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Reusability based on Life Cycle Sustainability Assessment: case study on WEEE

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Abstract

Reuse is one of the key strategies of Waste Electrical and Electronic Equipment (WEEE) recycling system in China. Reuse can help realize eco-efficient and sustainable WEEE management, with environmentally friendly materials recovery. At present, reusability of products and components is determined only by the products functional situation or the economic cost benefit analysis. It does not cover all the three pillars of sustainability, including environment, economy and society. In this study, the emerging integrated method, Life Cycle Sustainability Assessment (LCSA), is employed to measure reusability of typical electrical and electronic products and components. The results of case studies show that, LCSA based reusability of typical electrical and electronic products and components will help improve WEEE management policy.

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Keywords: Reuse; Reusability; Life Cycle Sustainability Assessment; WEEE.

1. Introduction

1.1 Concepts of reuse and reusability

Reuse, as one important strategy in 3R (Reduce, Reuse, Recovery) principles of waste management, plays an important role to moderate the environmental impacts in Waste Electrical and Electronic Equipment (WEEE) management (Truttmann and Rechberger 2006, Williams, Kahhat et al. 2008, Devoldere, Willems et al. 2009). Reuse means any operation by which products or components that are not waste are used again for the same purpose or a new application for which they were conceived (Stevels 1997, 2008). More specifically, reuse of Electrical and Electronic Equipment (EEE) or its components is to continue to use it (for the same purpose for which it was conceived) beyond the point at which its specifications fail to meet the requirements of the current owner and the owner has ceased use of the product (Initiative. 2009).

Accordingly, Reusability of products or components can be defined as the ability and advantageousness of EEE or its components to be reused, the same as the concept of *potential for re-use* in WEEE Directive of European Union (2008). More specifically, reusability can be defined as the ecologic, economic and social advantageousness of reuse compared to direct product recycling and disposal (Kissling, Fitzpatrick et al. 2012). If the time is taken into consideration as a factor, the reusability of a product can also be defined as a probability that a product having been used for a time period t ends its life in the following unit time (i.e., in the interval between t and t+1) but the product is reusable (Murayama, Yamamoto et al. 2004).

Reuse can be applied both at the product level or the component level. In the End-of-Life (EoL) of EEE, the depth of disassembly and recycling technologies greatly depends on the trade-off results of reusability and recyclability of components. Therefore, it is important to assess the reusability of components, which can greatly affect planning of WEEE

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treatment strategies and technologies. Moreover, compared with the products level reuse, the stakeholders in the components reuse is less and the relationships among them are also less complicated. In detail, components reuse is always done by the disassembly operator and re-application manufacturers, not the same as products reuse by consumers. In other words, components reuse is always similar to a “Business to Business” model, while products reuse is included in the “Business to Consumer” category. Compared with products reuse, it is more practical to reuse the parts or components to realize sustainable manufacturing as one type of life cycle based engineering.

In practice, components reuse is one of key treatment strategies and profit sources for WEEE recycling system, especially for informal sectors in China (Chi, Streicher-Porte et al. 2011). And from the environmental view, reuse is usually an eco-efficient option in the EoL of EEE (Kara, Mazhar et al. 2005, Jianxin Yang and Lu. 2008).

1.2 Literature review on reusability assessment

There are several factors that can affect the products and components reusability greatly. These factors can be categorized as technologic, economic, environmental, social and cultural and legal on reusability or the optimal focus on one factor (Initiative. 2009).

Reusability assessment and optimal product lifespan evaluation have a lot in common. Specifically, component reusability can be considered as the remaining lifespan of components in the EoL stage of products, which is determined by the ecologic, economic and social advantageousness of reuse compared with other EoL strategies. Therefore, in the following literature review of reusability assessment, the evaluation studies of the optimal lifespan are also chosen as the research base.

Most case studies on reusability assessment focus one factor, like the physical factor or the technology factor. From the physical view, the methods for assessing reliability of products such as Weibull Curve are employed to estimate the optimal lifespan, based on materials composition of products (Murayama and Shu 2001) and operating parameters (Mazhar, Kara et al. 2005, Mazhar, Kara et al. 2007). Maintainability, reliability, and wear-resistance characteristics are all studied as the causes for modeling and examining the reusability of a product and its components (Riedel et al. 1999, Weule and Buchholz 2001, Feng and Xu 2004, Sundin and Bras 2005). Except the physical factor, it is also approved that fast technology innovation and products replacement always shorten the optimal lifespan and lower the reusability of old generation products (Pandey 2008, Babbitt, Kahhat et al. 2009).

