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A review of developing an e-wastes collection system in Dalian, China

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ABSTRACT

With China's rapid development, e-wastes issue has become increasingly critical. Without appropriate collection and treatment, e-wastes will bring serious environmental challenges. This paper reviews e-wastes collection in Dalian, China. Our findings show that although the Dalian municipality has made progress in improving the collection rate of e-wastes, several challenges still exist, including unclear responsibilities of stakeholders for e-waste collection in laws and regulations; high collection costs for formal treatment plants; and the lack of appropriate infrastructure, especially collection centers. As part of the research study, we identify several potential solutions for policy makers to overcome these challenges. The initiatives used by Dalian can provide implications for other municipalities in China as well as in other developed and developing countries.

1. Introduction

E-wastes, which is also called as waste electronic and electric equipment (WEEE) or end-of-life (EOL) electronics, include all components, sub-assemblies and consumables that are deemed obsolete or unwanted by users (Bhuie et al., 2004; Cairns, 2005; Ramzy et al., 2008). The huge amount of e-wastes, with a myriad of toxic components and materials, can bring a high sustainable challenge without the right management (Hicks et al., 2005; Kahhat and Williams, 2012). To mitigate environmental impacts, it is necessary to increase the e-wastes collection rate (Reck and Graedel, 2012; Taghipour et al., 2012). Experiences in developed countries show that an effective collection system is one of the five key parts for e-wastes management (Khetriwal et al., 2009).

Developed countries have enacted regulations such as the WEEE directive which clarifies responsibilities of manufacturers, governments and consumers for e-wastes management. From a legal point of view, as early as 2002, nine countries enacted mandatory electronic recovery laws, including Belgium, Denmark, Italy, the Netherlands, Norway, Sweden, Switzerland, Portugal and Japan (Michele, 2002). Thirty-five countries established e-wastes take-back laws by 2010. Due to the mandatory implementation of such laws, those countries have significantly improved their e-wastes collection. For example, in Japan the recycling rates of air conditioners, fridges, washing machines and tube TV sets were 87%, 73%, 82% and 86% respectively in 2007, much higher than the requirements of 60%, 50%, 50% and 55% (Sakai et al., 2008). In the USA, with the help of the Extended Producer Responsibility Law, approximately 70% of e-wastes were collected by producers in 2003 (Ramzy et al., 2008).

In China, e-wastes have become an important waste stream, both in terms of quantity and toxicity (Hicks et al., 2005, Yu et al., 2010). In 2004, the National Development and Reform Commission (NDRC) launched four urban pilot projects for e-wastes collection and treatment in the cities of Hangzhou, Qingdao, Beijing and Tianjin, (Yu et al., 2010). With advanced treatment equipment and technologies, these four pilot cities had abilities to treat e-wastes in an environmentally friendly way. However, each city encountered difficulties to have enough quantities of e-wastes to be treated economically due to lack of effective and efficient collection systems. Hence, the major barrier to environmentally sound e-wastes management in China is not treatment technologies, but efficient e-wastes collection. In order to deal with such an issue, the Chinese central government promulgated the Chinese WEEE directive on February 25, 2009, which came into effect on January 1, 2011. Based on China's e-wastes regulatory policy, the central government has encouraged all the provinces and municipalities to establish their own collection systems by considering the local realities.

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Previous studies have presented successful e-wastes collection cases in developed countries, such as Germany, Japan and the USA (Ramzy et al., 2008). But the success of one collection system in one country or culture does not necessarily portend success in another country. Research in e-wastes collection in China has occurred. Studies related to e-wastes collection mainly examine residential behaviors for e-wastes discards (Wang et al., 2011a,b; Li et al., 2012), while one study introduces opportunities and threats of a collection system for used refrigerators in a medium-sized city of Taizhou (Streicher-Porte and Geering, 2010). How to collect e-wastes efficiently, especially in developed urban areas, is still a primary challenge for Chinese policy makers. A well defined urban e-wastes collection system has yet to be recognized. Thus, in this paper, we use Dalian, a unique industrial and well-known environmentally friendly city in northeast China, as our case study municipality to demonstrate the practices and challenges of introducing a public-private e-waste collection system.

We first introduced e-wastes collection systems in China in part 2 and the e-wastes situation in Dalian in part 3. We then presented Dalian's new collection model in Part 4. Based upon our detailed analysis, we identified key challenges and potential solutions for the e-wastes collection system. Finally we concluded with experiences from Dalian and further efforts that are needed.

2. An overview of e-wastes collection systems in China

To set the stage for our case study, we provide an overview of the policy and practice issues on e-wastes management with a focus on e-wastes collection in China. We briefly overview the types of e-wastes that are managed, the China's regulatory practices, the pilot projects, and the current collection systems.

2.1. E-wastes generated in China

The rapid economic growth, urbanization and the growing demand for consumer goods in China have induced significant consumption of electrical and electronic equipment (EEE), such as cell phones, private computers, TV sets, etc. The end-of-life of such equipment has naturally caused substantial e-wastes. These e-wastes pose a severe threat to the environment and the sustainable economic growth in China (He et al., 2006).

As a rapidly industrialized country, China has become a huge producer and consumer of EEE with a still yet to occur peak period in both ownership and dumping of household and office appliances (Hicks et al., 2005). A large amount of EEE and consumer products currently used by individuals and businesses were produced in the late of 1980s and the early of 1990s, which indicates that those products are very close to the end of their lives, and some of them may have had their lives extended and still be used, which is, in itself an environmental issue due to inefficient energy consumption.

