An overview of waste electrical and electronic equipment governance

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Abstract: The rapid expansion of waste electronic and electronic equipment (WEEE) not only means a serious waste of resources, but also causes corresponding environmental problems, which has made an enormous negative influence on ecological environment, economy and society development. This paper introduces the situation and experiences of WEEE treatment and utility in some countries and regions, and expounds the effects of WEEE on environment. Furthermore, compared with WEEE management in these countries, this paper has put forward some proposals and countermeasures for China’s better improvement.

Keywords: WEEE; WEEE management; environment; recycling system.

INTRODUCTION

Waste electronic and electric equipment (WEEE) is also called as E-wastes or end-of-life electronics, including household appliances, automatic dispensers and IT and so forth [1], and it has been one of the fastest growing wastes. It is reported that, the amount of WEEE has accounted for 8% of municipal waste [2], increasing by 3%-5% every year [3]. In consideration of technological progress in electronics industry, the life time of electronic and electric equipment (EEE) is becoming shorter and shorter, while its waste growth is in a tremendously speed [4]. According to a statistics, 12 million ton of WEEE is generated every year, but about 2.2 million tons of them are treated, only accounting for 18.3%. Therefore, it is necessary to make the WEEE to be re-used, recycled and recovered (called 3R) [5], and it has gotten great attention worldwide about the WEEE, especially in developing countries with a rapid industrialization and urbanization [6].

It is predicted that, old computers would increase about 500% by 2020 in India, and at the same time, it will be about 18 times higher than 2007 level with regard to mobile phones discarded [7]. The WEEE imported illegally to China is about 1.5-3.3 million tons every year [8], and more than 2.3 million tons of WEEE is produced annually with a growing trend all the time [9]. In developed countries, the total quantity of the WEEE is 20 to 50 million tons per year [10]. The quantity of the WEEE produced by the EU is between 8.3 and 9.1 million tons per year in 2005 [11], growing three times more compared to the growth of average municipal waste [12]. The amount of WEEE generated in America is 1.9 million tons in 2000, but it has achieved 3.41 tons in 2011 [13]. Due to lower recycling rate and so large quantity, televisions has become major concern in American and estimated that the amount of junk televisions is about 84.1 million in 2012, indicating every family has 40 pounds of scrap [14].

With the increasing use of electrical and electronic equipment, it has caused a severe pollution problem worldwide [15, 16]. Certainly, on account of the economic benefits and environment protection, it has attracted more and more attention to the recycling of the WEEE for the government and the public in recent years [17]. As we all know, waste electronic and electric equipment contains not only a variety of toxic and hazardous contaminants, but also a large number of valuable materials such as metals, glass, plastics and so on. Therefore, if it is treated in a proper way, a large number of valuable materials will be gained [18]. The most common materials found in E-waste are iron and steel (see Fig. 1), accounting for more than half of the E-waste [19]. With the development of science and technology, a large number of metals are used increasingly due to innovative technologies [20].

As is known from Fig. 1 that, the proportion of metal in the WEEE is 60.20%, and the proportion of plastic is much higher than the others. A statistics shows that the amount of E-waste has increased by 25% from 2007 to 2011, but the proportion for plastics has
reached 30% [19] because of the plenty of plastic utility in televisions, refrigerators and washing machines [21, 22, 23].

At present, the recycle of the WEEE has become an important topic [24], as it is necessary for energy recovery and waste treatment as well as the recycling of the valuable materials [4, 25, 26]. In fact, if we do not take any measures to deal with the E-waste based on environment consideration, then it will heavily pollute the environment [27]. Of course, there are still some obstacles in the recycle of the WEEE, including the technology, scheme, policy and so forth [25, 28, 29].

To date, substantial studies on the WEEE treatment in China have mainly focused on its treatment and technology. However, this paper will focus on the situation, effects and governance of the WEEE based on the existing researches, and it is expected that this review will be useful for researchers as well as practitioners and managers of the WEEE.

