismantling workshops, where workers extract the copper, gold, silver and other valuable metals using such processes such as acid leaching and open burning, processes which not only damage the health of workers but also severely pollute the surrounding environment.

From a product to waste, a mobile phone can change hands hundreds of times; they can be retained by consumers, returned to a retailer, sold to a second-hand shop or sent to recycling. The specific circulation paths are shown in Fig. 3.

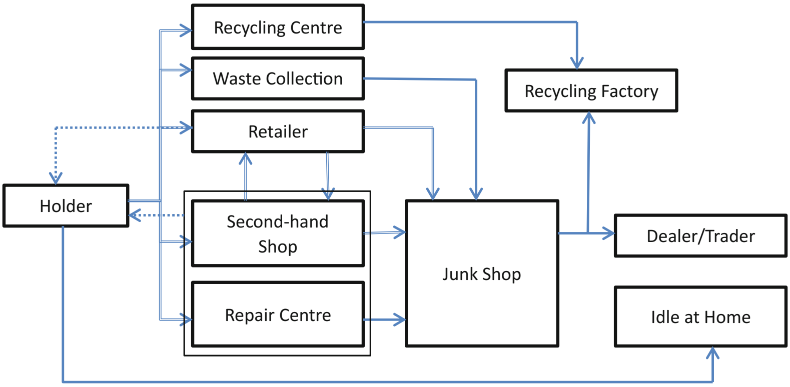

Fig. 3. The flow of waste mobile phones in China

2.2 Recycling Mode

This paper evaluates the pollution produced in the recycling phase from the perspective of material flows using the standard life cycle assessment method, examines the waste mobile phone recycling process in formal recycling facilities in China as a practical case study (see Fig. 4) and identifies the factors that adversely impact the environment in the recycling phase.

The brief description of the recycling process is as follows: after being transported to the waste treatment plant, the mobile phones are manually disassembled and the phone casings, printed circuit boards, lithium batteries, LCD screens and other main components extracted. Then, each of these components is processed separately. The ABS/PC plastic casings are crushed into plastic pellets then reused as raw materials, the stainless steel, copper and other metals are melted, with a further smelting processing step needed for the printed circuit boards and lithium ion batteries (recovery of electrolyte solvent) to recover the copper, gold, silver, palladium, cobalt, lithium, tin and other metals. LCD displays are generally incinerated to reduce environmental waste and the remaining residues are put into landfill.

Mentioned in the process: (1) the life cycle of the mobile phone at each stage from production, use, and disposal including the transportation of the various materials; however, the transportation and landfill residue stage after disassembly are not taken into account. (2) only lithium ion scrap mobile phone batteries and mobile phone LCD displays are considered.

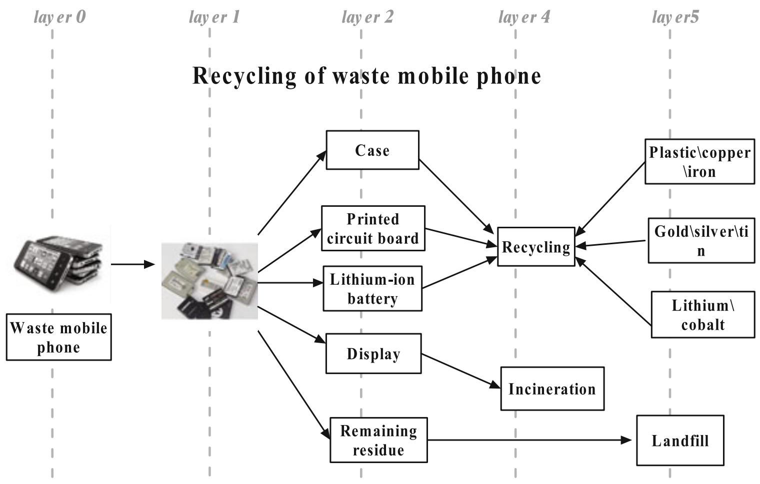

Fig. 4. Recycling process

3 LCA on Recycling Waste Mobile Phone

The LCA has four interrelated steps, which we applied to the mobile phone recycling process, the rough contents for which are shown in Fig. 5.