According to the 2009 statistics by the Chinese Home Appliance Association, China had 150 million refrigerators, 190 million washing machines, and 320 million TV sets in use (Shi and Wang, 2012). A report publicized by the United Nations Environmental Programme (UNEP) in 2010 showed that China produces over 2.3 million tons of e-wastes every year, ranking No. 2 following the USA with the annual e-wastes production of 3 million (Economic Information, 2012). These numbers have likely increased greatly due to greater average wealth and urbanization within China. It was estimated that by 2020, the annual end-of-life computers will double and the discarded cell phones will be seven times compared to the production in 2007 (Economic Information, 2012). The question remains, how can entities in China take back these e-wastes and reuse or recycle them? This issue is a challenge for all levels of Chinese policy makers, from local municipalities to provincial and national agencies.

2.2. Laws and regulations of e-wastes collection in China

Over the past two decades, the Chinese central government has struggled to introduce laws, directives, regulations, programs and policies to manage e-wastes (Yu et al., 2010). The basic e-waste regulatory framework includes at least three laws, one decree, and four administrative rules (Cai, 2011). In China laws were approved by the People's Congress and have the highest authorities, decrees were released by the State Council and should be compulsorily implemented across the whole country, and administrative rules were prepared and released by various ministries and should also be compulsorily implemented across the whole country, but with lower authorities comparing with decrees.

By the end of 2012, only one decree has direct items about e-wastes collection. It is the Collection and Treatment Decree on Wastes of Electric and Electronic Equipment, which was approved on August 20, 2008 by State Council and enacted on January 1, 2011. It is the China's counterpart to the EU WEEE Directive, and it is very important to establish an entire management framework for e-wastes collection and recycling in China (Liu et al., 2006). It stipulates that all e-wastes in the WEEE catalogue made by the Minster of Environment Protection should be taken back, recycled and disposed properly. EEE producers are encouraged to take back their own products by themselves, and they also can entrust their sellers, repairers, customer service divisions or collectors of e-wastes to take bake their end-of-life products. Although this decree has the item for e-waste collection, it does not allocate responsibilities to all stakeholders for e-wastes collection. No requirements about collection channels and measures have been provided.

Besides this decree, there are three laws and four administration rules for solid wastes management, but none of them have any items on e-wastes collection. For example, the Circular Economy Promotion Law, enacted on Jan.1, 2009 by National People's Congress, only sets up the requirements for the disassemble and treatment of e-wastes, but does not touch up e-wastes collection (Leng, 2012). Solid Waste Pollution Control Law, approved on October 30, 1995 and amended on Dec. 29, 2004, formulates that public institutions and individuals who generate solid wastes including e-wastes should take proper measures to prevent and reduce pollution caused by those wastes. But this law does not stipulate any concrete measures for e-wastes collection. The Clean Production Promotion Law, enacted on Jan. 1, 2003, partly focuses on cleaner production of EEE manufacturers. It puts forward some principals about the design and production of EEE and disposal of e-wastes, but it does not set up any requirements for e-wastes collection. As for the other four administration rules related to e-waste management, they set up some requirements for dismantle, recycling and treatment, but without any requirements of e-waste collection.

Generally, although Chinese government has issued some laws, decrees and administration rules on e-waste management, it is still unclear and uncertain for all stakeholders how to play their roles effectively in e-wastes collection system. Hence clear and detailed requirements for e-wastes collection should be made by the Chinese central government in order to establish a systematic e-waste collection law system.

2.3. Pilot projects of e-wastes collection in China

As another policy instrument, Chinese governments supported and funded some pilot projects for e-wastes collection and treatment with the intent to improve reclamation rate and to properly recycle and dispose e-wastes. Besides two national urban pilot

projects for e-waste treatment in Beijing and Tianjin supported by the central government, there were also two pilot regions with a focus on e-wastes collection. In December of 2003, the National Development and Reform Commission chose Zhejiang province and Qingdao city as two pilot regions to establish e-waste collection system at the provincial and municipal levels, respectively. In 2005, the National Development and Reform Commission provided RMB 77.6 million for these two pilot projects with a focus on e-waste collection and the other two pilot projects on e-waste treatment in Beijing and Tianjin.

Zhejiang Province planned to construct a treatment center in its capital city of Hangzhou and some collection sites in both Hangzhou and other eleven cities of Zhejiang Province. By the end of 2005, the treatment center had been established by the Hangzhou Dadi Environment Protection Company with the treatment capability of 60 thousand items of e-wastes per year. Besides, 47 collection sites had been established, but all in Hangzhou. These 47 collection sites were scattered in communities, public institutions, schools and universities.

As for Qingdao, eight municipal bureau-level agencies set up 'administration rules for e-waste collection and treatment pilot region' in 2006. Qingdao also decided to establish three kinds of collection channels, they are, an inter collection channel in Hair Group (a very famous home appliance manufacturer in China), fixed collection sites in curbsides, and commercial collection sites in communities, public institutions, schools and universities. For the case of Haier, one of the largest home appliance manufacturers in China, the management planned to construct a collection and treatment center with a capacity of dealing with 600 thousand e-wastes per year in 2005. But due to the worry on lack of enough volume of collected e-wastes, Hair Group gave up this plan eventually. Thus, only the other two channels were finally operated under this project.