Fig-1: Typical materials in E-waste

WEEE MANAGEMENT SITUATION
E-waste contains a variety of valuable resources such as copper (Cu), gold, aluminium (Al) and so forth. If those valuable resources are not reused, it will not only cost a lot of resources, but also damage environment. Therefore, many countries have made a series of policies and means to recycle the WEEE [19].

WEEE management in Asia
In recent years, more WEEE has been produced in the Asian countries because of rapid economic growth [30]. India has a well-networked informal sector for the WEEE treatment [31], including some key players such as scrap dealers, the vendors and the recyclers [32]. However, India has become one of the major destinations of WEEE coming from OECD countries with approximately 50K tons of WEEE per year, showing an increasing trend [33, 34]. Fig. 2 shows the amount of the PCs sold in India from 2001-2009 [35].

Fig-2: Total PC sales in India from 2001 to 2009

China is a largest consuming and manufacturing country globally [36]. Because of rapid economic growing and urbanization, the consumption of EEE in China has been a rapid growth, resulting in enormous WEEE along with about 2.3 million tons of WEEE generated at home per year [37]. To this end, Chinese

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government has made recycling policies to encourage proper recycling since the late 1990s [38, 39]. At present, there are four sectors (e.g., supply, marketing cooperatives, manufacturers, individual recyclers, and dismantling companies, etc.) to recycle WEEE [40], and has made a great contribution to reuse and recycle the WEEE for economic and social implications [41]. Approximately 5 million people worked in the WEEE treatment industry in 2005, while people working in such industries have reached 0.7 million in 2007 and 98% of people work in informal recycling sectors (see table 1) [42].

### Table 1: Workers in the recycling sectors

<table>
<thead>
<tr>
<th>Stages</th>
<th>Number of employees per sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Formal</td>
</tr>
<tr>
<td>Collection</td>
<td>-</td>
</tr>
<tr>
<td>Disassembly</td>
<td>400</td>
</tr>
<tr>
<td>Material recovery</td>
<td>15000</td>
</tr>
<tr>
<td>Final disposal</td>
<td>600</td>
</tr>
<tr>
<td>Total</td>
<td>16000</td>
</tr>
</tbody>
</table>

In Japan, more than half of the end of life computers and home appliances maxed out has been transferred to other Asian countries such as China, Afghanistan, Philippines and others, and the WEEE is regarded by them as second-hand goods [43]. The policy about the “Recycling of Specified Kinds of Home Appliances” was issued in 1998 and come into force in April 2001 in Japan. The system of recycling WEEE in Japan is unique. Firstly, it includes a limited number of target appliances. Secondly, the system consists of a recharge fee system that consumers have to pay for the recycling treatment when disposes. The last is a direct recycling obligation for manufacturers (see Table 2) [44].

### Table 2: Average recycling fees (2007)

<table>
<thead>
<tr>
<th></th>
<th>Washing machine</th>
<th>CRT TV</th>
<th>Air conditioner</th>
<th>Refrigerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>US$</td>
<td>22</td>
<td>25</td>
<td>32</td>
<td>42</td>
</tr>
<tr>
<td>Euro(€)</td>
<td>16</td>
<td>18</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>Yen</td>
<td>2520</td>
<td>4830</td>
<td>3675</td>
<td>4830</td>
</tr>
</tbody>
</table>

**WEEE management in Europe**

In 2005, the quantity of WEEE in Europe has reached about 5 million tons, and is estimated to be 12.3 million tons by 2020 [45, 46]. Table 3 shows the kinds of WEEE recycled in Europe.

