



“Gheorghe Asachi” Technical University of Iasi, Romania



STUDY ON WEEE COLLECTION AND RECYCLING SCHEME IN TYPICAL ASIA-PACIFIC COUNTRIES

Yuan Chen¹, Shite Li¹, Quanyin Tan¹, Jinhui Li¹, Youping Miao^{2*}

¹Key Laboratory for Solid Waste Management and Environment Safety (Tsinghua University),
Ministry of Education of China, School of Environment, Tsinghua University, Beijing, 100084, China

²National WEEE Recycling Engineering Research Center, Jingmen, Hubei, 448124, China

Abstract

The environmental and economic impacts posed by waste electrical and electronic equipment (WEEE) make an effective collection and recycling scheme necessary for developing countries. Currently, developing countries in the Asia-Pacific regions are highly variable in terms of their present state of WEEE management, due to different economic conditions and levels of management. In this paper, we surveyed existing WEEE collection and recycling system in three Asia-Pacific developing countries – China, Sri Lanka, and Pakistan, using SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis, analyzed key factors for an effective formal collection and recycling system, and identified priority fields that can be targeted by governments. Key factors that were considered include: government involvement, legislation, functional mechanisms, the presence/absence of advanced technology and facilities. Priorities for China were identified, including: expansion of WEEE scope that would be covered by the formal collection and recycling scheme, continued WEEE flow to the formal WEEE recycling sector, and enhancing law enforcement. For Sri Lanka, putting into place specific WEEE legislation and policies, establishing effective facilities for collection and recycling of a greater range of WEEE types, and the enhancement of pollution control are priorities. In Pakistan, commencement of government involvement and policy interventions on WEEE are considered to be of priority. General policy recommendations were also proposed for reference.

Key words: collection and recycling scheme, recommendations, SWOT analysis, WEEE

Received: August, 2017; *Revised final:* March, 2018; *Accepted:* June, 2018; *Published in final edited form:* July 2019

1. Introduction

As has been reported, the global generation of waste electronic and electrical equipment (WEEE) has grown to 44.7 Mt in 2016, and will continue to increase in the future (Baldé et al., 2015, 2017; Gorauskiene and Stasiskiene, 2017; Rucevska et al., 2015). The growing trends of WEEE generation has become a great challenge to the environment at the global level.

WEEE contain valuable materials, including copper, precious metals (gold, silver, palladium), and other recyclable materials (such as, ferrous metals, plastics, rubbers, etc.). Effective recycling is of great economic value and can offset the consumption of

natural resources. WEEE also contains hazardous components or materials, for example, lead, mercury and brominated flame retardants, etc. Inappropriate treatment will lead to emission of pollutants to the air, water and/or soil, posing great risk for human health and the environment. Therefore, efficient treatment and recycling of WEEE is critical for countries to balance the environmental and economic impacts of WEEE.

Although in 2016, only 20% of WEEE generated globally was formally collected and recycled, more countries are developing policies and legislations to deal with the challenges WEEE poses (Baldé et al., 2017). According to the known statistics, countries covered by national WEEE legislation have

* Author to whom all correspondence should be addressed: e-mail: jinhui@tsinghua.edu.cn; Phone: +86 10 82686410; Fax: +86 10 62772048

increased from 61 in 2014 to 67 in 2017 (before January 2017). Some countries/regions such as the European Union, Japan, and Republic of Korea began formal management in late 20th century and have in place well-developed and effective legislation. Some countries like Australia, China and India have developed specific WEEE regulations, while gaps still exist in its implementation, the involvement of producers, control of informal sectors etc. (Amato et al., 2017; Awasthi and Li, 2017; Baldé et al., 2017; Kumar et al., 2017; Herat and Agamuthu, 2012; Morris and Metternicht, 2016, Salhofer et al., 2016;). Some countries such as Indonesia and Philippines have legislation under development but not yet in place (Yoshida et al., 2016). For most developing countries, national WEEE management is completely absent, and WEEE is more likely to be treated as general waste, leading to the waste of resources and uncontrolled environmental pollution (Baldé et al., 2017; Herat and Agamuthu, 2012; Premur et al., 2018).