Unfortunately, both of these two pilot regions faced the same challenge, namely, lack of enough e-wastes for efficient and economical treatment through their collection channels (He et al., 2006). Therefore, how to develop an e-waste collection system has become a crucial problem in China to garner acceptance and adoption of e-waste systems.

2.4. Current e-wastes collection systems in China

Collecting and managing e-wastes can, and does, include both economic and ecological concerns. E-wastes could bring substantial economic payback, whether through formal or informal channels. Four kinds of collectors in China exist, namely, peddlers, dealers/retailers, specialized collectors and secondhand markets. Consumers can determine to give their e-wastes to any of them.

In reality about 88% e-wastes are collected by peddlers (Wang and Ma, 2011). Usually these peddlers form an 'informal' economy. They ride their manual or motorized bicycles or drive small trucks around communities or residential areas to buy e-wastes. They pay from tens to hundreds of RMB according to the e-waste types and quality. Peddlers usually sell their collected e-wastes to a local collection center. These collected e-wastes are grouped into two quality categories. The first group, which has operable basic functions and can be reused, is usually resold in rural areas. The second group, which has very low useable functionality and cannot be reused anymore, is usually dismantled in order to get valuable materials. But such dismantling processes are mostly operated in simple ways in those illegal (unauthorized) small dismantling plants.

The remaining 12% of e-wastes are collected by the other three kinds of collectors (Wang et al., 2011a,b). Using Beijing as an example, about 6% of e-wastes are collected by dealers. Specialized collectors such as registered treatment plants collect 3% of e-wastes by cooperating with communities or enterprises. Besides, some consumers sell their used EEE to secondhand markets directly, and about 3% of e-wastes are collected by this way.

Generally, the current collection system in China is still a relatively informal economy that results in a disordered market system with little government oversight. Even after all these regulatory policies and pilot projects were initiated, an effective, safe, and environmentally sound e-waste collection system has yet to be established in China. We now show how one case study municipality is continuing to deal with this issue. We have to admit that it is a work in progress, but initial insights into enablers, barriers, and opportunities can benefit the broader research and policy community.

3. Method and case study location

Chinese cities have made efforts to develop e-waste collection systems. We employ a case study method for evaluation of municipal e-wastes collection management in China. We have identified a large city located along the east coast of China, Dalian, as an illustrative example. Experiences and lessons of this city can be shared by other Chinese cities.

Dalian is located in the southern tip of the Liaoning peninsula in the northeast of China. The city has a total administrative area of 12,573 km^2 which includes urban and rural areas (248 km^2 and 2450 km^2, respectively), as well as protected ecological areas/nature preserves (9875 km^2). The total population in Dalian is 6.7 million, including 3.3 million urban population and 3.4 million rural population. Dalian is one of China's most prosperous business areas as well as a distribution center for goods and materials in the northeast of China. It is a key hub of land and sea communications, and its seaport is important nationally since it is the most convenient sea outlet for all of northeast China (Wang and Geng, 2012).

Dalian city was chosen for this study because it is a good representation of most large cities in China, not only in economic development, but also in the income levels of its residents. It is also emblematic of most cities in China, as it continues to undergo rapid urbanization. It not only has developed country city characteristics, but also has many developing country issues it must face, such as a large poorly educated and recently urbanized (migrant) workforce.

Dalian city is an especially apt case study for e-wastes collection for a number of additional reasons. First, the electronic and electrical industry in Dalian has become one of its four "pillar industries", contributing to 20% of the gross industrial output value in Dalian (Wang and Geng, 2012). Over 100 electrical and electronic manufacturers were established in Dalian by late 2011. Many of these companies are large-scale household leading international manufacturers, including Canon, IBM, Intel, Sanyo, Hewlett–Packard, Toshiba, and Panasonic. These companies are quite familiar with the WEEE directive and other environmental regulations.

Second, Dalian has one of the most prosperous software parks in China. More than 500 software companies from all over the world are operating their businesses in the software park, including forty-three of World Top 500 companies such as IBM, Accenture, Panasonic, Toshiba, Dell, Sony and HP. These software companies require the latest technologies to function. Due to the rapid obsolescence of electronic products in the software industry, this software park is a continuous and large source of discarded (obsolete) computers and printers.

Third, Dalian has a specialized e-wastes treatment company, Dalian Dongtai Industrial Waste Treatment Company (Dongtai), established in 1991 with the designed capacity of treating 200 thousand tons of e-waste per year. Dongtai is the largest e-wastes management service provider in the northeast of China, and one of the largest in all of China. It engages in collection, recycling and

disposal of e-wastes, as well as other wastes management and disposal like municipal sludge and sewage treatment, hazardous and toxic waste landfill. With knowledge in this industry for over 20 years of experience, Dongtai has become a rare specialized e-wastes treatment company certificated by the national government. We include Dongtai's role in our case study of municipal e-wastes collection.

In order to complete our structural analysis of Dalian e-wastes collection, and the typical methods and roles of the Dalian municipal government stakeholders, a number of measures for data collection were completed. We reviewed the secondary sources of information from published technical and governmental reports and papers, web pages and statistical reports. Next interviews with stakeholders, including governments, communities, residents, peddlers, dealers of secondhand markets and industry (Dongtai), were completed in order to obtain details about situations and problems of e-wastes collection in Dalian. Finally, the e-wastes flows in Dalian were generally generated based on the information obtained through literature reviews and interviews, as well as estimates based on general sales and population numbers.