### Table 3: Types of WEEE recycled in the Europe

<table>
<thead>
<tr>
<th>EU WEEE Category</th>
<th>The proportion of WEEE recycling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large household appliances (washing machines, refrigerators, ovens)</td>
<td>49.07</td>
</tr>
<tr>
<td>Consumer equipment (TVs, DVD players)</td>
<td>21.10</td>
</tr>
<tr>
<td>Communication tools and IT(cellphone, laptop)</td>
<td>16.27</td>
</tr>
<tr>
<td>Small household appliances (toasters, vacuum cleaners)</td>
<td>7.01</td>
</tr>
<tr>
<td>Electronic tools and electrical (saws, drills)</td>
<td>3.52</td>
</tr>
<tr>
<td>Lighting equipment (lamps)</td>
<td>2.40</td>
</tr>
<tr>
<td>Automatic dispensers (money dispenser, drink)</td>
<td>0.18</td>
</tr>
<tr>
<td>Medical devices (dialysis)</td>
<td>0.12</td>
</tr>
<tr>
<td>Leisure, sports equipment and toys</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The European Union has taken strict recycling quotas for different categories of the E-waste [47]. Because the WEEE contains a mass of plastics, the proportion of plastics quotas is increasing all the time [48, 49]. Under the guidance of WEEE, the countries in European have increased the recycling of WEEE containing all the EEE for consumer and professional use [50]. However, it is reported that, merely 1/3 of the WEEE is collected separately and treated appropriately in Europe in spite of the regulations on recycling and collection, while the rest of the WEEE is possibly transported to landfill or sub-standard treatment places in Europe or outside illegally [51].
**WEEE management in America**

America has disposed over 1.3 million tons of WEEE per year in the first decade of the 21st century, and has issued relevant laws to manage the WEEE [52]. It is estimated that, 20-24 million wastes of computers and TVs are stored up instead of being recycled or disposed every year in 2002 [18].

**THE EFFECTS OF WEEE ON ENVIRONMENT**

WEEE has become a global problem, while approximately 1/2-4/5 of the WEEE has been exported to the developing countries (e.g., the Africa and the Asia, etc.) [53, 54, 55]. Therefore, those developing countries are confronted with huge challenges for electronic waste treatment. Hazardous substances in electrical and electronic equipment (EEE) have heavy metals such as gold, iron, copper and others as well as a variety of harmful plastics including flame retardants, polybrominated diphenyl ethers (PBDEs) and other substances, which will pose significant environmental and human health risks if not properly treated (see Table 4) [2, 56].

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Sources</th>
<th>Concerned substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT (Cathode ray tubes)</td>
<td>Old televisions, PC monitors, OSC (oscilloscope)</td>
<td>Pb in cone glass, Ba in electron gun getter, Cd in phosphors</td>
</tr>
<tr>
<td>PCB (Printed circuit boards)</td>
<td>Ubiquitous, from beepers to PCs</td>
<td>Pb, Sb in solder, Cd in contacts, Hg in switches, BFRs (Brominated Flame Retardants) in plastics</td>
</tr>
<tr>
<td>Cells</td>
<td>portable instrument</td>
<td>Cd in Ni-Cd batteries, Pb in lead acid batteries, Hg in Hg batteries</td>
</tr>
<tr>
<td>Gas discharge lamps</td>
<td>Backlights of LCDs</td>
<td>Hg in phosphors</td>
</tr>
<tr>
<td>Plastics</td>
<td>Wire insulation, plastic housing, circuit boards</td>
<td>PVC(polyvinyl chloride), BFRs (Brominated Flame Retardants)</td>
</tr>
</tbody>
</table>

If heavy metals in the WEEE are not treated properly, it will be remained in the environment, which will bring about poisoning at low concentrations through bioaccumulation in animals and plants to gather in food chain [57]. It is well known that, the plants can absorb heavy metals through uptaking from soil, while human beings and animals can absorb them through water, air, food, even skin contact [58]. When we eat meat on higher food chain, some heavy metals will be more accumulated in our bodies [59].

**The WEEE and environment**

The composition of the WEEE is so complex that the type of WEEE is diversity, which will have a serious pollution to environment [60]. The processing site of WEEE is often situated in the fields which are adjacent to land usually used for the purpose of agriculture in China, particularly for the informal recycling of WEEE [61]. The contaminants of WEEE could go into aquatic systems via lixiviating from WEEE dumpsite [62]. The vegetables and crops grown in the land can be polluted by the heavy metals through soil. If people irrigate vegetables and crops with the contaminated water, they will be polluted, too. As is known to all, these metals can be absorbed by the plants through their roots from soil, then enter into plant shoots, and finally accumulated inside plant tissues [63].