A few studies take two factors into consideration when assessing products reusability. The reusability of CRT TV was evaluated on both physical and economic factors (Anityasari, Bao et al. 2005), and another study showed that both physical lifespan and technology lifespan will affect the reusability of TV set (Rugrungruang, Kara et al. 2009). So the physical evaluation based on the inspection of a product or its component and based on its use time should both be taken into consideration (Murayama, Yamamoto et al. 2004). Another case for reusability assessment is based on physical characteristics of products including their lifetime prediction parameters and associated component physical failures, to establish the relationship between different products, their lifetime prediction design parameters and associated component failures (S.Ibbotson 2006). Moreover, a decision model has been developed for long range product planning that facilitates consideration of cost, reliability and environmental impact to determine the optimal take-back period, another name of optimal products lifespan (Mangun and Thurston 2002).

However, there is little consideration in the literature on sustainability, especially from the view of entire life cycle, when implementing reusability assessment. Therefore, this paper will try to employ LCSA method to assess reusability of electronic components from WEEE.

2. Methodology

Theoretically, the reusability of products and components is basically determined by the physical situation as an internal factor, and the technology development as the external factor. And in practice, it is always the economic cost that mainly affects the products reusability. But, from the point of sustainability view, reusability of products and components should also be evaluated based on environmental and social factors.

However, considering the data availability, it will become too difficult to acquire enough data to evaluate the time-related reusability. Therefore, in this study, reusability is evaluated only via the environmental, economic and social advantageousness of reuse compared to other EoL strategies including materials recovery and disposal.

Life Cycle Sustainability Assessment (LCSA) is one of suitable tools to assess reusability of products and components. LCSA is an integrated life cycle based method, including Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA). LCSA is not just a simple integration of 3 life cycle based methods, but also broaden and deepen the scope of traditional LCA (Curran 2012).

2.1 Environmental reusability assessment

LCA is a method for assessing resource consumption and environmental impact associated with the entire life cycle of a product, process or activity. According to ISO 14040:2006, it includes four phases: goal definition and scope, inventory analysis, impact assessment and interpretation. LCA has been proved to be a useful tool to assess the environmental impact of EoL management options, because it offers a framework for quantifying the environmental performance of alternative solid waste handling strategies (Schmidt, Holm et al. 2007).

However, there are only a few LCA references on reuse activities of WEEE. Based on life cycle thinking, in a comparison of the end-of-life strategies for several products, including reuse, remanufacture and recycling, only the avoided environmental impact of original manufacture was taken into consideration of reuse strategy (Rose 2000). In an analysis on life cycle energy of three end-of-life options for personal computers: resell, upgrading and recycling, the reuse option (resell) is also modeled simply by adding a second use time to a normal life cycle, which can not reflect the sequent effects of reuse and recycling option (Williams and Sasaki 2003). In a study (Schischke, Kohlmeyer et al. 2003), energy consumption of PC reuse is assessed in three scenarios, which includes corresponding results of different reuse situations and the conclusion indicates that reuse of PCs saves more energy than recovery and disposal. In the eco-efficiency analysis study on reused washing machines (Devoldere, Willems et al. 2009), decreased efficiency of worn-out washing machines and technological progress embodied in new ones are both taken into consideration. From the aspect of sustainable consumption (Tomohiro, Masaharu et al. 2008), a "prescriptive" LCA framework is established to judge whether reuse or replacement is more environmentally friendly. To summarize, LCA can be used as the suitable method for reusability assessment even there is no generally acknowledged method for comparison of different EoL options including reuse.

Specifically, the Eco-indicator 99 (EI99) method is employed as life cycle impact method in this study (Goedkoop and Spriensma. 2000). The EI99 method is a damage-oriented method for assessing adverse environmental effects on human health, ecosystems, and natural resources. The higher the resulting points, the worse the environmental effects of that target waste.

2.2 Economic reusability assessment

LCC is a tool which "summarizes all costs associated wit the life cycle of a product that are directly covered by one or more of the actors in that life cycle" (Hunkeler and Lichtenvort 2008).

In the reusability assessment process, LCC is employed to calculate and compare the cost of reused components, and recovered materials, including all end-of-life stages.

At present, there are 3 types of LCC, including Cost Benefit Analysis LCC (CBA-LCC), Budget LCC, Life Cycle Assessment LCC. LCA type LCC is used in this study, which is based on the same functional unit as LCA. The basic idea of this type LCC is to acquire the data of life stage cost and then sum them up as the total cost at the system level. In this study, only the cost of stakeholders in the EoL stages are included in the system but not that in other stages.