4. E-wastes production, collection and flows in Dalian

We now provide an overview of e-wastes production, collection, and flows within Dalian. We include some descriptions on the types and quantities of e-wastes produced in this area. A summary of the stakeholders involved in this system is also presented in this part.

4.1. E-wastes produced in Dalian

The quantity of e-wastes is hard to predict though related models are developed (Chung, 2012). Dalian currently has about one million households in its urban area (Dalian municipal government, 2011). As a coastal city, Dalian has a relatively high level of per capita GDP. The per capita GDP of Dalian in 2011was USD14,454, while the per capita GDP of the whole country in 2011was USD5,432. According to the Dalian Environment Protection Bureau, the home appliance consumption was 140% of the China's average level in 2008 (DEPB, 2009). Compared to the results of national statistics (National Statistical Bureau, 2010), Dalian has at least1.5 million TV sets, 1.06 million refrigerators, 1.18 million air-conditioners, 1.06 million washing machines, 2 million mobile phones and 0.73 million computers in operation.

A large amount of these electronic and electrical appliances were produced during the 1980s and 1990s and are at or very close to end-of-life. According to the DEPB (2009), about 3% of these appliances came to the end-of-life annually. In terms of average weights, a TV set is 30 kg, refrigerators are 80 kg, 40 kg for an air-conditioner, 70 kg for a washing machine, 10 kg for a computer and 0.1 kg for a mobile phone. Hence, the weight of these e-wastes produced by the residents in Dalian is over 7500 tons annually.

Besides aforementioned e-wastes, there are also many other e-wastes, such as end-of-life microwave ovens, water heaters, telephones, radios, hair driers, shavers, and dishwashers. According to the director of DEPB, the weight of these e-wastes produced annually in the recent years was also over 7500 tons in Dalian.

Besides residential sources, public, industrial and commercial institutions also produce a large amount of e-wastes each year. The main e-wastes from those institutions include computers, printers and photocopiers. At least 15,000 computer and/or printer systems from institutions have been discarded annually in the municipality (Liu, 2011). Just these systems and measured sources are approximately 1,500 tons. Informal disposal streams are difficult to measure, but may even be at larger rates due to the economic value associated with these relatively high quality electronic systems.

The distribution of e-wastes produced by residents and institutions during 2009 and 2011 in Dalian are shown in Fig. 1.

4.2. E-wastes flows in Dalian

The traditional and main channel for collecting e-wastes in Dalian is best termed as informal. Individual or small groups of peddlers collect most e-wastes in this informal system. They wander through communities and buy used home appliances from residents usually in cash. They could announce, publicly and loudly, that they are looking for old appliances and electronic products. The used home appliances they buy are either refurbished and then resold in rural areas as secondhand products or are sold directly to unregistered small e-wastes treatment plants.

Although Dalian does not have medium or large-sized unregistered e-wastes treatment plants such as those that exist in Guiyu, Guangzhou province or in Taizhou, Zhejinang province (Wang and Ma, 2011), some small ones still exist. These plants collect and process valuable materials from e-wastes in rough and usually environmentally unfriendly ways. Such practices as open incineration, acid baths, and open air dumping, which are serious causes of pollution and environmental degradation, are quite common in these unregistered treatment plants.

Currently e-wastes from institutions are collected by informal peddlers, the Dongtai company or delivered to low income households through philanthropic or charitable channels, typically in rural areas. Due to resale and dispersion to rural and lower socio-economic communities, there is great uncertainty in the actual end-of-life disposal of these collection and treatment systems.

Although Dalian has a registered specialized e-wastes treatment plant with a treatment capacity of 10,000 tons of e-wastes per year, most e-wastes generated in Dalian are not collected, recycled and disposed through official channels (Liu, 2011). A rough summary of e-wastes flows in Dalian are presented in Fig. 2.

5. The e-wastes collection model in Dalian

In order to collect e-wastes effectively, the Dalian municipal government initiated three programs for collecting and recycling e-wastes in 2006. The first program was to develop a cooperative network among general public institutions (such as schools, hospitals, governmental agencies, etc), Dongtai (a private registered e-wastes treatment company), and the Dalian municipal government. The second program involved developing a residential e-wastes collection channel as one part of the local "green communities" program. The third program to aid the e-waste collection

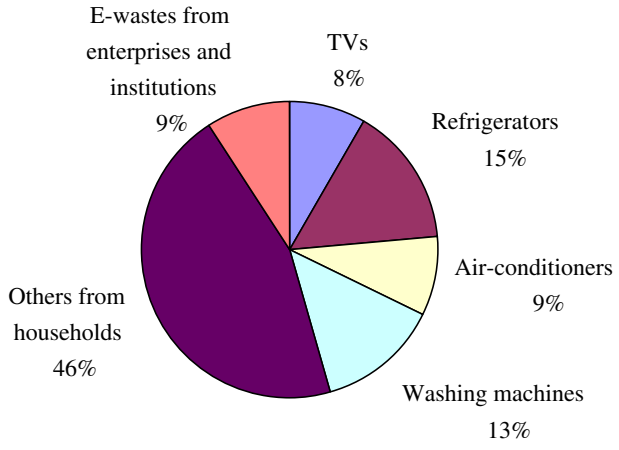

Fig. 1. Sources of e-wastes in Dalian.