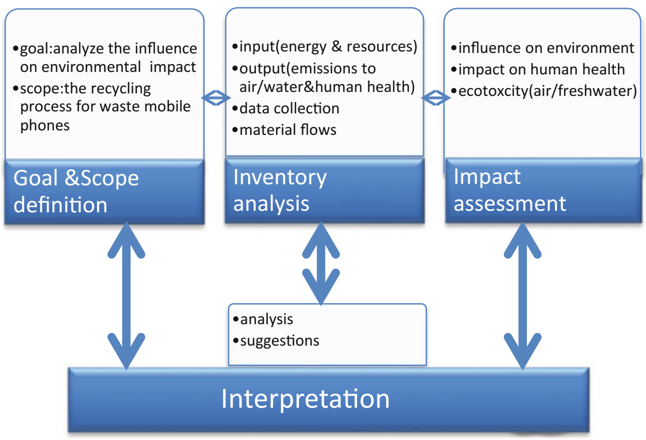

Fig. 5. Detailed content of the four steps

3.1 Goal and Scope Definition

The study object in this paper is the abandoned mobile phone. The functional unit is set to a tonne of phones of various brands and models, with the data for each component being set at an average value. The study scope for the system

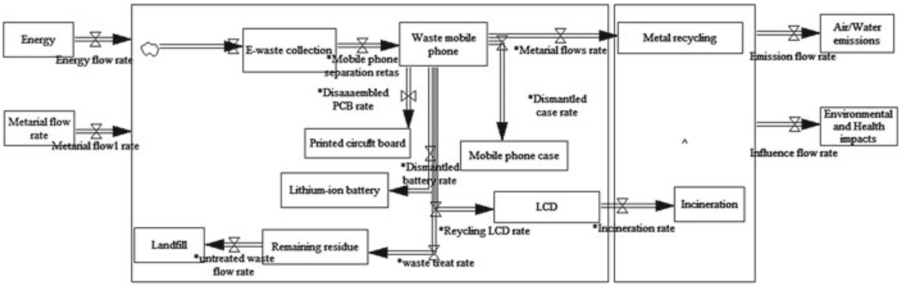

Fig. 6. Flows at a formal recycling facility

is set for disassembly, waste collection, sorting, processing and final disposal (Fig. 6) and an inventory analysis and impact assessment for the energy and resource consumption and pollutant emissions at each stage is established.

3.2 Inventory Analysis

From relevant research data regarding domestic and foreign waste mobile phone processing and combined with the Chinese current waste recycling, the main process inventory data related to the recycling process was determined (see Table 1). The data in this paper was taken from the ecoinvent database [7];

Table 1. Inventory analysis

Process flow	Inventory data
Disassembly	GLO: manual treatment plant, WEEE scrap [Recycling] = 2500 tone/yr. GLO: mechanical treatment plant, WEEE scrap [Recycling]/GIO/IU = 50,000 tone/yr
Plastic recycling	GLO: manual treatment plant, WEEE scrap [Recycling] = 2500 tone/yr
Iron metal	RER: steel, electric, un- and low-alloyed, at plant [Beneficiation]
Metal	SE: copper, secondary, from electronic and electric scrap recycling, at refinery [Beneficiation]
Printed Circuit Boards (PCBs)	GLO: disposal, treatment of printed wiring boards [Recycling] SE: gold, secondary, at precious metal refinery [Beneficiation] SE: silver, secondary, at precious metal refinery [Beneficiation] SE: palladium, secondary, at precious metal refinery [Beneficiation]
Tin	RER: tin, at regional storage [Beneficiation]
Li-ions batteries	GLO: disposal, Li-ions batteries, hydrometallurgical [Recycling] GLO: cobalt, at plant [Beneficiation] GLO: lithium hydroxide, at plant [inorganics]
LCD	CH: disposal, LCD module, to municipal waste incineration [municipal incineration]
Landfill	Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH U

as an overview and methodological framework for the LCA, the ecoinvent database is the most consistent and transparent life cycle inventory database in the world [22].