2.3 Social reusability assessment

As the social reusability assessment is implemented, S-LCA is used to evaluate the effect on social hotspots in China.

The method of S-LCA is still in its fancy stage, compared with other 2 life cycle based methods. It is still a key challenge that how to connect the macro social factors with the micro product functional unit in theory, while in practice, it is difficult of social LCA results to support the policy making process (Kloepffer 2008). The indicators are also of different levels in S-LCA, including not only mid-point indicators as employment rate, housing and education rate (Hunkeler 2006), but also end-point indicators, such as quality adjusted lifespan based on human life and well-being (Weidema 2006) and Human Dignity and Well-being (Dreyer, Hauschild et al. 2006).

In this study, we try to follow the *Guidelines for Social Life Cycle Assessment of Products*, developed by Life Cycle Initiative in 2009. The working hours are set as the intermediate as the connection of social factors and product to be evaluated (Lu, Yang et al. 2010). The mid-point evaluation indicators including employment, housing and education are used in this study.

3. Case Study

The mobile phone has become the most poplar personal electronic product. It was estimated that there were 5.9 billion mobile phone subscribers globally in 2011, of which 0.98 billion were in China. Meanwhile, the rapid technology innovation with better functions and models impelled the customers to change mobile phones more and more frequently, which leads to shorter lifespan of mobile phones. As a result, the quantity of used or waste mobile phones increase more quickly. In this case study, the reusability of mobile phone components will be assessed, in order to improve EoL strategies of waste mobile phones in China.

The typical modes of waste mobile phone in the informal and formal collection and treatment systems in China are different in reuse and materials recovery strategies, as shown in Figure 1 and Figure 2.

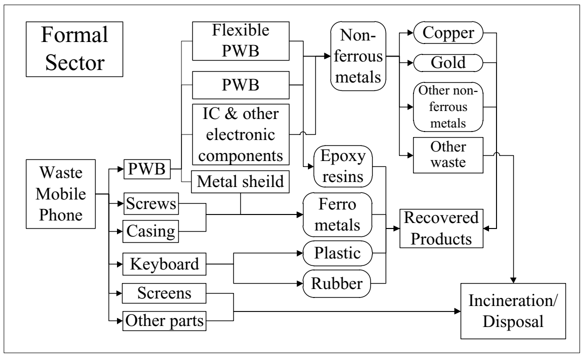

Fig. 1. Materials Flows of Waste Mobile Phone in the formal collection and treatment sector in China

The formal system in China is based on Extended Producer Responsibility principle, but not run well at present, while the informal system operates well as a cost efficient competitor. Further, the waste mobile phone has not been added into the China WEEE regulation list. So the reusability of waste mobile phone components can provide scientific information for policy making on waste mobile phone management.

From the results of materials flow analysis, it is recognized that the reusable and reused components of waste mobile phone are the ICs, cameras, telephone transmitter, receivers, vibrators, which can be reused in repair or re-assemble process.

The functional unit chosen for this case study are the typical components of 100 waste mobile phones, which are produced around the year of 2010. The referred system include the collection, disassembly, shredding, sorting,

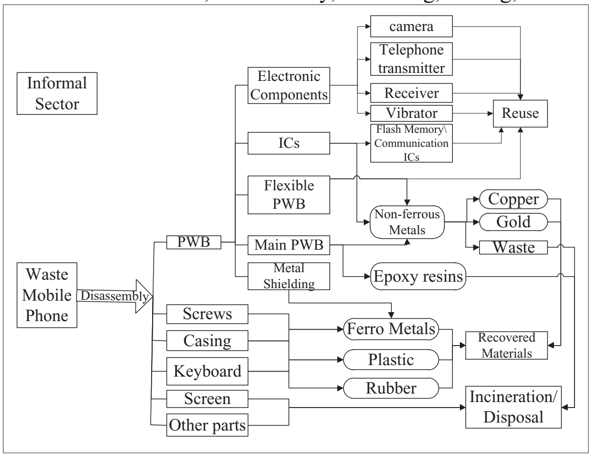

Fig. 2. Materials Flows of Waste Mobile Phone in the informal collection and treatment sector in China

materials recovery, components reuse and final disposal stages. The LCA data is mainly obtained from practical field investigation, and the Chinese basic energy system data come from RCEES LCI database and other commercial LCA databases.

Two waste telephone collection and treatment systems are compared: (A) components reuse mode and (B) materials recovery mode. Here it is assumed for simplification that materials recovery and final disposal technologies are the same in both modes, although in practice these are different in the formal and informal systems.