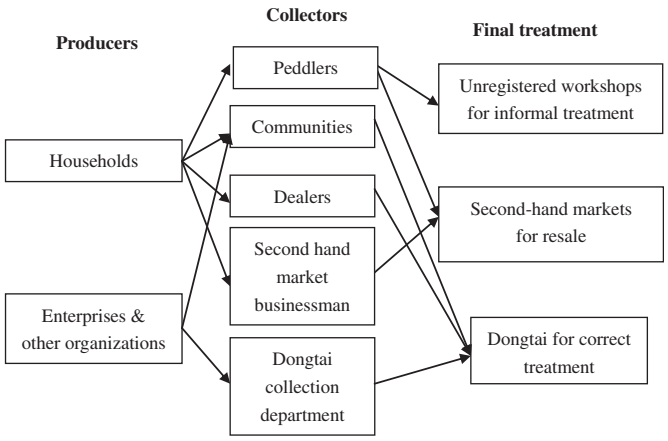

Fig. 2. E-waste flows in Dalian.

was a provincial level program supported by the national government. The Liaoning province, which Dalian belongs to, is also one of nine pilot provinces of the national subsidization project "buy a new one with a used one" initiated by the Chinese Central Government in 2009. A large amount of e-wastes were collected under the support of this project.

5.1. Developing a cooperation network

In 2006, three municipal government agencies, the Dalian Economic Committee, the Dalian Development and Reform Committee, and the Dalian Environmental Protection Bureau, jointly initiated a program of Collecting and Recycling E-wastes from public institutions (CREP). This program required all public institutions give their e-wastes to registered treatment companies such as Dongtai.

To promote the CREP program, the Dalian municipal government organized a special meeting to inform all public institutions of the potential hazardous impact of e-wastes on the environment and human health, as well as the importance of collecting and recycling e-wastes properly.

Similar to the situation across China, public institutions in Dalian stored their e-wastes in warehouses and sometimes donated usable used e-products such as computers to rural areas (Wang et al., 2011a,b), especially rural schools. After understanding the potential environmental impacts of e-wastes, most public institutions in Dalian expressed their willingness to support the program (DEPB, 2009). Usually, these public institutions appointed a person to communicate and collaborate with Dongtai on issues related to shipment timing and volumes of e-wastes. Also cost and the price negotiation were completed during this process.

To support the program, the Dalian municipal government also initiated a program called "Governmental Green Procurement". Within this program when a public institution needs to replace its used office appliances such as printers, computers and fax machines with new ones, it is required to contract with Dongtai to take away used office e-wastes. This initiative allowed Dongtai to develop agreements with hundreds of public institutions, including universities, hospitals and governmental agencies.

Meanwhile, in order to establish a green image and become more socially responsible, some state-owned enterprises (these are companies producing products or services that compete with private for-profit enterprises) also volunteered to join the program. Simultaneously, Dongtai also dispatched its marketing and communications staff to these public institutions and state-owned companies to explain the process and program.

With all these efforts, significant progress has been made. For instance, in the first year more than 100 tons of e-wastes were collected by Dongtai from public institutions and state-owned companies (Liu, 2011).

5.2. Constructing collection channels in green communities

For residential e-wastes collection, the Dalian municipal government introduced the "Green Communities" program in 2008. This program was also in cooperation with Dongtai. The green communities program sought to develop a public participation mechanism through infrastructure establishment and joint effort by multiple stakeholders. All the e-wastes collected in the green communities program were sent to Dongtai for treatment, thus circumventing many of the informal collection channels.

Green community partnership committees were established, composed of a variety of stakeholders, including the Environmental Protection Bureau, representatives from local communities, and property management companies. Such committees organize periodic workshops about e-wastes management. These workshops serve multiple purposes such as summarizing and sharing successful experiences, which improve environmental awareness of participants and, at the same time, build up legitimacy and trust in the program among stakeholders. Overall the committees function in three ways with related stakeholders.

First, they invite experts and specialists in e-wastes from the Dalian University of Technology (a local leading national university) and the Dalian Environment Protection Bureau to disseminate knowledge on the hazardous and harmful characteristics of e-wastes. In addition, they clearly introduce the necessity and benefits of e-waste collection for proper treatment and disposal. An effective collection system can not only reduce hazards from eco-wastes, but also reclaim valuable materials such as heavy metal. Thus, another stakeholder, the academic and research community has been brought into the multi-stakeholder effort.

A second major effort aims for community knowledge building. The committees organize 'open houses' for participants of green communities, especially community residents, to visit Dongtai. Once again such efforts allow residents to better understand and appreciate the importance of collection for proper treatment and disposal of e-wastes. With the help of the local government and Dongtai, the committees also introduced Dongtai's experiences in recycling and disposing of e-wastes through local TV, radio and newspapers to improve local environmental awareness of all local residents. This multipronged effort has incorporated another stakeholder (albeit a secondary stakeholder) the media into the process.

Thoughtful and tactical scheduling of actual collection events is the third major function of the green community teams. They organize collection activities during weekends to encourage residents to sell their e-wastes to community committees. This is the operational and logistical function side of the green community effort. To encourage participation in the logistical and operational activities, residents could get 'payment' in terms of rewards such as towels, toilet papers and portable radios. This provides the incentive to local residents to actively participate in. Knowing the benefits to the communities may have been motivation for some, but tangible incentives are necessary to acquire greater community participation.