The largest city of WEEE recycling is Guiyu with its surrounding towns located in southeast Guangdong province of China [62]. Since 1995, the people in Guiyu have been engaged in the recycling of the WEEE [64]. About 80% people of Guiyu are engaged in the WEEE recycling recently [65]. However, because the techniques of WEEE treatment are simple, it has caused serious environmental pollution [66, 67]. In fact, a large number of sediments with basic physicochemical characteristics have been discovered in Guiyu (see Table 5).

<table>
<thead>
<tr>
<th>sediment</th>
<th>PH</th>
<th>TOC(%)</th>
<th>S(%)</th>
<th>N(%)</th>
<th>H(%)</th>
<th>C(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average values</td>
<td>3.97</td>
<td>39.3</td>
<td>0.80</td>
<td>1.42</td>
<td>4.66</td>
<td>40.0</td>
</tr>
<tr>
<td>Minimum values</td>
<td>3.68</td>
<td>35.7</td>
<td>0.63</td>
<td>1.21</td>
<td>3.99</td>
<td>37.4</td>
</tr>
<tr>
<td>Maximum values</td>
<td>4.35</td>
<td>41.6</td>
<td>1.02</td>
<td>1.78</td>
<td>5.06</td>
<td>44.1</td>
</tr>
<tr>
<td>Note: Depth in 0-80 cm and number of samples is 45.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

At the same time, it is found that, the pb concentration in the downstream river is 0.4 mg/L because of waste processing factories located in the upstream in Guiyu. What’s worse, the pb concentration
in some parts of the river is 8 times higher than local drinking water standard (0.05 mg/L) [68]. 22 PBDE congeners in the air are detected in PM2.5 [69]. Moreover, the levels of heavy metals are also very high in the air, leading to serious biological and environmental problems [70]. WEEE recycling in Guiyu has caused serious environment pollution of heavy metals in dust, too [59, 71].

The WEEE and human health

The WEEE includes more than 1000 materials and most of them are hazardous and toxic, which has caused a lot of serious problems to environment and human health. For example, for a recycling treatment worker on printed circuit board (PCB), the estimated oral daily dose of lead on average is 50 times more than that of the safe standard, indicating that it has adverse health effects [2]. Especially, heavy metals will cause the elevated levels of total suspended particles (TSP) in ambient air, which can increase the risks of mortality and morbidity of people [71].

According to the existing research, the heavy metals of WEEE could get into hair through different ways. For example, when the hair shaft is taking shape, the heavy metals can enter the blood and deep skin [72, 73]. In other words, the hair can be considered as an appropriate indicator to show the people’s health exposed to heavy metals of WEEE for a short and long term. Through detection, it may found that the levels of five heavy metals are ranked in the following order in Ni<Cd<Cu<Pb<Zn, while the levels in occupationally exposed workers is the highest [74]. 70.8% of the children in Guiyu have more blood Pb levels than 10 ug/dl, and 20.1% of the children are over 2 ug/L blood Cd levels [75]. In addition, people living in Guiyu have a much higher proportion of diseases than national average level in China, for instance, cutaneous infections, leukemia, and so forth.

THE SOLUTION OF WEEE PROBLEM

Compared with traditional municipal waste, the WEEE is a new kind of waste [76]. As we all know, the WEEE contains a variety of toxic substances, posing a danger to health and environment. As the policies aiming at traditional waste management cannot be applied to WEEE directly, so it is necessary to make a new way [77].

Effective WEEE management system construction

It is better to have an effective regulatory system for monitoring shipments, appropriate labeling and recycling of WEEE [78]. Up to now, although the legislation about WEEE management has issued, there are too many defects in China’s WEEE treatment.

Generally, there exist three channels to do with the WEEE in China [79]. The first is that the WEEE is transferred to second-hand markets where the WEEE can be sold for a reasonable price [18]. The second is that the WEEE owners would rather donate their idle home appliances to poor people who live in rural areas rather than selling them in second-hand markets in spite of such behaviors forbidden by national regulations [80]. The last is that the owners of WEEE sell their abandoned WEEE to packmen which will sell WEEE collected to WEEE dealers [1]. In China, the third channel is the main channel for WEEE.