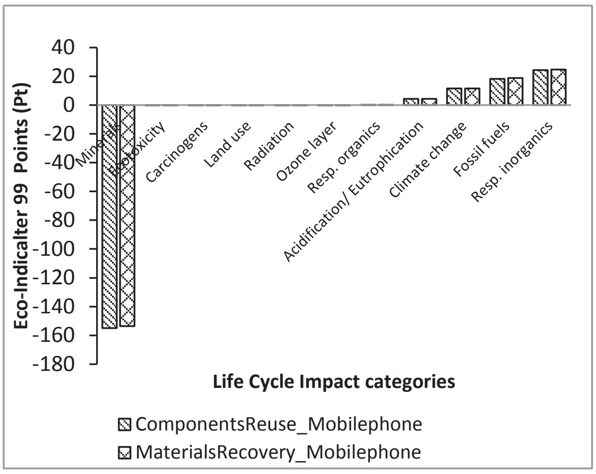

Fig. 3. LCA results for reusability assessment

The LCA results in Figure 3 show that in all the life cycle impact categories of the EI99 method, the values of system A are higher than those of system B. The category 'Minerals' in both modes are minus values, which means both systems can obtain positive environmental benefits due to avoided original raw materials and components production. And the positive values in the other categories indicate that both systems cause the environmental loss, and the system A is lower in environmental impact than system B. Therefore, it is can be inferred that components reuse mode is more environmentally friendly than materials recovery mode.

The system boundary of LCC in this case is the same as the LCA. Most of the cost data is from the investigation implemented in the beginning of 2012. In this case, the *cost paid to collectors* in two scenarios are assumed to be the same. But the *long distance transportation cost* are different because in the formal sector, there are regional WEEE recycling plants in most provinces, but most informal operators will transport the waste phones to Guangdong province in south part of China. The *treatment cost* of formal sector is lower than that of informal sector, because there are more labor cost in the informal sector and their cost are higher than the operation cost of machines in the formal one. The *final value* only include the value of recovered materials in the formal sector, but include the value of reused components and recovered materials.

The results of LCC are shown in table 1, which indicates that the benefit of components reuse is higher than the materials recovery mode. The main reason is that the valuable materials in these components are too low in content to be recovered while the reusable components is much higher in price.

Table 1 Results of life cycle costing analysis

Life cycle cost (Yuan)	Formal Sector	Informal Sector
Cost paid to collectors	500	600
Long distance transportation cost	40	140
Treatment cost	80	150
Final value	800	1500
Added value	180	710

In Social LCA, the stakeholder category including workers and local community groups are analyzed in this case study, with human health, wages and job creation subcategories. The technology roadmap of Social LCA in this study is shown in Figure 4.

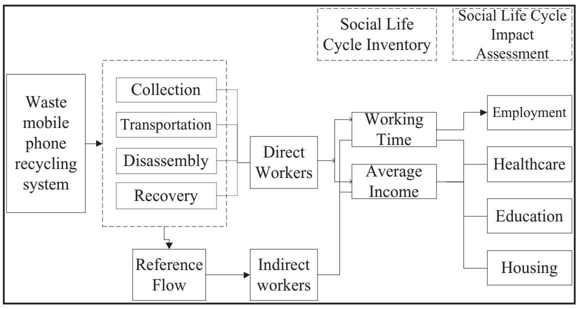

Fig.4. Social LCA study roadmap

The analysis results of Social LCA indicate that, in the formal sector, there are less employment creation, but wages and social guarantee are higher than that in the informal sector. Meanwhile, health conditions are also better in the formal sector than that in the informal sector.

4. Discussion and Conclusion

The reusability of waste mobile phone components are assessed based on the emerging LCSA method in this study. LCA and LCC results showed that the reusability of studied components is high, which means that it is better to reuse these components than simple materials recovery, from the point of environmental and cost-benefit view. However, the Social LCA results showed that social reusability is obscure, because it can not be determined that whether job creation is more important than the health risk or not. Therefore, components reuse should be promoted accordingly in the policy making process for both government and recycling industries.

However, reusability are affected by many factors as discussed above, including time range, physical situation and technology innovation speed, and other macro and micro conditions, so it is necessary to take more other factors into consideration in practice.

LCSA can be used by waste recycling practitioners to choose sustainable end-of-life strategies with lower health impacts for workers. Thus, it is necessary to improve the methodology of LCSA, especially in the integration methods of three sustainability aspects: environment, economic and society.

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