Twenty e-waste collection stations were established through the green community efforts. Fifty-seven green community committees appeared and continue to operate in Dalian. With the green community efforts, the amount of e-wastes collected in green communities has increased significantly. It is important for residents to realize that these alternative and safe channels are available to them.

The green communities effort was planned through multiple stakeholders and multiple function processes. The committees of the program have continuously sought new ways and methods to improve outreach and participation.

5.3. Implementing the project of "buy a new one with a used one"

A third major programmatic effort to collect e-waste products was a program initiated by the Chinese central government. The program titled "buy a new one with a used one" began in 2009. It stipulated that a consumer could receive subsidies (rebates) of up to RMB400 (about $65) for a used home appliance when purchasing a new TV, fridge, washing machine, air-conditioner, or computer. This program ran for approximately two and a half years from the middle of 2009 to the end of 2011. The Dalian municipal government actively promoted the program. Again, the e-wastes collected in this program were sent to legitimate, registered channels, specifically Dongtai. In the first two years, Dongtai collected over 6300 tons of e-wastes, when only 100–200 tons each year were collected before implementation of this project (Liu, 2011). Thus, clearly, financial incentives were a major factor in encouraging participation in e-waste collection. The successful factor of this program was a higher payment and a more convenient collection channel.

6. Challenges and solutions

As with all programs, there are both advantages and disadvantages. We provide an overview of the major challenges faced by the collection programs introduced in the past few years. We also provide some potential policy and operational solutions to these challenges. Both the challenges and the solutions are those that may and will be encountered in most municipal collection programs, especially those in China.

6.1. Challenges

As introduced earlier, the Dalian Municipal Government has made progress in e-wastes collection with two unique localized programs for public institutions and residents, in addition to introduction of the central government's subsidization program. However, there are also several challenges impeding complete implementation of e-wastes collection.

6.1.1. Unclear responsibilities for stakeholders

The first challenge is a lack of clear responsibilities for stakeholders. In fact, extended producer responsibility (EPR) has been adopted by many countries, with the European Union and Japan already achieving remarkable success in e-wastes collection and recycling under EPR (Wang et al., 2011a,b). Experiences in Spain show that a country could not assign clear responsibilities of e-wastes for all stakeholders in a short term, and efforts are needed to establish a mature collection system step by step (Queiruga et al., 2012).China has set up its own WEEE Directive and enacted it in January 2011. However, the responsibilities of collectors, producers, treatment plants, governments and consumers in e-waste management systems, especially for e-waste collection, are still unclear. This lack of responsibility for actions by stakeholders is the most difficult obstacle for building an effective e-waste collection system (Wang and Ma, 2011).

In developed areas, it was found that residents' behaviors, attitudes are important to successfully collect e-wastes while residents need to pay for e-wastes management, treatment or even collection (Song et al., 2012). However, in developing countries, e-wastes producers expected to be paid while the government financial support provides one way to encourage consumers to sell their e-wastes through formal collection channels (Manomaivibool and Vassanadumrongdee, 2012).

Similar to other areas within China, local or regional governments such as Dalian, have yet to develop and implement standards for end-of-life EEE. It is still not clear for the general public to understand how to distinguish old and waste EEE, and which kind of e-wastes have to be disposed rather than treated for reuse. Simultaneously, no standards exist for the quality control of secondhand EEE. All these practical problems bring many difficulties to the whole e-waste collection system, not only the collection stage, but the treatment and final disposal stages.

6.1.2. Uncompetitive collection prices and channel of formal treatment plants

The second challenge is the economic factor for collection. Essentially, the cost to develop formal, registered treatment plants is very high. In developed countries, consumers are required to send back used e-products by themselves free of charge (e.g. Germany), and even need to pay money for e-wastes discarding (e.g. Japan), which ensures that treatment plants could get enough e-wastes for economical treatment (Cai, 2011). However, in China, consumers can get money by selling their e-wastes.

Peddlers collect and send e-wastes to informal treatment plants. These informal treatment plants take away valuable materials from used e-products for reuse or recycling, and then discard the rest of e-wastes directly to the surroundings. They do not have specialized equipment, and dispose e-wastes in simple and unfriendly ways such as open incineration and acid baths. The informal channels usually reclaim, primarily through facile appearance improvement of old e-products and then sell them in rural areas for several hundred RMB. As a result, because of the quite low "disposal" cost, these illegal treatment plants could pay much to residents or peddlers for e-wastes collection. The related environmental damages have not been considered at all.

Formal treatment plants have to invest in innovative technologies as well as very rigorous and planned treatment processes to make sure that all activities are environmentally sound. Thus, the formal and registered treatment plants have to pay much less for e-wastes collection, resulting in that they always receive the least valuable e-wastes. In Dalian, registered treatment plants like Dongtai are not able to compete in collection prices with those illegal treatment plants.

In addition to competitive collection prices of e-wastes, informal peddler networks are able to provide residents with customized logistical support for collection of their e-wastes. That is, many peddlers can actually go to residential apartments while registered treatment plants could not provide this very convenient service due to economic infeasibilities associated with formal logistics networks. Therefore, most residents prefer to sell their e-wastes to peddlers rather than registered treatment plants. For example, a used TV set is sold at 50–100 RMB to a peddler while Dongtai could only provide about 15 RMB (Liu, 2011). As a result, Dongtai only collects 200–300 tons of e-wastes each year (pre-programs) while the annual generation of e-waste in Dalian has been estimated to be over 16,500 tons.