However in Europe, American and Japan, the technologies of WEEE treatment are more mature and the degree of mechanization is higher [81]. According to Masahiro Oguchi et al. (2013), most of the metals contained in WEEE are handled as municipal solid waste. Therefore, the next target for metal recovery in Japan could be the small-grain fraction from the shredding and separation process in terms of both metal amount and content. During the process of recycling WEEE, the innovative separation and beneficiation techniques of different materials have a major improvement [2].

WEEE management policies

China has been aware of the environment and health effects of WEEE for a long time [82]. Therefore, Chinese government formulates relevant policies, laws and professional guidance to manage and control the WEEE recycling and the EEE production. The enterprise needs business licensing to collect, reserve and handle the hazardous waste in WEEE from July 1, 2004. The China WEEE Regulations was issued in August 2008 by the State Council, and it stipulates the implementation of EPR (Extended Producer Responsibility). At the same time, the “3R” indicating reduced, reused and recycled treatment principles has begun to come into force, and the illegal importation of WEEE is banned [83]. Of course, the framework of WEEE management is still imperfect in spite of a large number of laws and regulations in China. Not only is it lack of effective supervision and enforcement, but also is short of profession norm and standard.

Japan and the EU are the leaders in the WEEE treatment. Since February 2003, the legislation that restricts the use of hazardous substances in EEE in EU has been in force. From then on, many counties have started to issue similar legislation. In European countries, the collection schemes that the people who possess used e-waste can return them for free [52]. The schemes help to recycle or reuse the WEEE greatly. However, it is reported that, only 1/3 of the E-waste is collected separately and treated appropriately in
European in spite of such a regulation about recycling and collection (European Commission).

Since 2001, the recycling laws of home appliance have been issued in Japan, including for CRTs [84]. In Japan, the customers need to pay a recycling fee from 20 to 55 dollar which depends on the type of item and the retail outlets providing collection point. And if the producer is absence of recycling the WEEE, another firm must be designated for the role.

**WEEE plastic recycling**

The “3Rs” (reduce, reuse, recycle) was put forward by Japan at 2004 G8 summit [84]. The representative WEEE contains approximately 10-30wt % of plastic [85]. The important components of WEEE are PWB (Printed Wire Board) and PCB (Printed Circuit Board) with an ever increasing tonnage being generated [86]. Nevertheless, it is lack of the methods of WEEE recycling. The percentage of plastic in different appliances is summarized in Fig. 3 [17].

![Fig. 3 The percentage of plastic in different appliances](image)

Note: 1 indicates large cooling appliances, 2 small WEEE, 3 printers, 4 copying equipments, 5 CPUs, 6 CRT monitors, 7 CRT televisions, respectively.

At present, the widely used method of plastic waste recycling is incineration, and plenty energy can be obtained and used for electricity generation [87]. Whereas, it will produces a large number of harmful substances that could be dangerous to the environment in the process of incineration, too. The materials, during the process of pyrolysis, are heated to very high temperatures, and will decompose into smaller molecules such as oils, gases and chars for reuse due to lack of oxygen. Therefore, this technology is worthy to be popularized in China [88, 89].

**CONCLUSION**

In recently years, as the rapidly growing production of EEE has caused a great pressure for environment and issues, so WEEE recycling and management have made a great attention in the world, especially in developing countries [27]. In the near future, with the development of advanced information technology, a large quantity of WEEE will be generated.

The WEEE not only contains a larger number of useful metals such as copper, iron, aluminum and others, but also all kinds of harmful materials. The conventional methods of WEEE recycling have a great effect on environment and people health, which will cause serious environment pollution and complicated disease for people. To deal with the WEEE more efficiently and economically, China must consider a systematic method to solve all the associated problems [86]. Although China has issued a series of laws on WEEE recycling, the situation of WEEE recycling is still worrying. Therefore, how to solve the problem of the WEEE effectively is a long-term and arduous task for China.

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