Inventory analysis involves the tracking of the input and output flows of a product system including the materials, water and energy used and the waste released to the air, land and water [17]. In the model developed in this paper, energy and raw materials consumption is taken into account and GaBi, a powerful life-cycle assessment tool, is used to generate the model from the inventory data to assess the sustainability solutions [24].

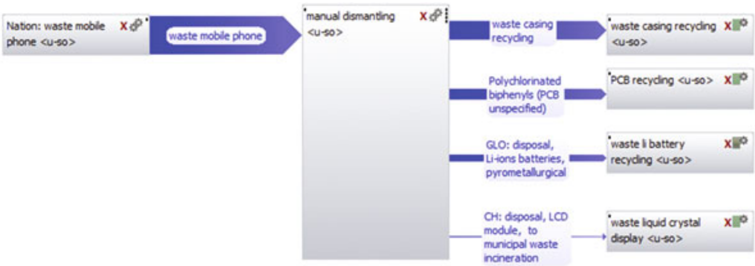

Fig. 7. Gabi built model

As shown in Fig. 7, the input for this model is 1000 kg of waste mobile phones.

3.3 Life Cycle Impact Assessment

LCIA is a qualitative and quantitative analysis of environmental impacts based on the elements listed in the inventory analysis (LCI) [20]. It is used to evaluate and interpret the environment impacts of a product system by assigning quantifiable measurements and connecting the input and output material inventories to obtain the damage points of a specified boundary system.

Generally speaking, the LCIA includes the following steps: classification of the elements listed in the inventory analysis process; a qualitative and quantitative analysis of the elements; identification of the major environmental factors in all aspects of the system; and analysis and judgment of the environmental factors. This paper identifies and analyzes the major environmental factors in the mobile phone recycling process. The environmental factors include ecotoxcity, cancer effects and human ecotoxicity [16].

3.4 Interpretation

In this section, the evaluation and improvements for the mobile phone recycling process are discussed, after which, with the aim of reducing the burden on the environment, suggestions are given to improve the current recycling mode of

China. In line with the goals and scope of the analysis, the recycling process results were evaluated, from which we were able to come to conclusions and develop recommendations.

The inventory results from the model focused on three main aspects. The first was the recovery of resources and materials. Valuable materials, such as copper, gold, and silver, which can be recycled and reused, were retrieved and the other materials treated as waste. The second aspect was human health concerns. Many related environmental issues such as carcinogenic materials, climate change, ozone depletion, radiation, and organic and inorganic respiratory irritants can cause various diseases, premature death and other non-normal deaths, reducing life expectancy. This aspect was measured in units of disability adjusted life years (DALY), which examined two kinds of health losses; disability and death; to determine the social impact of possible medical conditions on population health. This indicator has also been adopted by the World Bank and the World Health Organization. The third aspect focuses on ecosystem quality which refers to the ecological environmental biodiversity loss within a given time and space caused by environmental issues such as acidification/eutrophication of land and water bodies, toxicity, land-use changes [5], and air emission [9]. The measurement units for this aspect were the potentially disappeared fraction (PDF) m^2yr and the potentially affected fraction (PAF) m^2yr.

4 Discussion

The Chinese recycling waste mobile phone process was examined in this paper using LCA as the evaluation tool. A model was proposed and the possible three impact factors; resources, human health, and ecosystem quality; were analyzed to assess the environmental impact of the recycling process. In the model building procedure, resources consumption and material emissions were found to have a certain degree of impact on the environment, and further research can extract specific data to analyze the effects of specific substances such as heavy metals, CO_2 and NO_2. Because of the speed of mobile phone technological development, the rate of mobile phone disposal is expected to increase, further impacting the environment. If waste mobile phones can be effectively recycled, there will be less environmental and health effects, improving both the economy and the residents quality of life. This paper gave an assessment on the recycling process of waste mobile phone in China, identified the main factors affecting the environment. On the basis of this analysis, proposals were given to improve the eco-efficiency in recycling process. First, relevant policies should be presented to standardize the recycling behavior of citizens and market. Second, the recycling technology should be improved. Besides, a more eco-efficient recycling model is needed. The three main factors in this paper; resources, human health, and ecosystem quality; will be taken into account in the model.

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