Finally, the national project of "buy a new one with a used one" ended at the end of 2011, which means that national subsides are not available any more. As a result, many residents began to sell their e-wastes to peddlers, rather than bring them to official collection sites.

6.1.3. Insufficient supporting infrastructure

An effective e-waste collection system needs supporting infrastructure such as collection and transfer centers. For example,

Germany developed different e-wastes collection channels for residents (Rotter et al., 2011). The USA has a variety of e-wastes collection options, including from curbside, permanent drop-off sites or through special drop-off event sand point-of-purchase to facilitate collection of e-wastes (Kang and Schoenung, 2005). Japanese governmental agencies at multiple levels cooperate with enterprises to have established 380 collecting centers and 38 treatment plants. Residents can send their e-wastes to those centers or retailers (Sakai et al., 2008), greatly improving the e-waste collection rate. Usually those collection centers are conveniently located for residents. Door-to-door or calling services are also available.

Developed countries such as Germany, Japan and the USA have well established effective and flexible collection infrastructure for e-wastes collection. Green communities in Dalian could provide some of this service, however, there are only fifty-seven green communities now and the e-wastes collected by green communities only account for 2% of the whole city. A significant effort is still needed.

As mentioned above, the Dalian municipal government initiated the CREP program. However, only 17–33% of total e-wastes produced by public institutions are collected by Dongtai each year. Although better than residential collection, much more need to be done in order to further improve the whole collection system. A major reason for this less-than-stellar outcome is due to the voluntary nature of this program. Thus, there is no guarantee that all public institutions will participate in.

Although the program was initiated, details and standards on collection of these e-wastes produced by institutions are still not well planned and controlled. For example, the existing financial accounting system requires that the rest value of a used fixed asset account for 5% of its original purchasing price. This means that the rest value for an e-waste, for example, an end-of-life computer, is about 250 RMB. This rest value is required to be paid based on the official accounting system. Dongtai, the major registered and formal treatment company, is unable to afford such a high price. Actually Dongtai can pay approximately 1,000 RMB per ton (about 100 computers) for e-wastes. Thus, even these public institutions still prefer to sell e-wastes to peddlers rather than to Dongtai.

6.2. Potential solutions

Recognizing that these major cultural, operational, infrastructural and economic challenges for e-waste collection exist, the Dalian municipality should adopt several measures to improve e-wastes collection management. Potential measures include developing local regulations to clarify responsibilities of stakeholders, introducing subsidy policies for e-wastes collection, and constructing more collection centers.

6.2.1. Clarifying responsibilities of stakeholders

Collecting and then disposing e-wastes effectively and efficiently requires clarified responsibilities of various stakeholders. Germany clearly designates responsibilities to stakeholders for e-wastes both from residents and institutions (Rotter et al., 2011). Using a typical city of Leipzig as an example, residents can put their small e-wastes in special yellow trash bins in their communities or send their e-wastes to one of 22 designated recycling centers free of charge. A municipal corporation is responsible to transport e-wastes from recycling centers to transfer stations, and this corporation also provides call-for-pickup service for large e-wastes while residents need to pay 10 Euro for each delivery. Treatment plants assigned by manufacturers provide special containers for different e-wastes, and they are responsible to take away e-wastes from transfer stations.

However, without strict and clear regulations, it is hard for a Chinese municipality to copy experiences from Germany, especially for including manufacturers to take responsibility (Kojima et al., 2009). Stakeholders of current e-wastes collection systems in China mainly include e-wastes producers, collectors and governments while manufacturers are not included. In developed countries, informal collectors were replaced by formal collection system, but in developing countries incorporating informal collectors into under-developing formal collection system can bring economical, environmental and social benefits (Besiou et al., 2012). In Germany, e-wastes from individual residents can be collected by different groups while e-wastes from institutions are only collected by municipalities (Rotter et al., 2011). Thus, learning from experiences in developed countries while considering the local situation, Dalian could exclude informal collectors to collect e-wastes from institutions, especially from public institutions, while include informal collectors in the developing collection system for e-wastes from residents.

Based on the Circular Economy Promotion Law enacted on January 1, 2009, the Dalian municipal government developed the Dalian Circular Economy Promotion Ordinance, which was enacted on October 1, 2010. This ordinance is a first step in clarifying responsibilities of stakeholders for a formal collection system of e-wastes from public institutions. Local governments and public institutions are responsible for establishing e-waste collection facilities and all public institutions should sort wastes and send them to qualified treatment enterprises. The municipality can include and even require other institutions such as enterprises to give their e-wastes to registered collection or treatment companies.

As for e-wastes from residents, informal collectors take the key role in collection. Chi et al. (2011) suggested that new formal e-waste recycling systems should take existing informal sectors into account while more policies need to be developed to improve recycling rates, working conditions and the efficiency of informal players. Similar to other areas in China, the increased urbanization in Dalian has brought more peddlers. Instead of simply prohibiting and/or punishing these informal collectors, the Dalian municipal government could employ and/or subsidize these peddlers to delivery e-wastes to registered treatment enterprises such as Dongtai. The government should realize that providing greater job opportunities and benignly treating or disposing e-wastes are dual socially beneficial goals.

6.2.2. Extending the “Green Communities” and “buy a new one with a used one” programs

According to the US EPA (2007), in the USA more than 800 local communities have taken measures for e-wastes collection and they have played a very important role in household e-wastes management. Learning from these US experiences, Dalian established 57 green community committees. These committees have played a very important role in e-wastes collection. However, it has not proven sufficient for coverage of the whole e-wastes collection system. In order to extend this model of e-wastes collection, the Dalian Municipal Government needs to construct new green communities in newly developed and urbanized areas (greenfield locations) as well as to encourage more existing communities to become green.

The Dalian municipal government need to increase economic benefits through subsidies to those green communicates and help further construct public infrastructure for collection in these communities. Leipzig, a city in Germany, put special yellow trash bins in all communities so that local residents can put small e-wastes in these bins. In Dalian, collection centers or e-waste collection bins can also be built in green demonstration communities with effective and clear marks. Communication and collection activities also need

to be held frequently in communities to cultivate and improve residents' environmental awareness.

Different from developed countries, financial support is still needed to encourage e-wastes collection through official channels in developing countries (Manomaivibool and Vassanadumrongdee, 2012). Although the national program "buy a new one with a used one" ended, in order to encourage the local citizens to continue to bring back their used EE products when they purchase new EEE products, the Dalian municipal government could provide continuous financial support. The budget for such a consideration may come from local pollution charge. While such charge is generally used to support those end-of-pipe treatment projects (Geng et al., 2010), now the local government could reconsider the use of such a budget so that such a pollution prevention effort can be prioritized.

6.2.3. Encouraging public participation

To gain public support and legitimacy, it is necessary to encourage the public to participate in promoting e-waste collection. The municipal government can further disseminate e-wastes related knowledge and best practices to the general public through media such as television, newspaper, Internet and bulletin. Such activities have been effective in Japan, the USA and the EU.

To successfully collect e-wastes in a developing country, a training program is needed to improve public awareness of importance for a suitable e-waste collection (Taghipour et al., 2012). Environmental education in primary, middle and secondary schools can set the initial stage for both short- and long-term cultural and behavioral changes. Building and disseminating knowledge to youths on e-wastes' hazardous and value qualities are important. Schools provide a valuable vehicle to do this. As early as the 1980s, many countries such as Canada and the USA adopted environmental education in schools and such kind of education played a very important role in improving students' environmental awareness. Generally it is not easy to change adults' environmental awareness and behaviors. Environmental education in schools can affect children's future environmental behavioral practices, and at the same time children can also influence parental decision making and knowledge.

Training workshops on e-wastes collection in Dalian for the general public have been successful in disseminating knowledge. Such activities should continue to be organized regularly in various communities, enterprises, government agencies and universities by the Dalian Environmental Protection Bureau.

Lastly, the municipality could develop new input and output indicators to evaluate the result of public participation (input) and e-wastes collection rate (output). Such a result can evaluate the achievements of green communities more effectively, and thus provide incentives for those best practice communities and individuals. Sharing best practices, through benchmarking, is another outcome of an effective participant indicator system. How to encourage continuous improvement among green communities, and how to summarize and disseminate experiences in benchmarking green communities need be thoroughly developed, as well.

7. Conclusions

Effective and efficient approaches and systems for e-wastes collection can increase reuse of economic equipment and parts, and increase the recyclability of materials reclaimed from e-wastes (Ramzy el at., 2008). Chinese governments at different levels have taken actions in developing e-wastes collection systems. Experiences in developing areas show that recycling facilities and laws on e-waste still need to be developed while residents' behaviors, attitudes, and willingness to pay are key factors for e-wastes collection (Song et al., 2012). The case of Dalian shows that there is a great potential to effectively and efficiently collect e-wastes from both public institutions and residents. One effective program is to have developed a network between public institutions and registered treatment plants under the support of the local environmental protection bureau. To collect residents' e-wastes, the municipality initiated the "green communities" program. However, challenges still exist, and Dalian needs to further improve its e-wastes collection system. The municipality has encouraged public institutions, large state-owned companies and green communities to send their e-wastes to formal and registered treatment companies such as Dongtai. A mix of policies including regulations, providing financial incentives, raising awareness, providing better supporting infrastructure, and awarding honors are all potential ways for improving outcomes.

This study provides a thorough evaluation of how one large city has been addressing this important issue. Lessons learned are important, insights into new practices provide additional knowledge, and directions for future advances have also been provided. As an environmental-friendly city in China, Dalian's experiences in e-wastes collection could be a benchmark for other cities in China and emerging countries. There have been a number of pilot projects, and it is important to share experiences across various municipalities, especially those that have similar socio-economic, political, and cultural characteristics. However, each city should develop its own action plan for a collection system of e-wastes by considering local realities.

Understanding the practices and some of the underlying mechanisms driving the various stakeholders in this urban setting is important for future advancement. This research of case study provides initial investigations for other studies. For example, further evaluation of some of the current existing and proposed programs is necessary to determine what is truly effective for both short-run and long-term policy initiatives. These issues here are not easily solvable, understanding them is the first step, improving upon them are the next steps. We hope that this case study provides additional insights for both researchers and policy makers who have to deal with these difficult and complex problems.

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