Many developing countries face even more severe challenges on WEEE management. Apart from domestically generated WEEE, illegally imported WEEE from developed countries also pose a major challenge. Most countries in the South and Southeast Asia have been shown to be the major illegal waste export destination, for example, Pakistan, Thailand, Vietnam, Malaysia, Philippines, Indonesia and India (Ikhlayel, 2018; Rucevska et al., 2015). However, through an extensive survey, most developing countries in Asia-pacific regions have been found to be incapable of properly recycling and treating the significant amount of WEEE they confront. The informal sector invariably constitutes a major receiver of WEEE – virtually guaranteeing that environmentally sound management does not occur. The informal sector tends to involve mostly people who are at the bottom of the economic ladder; mired in poverty. In these countries, such person derive their live hoods from the WEEE collection and recycling industry. Driven to escape poverty, they tend to have scant knowledge of pollution control or personal safety protection, and thus face higher risks of health- and environment-related harm. For such developing countries that face WEEE-related challenges, the establishment of effective formal system to promote the environmentally sound collection, recycling and treatment of WEEE, to formalize the existing collection and recycling industry will be necessary. Such “formal” scheme would comprise a system for the environmentally sound collection and processing of WEEE overseen by government, with private sector participation where appropriate.

Normally, the experience of WEEE management in some developed countries can provide guidance to those developing or emerging countries that lack comprehensive systems. While considering the specific and unique issues or challenges different countries may face, it is important to refer to developed country experience and customize more adaptable and localized management strategies and policies, appropriate to their needs and unique

situations. Therefore, to identify the specific challenges each country faces to formalize its WEEE management system is necessary. In this paper, three Asia-Pacific developing countries at different development stage regarding WEEE management - Pakistan, Sri Lanka and China were studied to provide guidance on how to identify challenges and establish a clear formal management system for similar developing countries. First, the current status of WEEE policy, collection, recycling and treatment in these countries has been surveyed through information review and site visits. Second, a set of general factors one could consider for the development/strengthening of a formal scheme were considered through SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis. Based on the analysis, recommendations for specific priority challenges that could be targeted by these three countries were put forward. Third, recommendations to establish or optimize an effective formal scheme were proposed for other countries facing similar WEEE issues.

2. Case studies

2.1 WEEE generation in China, Sri Lanka and Pakistan

Fig. 1 shows the domestic volumes of WEEE generated in some developed and developing countries in 2016 (Baldé et al., 2017). By comparison, the WEEE generated per inhabitant in most Asia-Pacific developing countries including China (5.2 kg), Sri Lanka (4.5 kg), Pakistan (1.6 kg), Cambodia (1.0 kg), Myanmar (1.0 kg), Philippines (2.8 kg), Lao PDR (1.0 kg), Viet Nam (1.3 kg), Nepal (0.8 kg) are far less than that in developed countries - such as Japan (16.9 kg), Norway (28.5 kg), and USA (19.4 kg). Nevertheless, considering population size, the total waste of some Asia-Pacific countries is significant. For example, the total volume of domestic WEEE generated in China ranks highest in the world - 7211 Metric kilotons (Mt). The total volume of WEEE generated in some developing countries include Pakistan (301 Mt), Philippines (290 Mt) and Nepal (230 Mt) is greater than Norway (150 Mt), which generated the most WEEE per inhabitant.

More specifically, China has become one of the biggest WEEE generator in the world. In 2016, WEEE generated in China accounted for nearly 16.1 percent of the worldwide WEEE (Baldé et al., 2017). In Sri Lanka, the WEEE generated per inhabitant is approximately the same as in China and is relatively high among Asia-Pacific developing countries. The increasing usage of EEE among the public (Maheshi et al., 2015; Mallawarachchi and Karunasena, 2012) and import of some used or reconditioned WEEE will keep contributing to future annual increases of WEEE. In Pakistan, the volume of domestic WEEE generated is higher than other surrounding developing countries including Cambodia, Myanmar, and Viet Nam etc (Fig. 1).

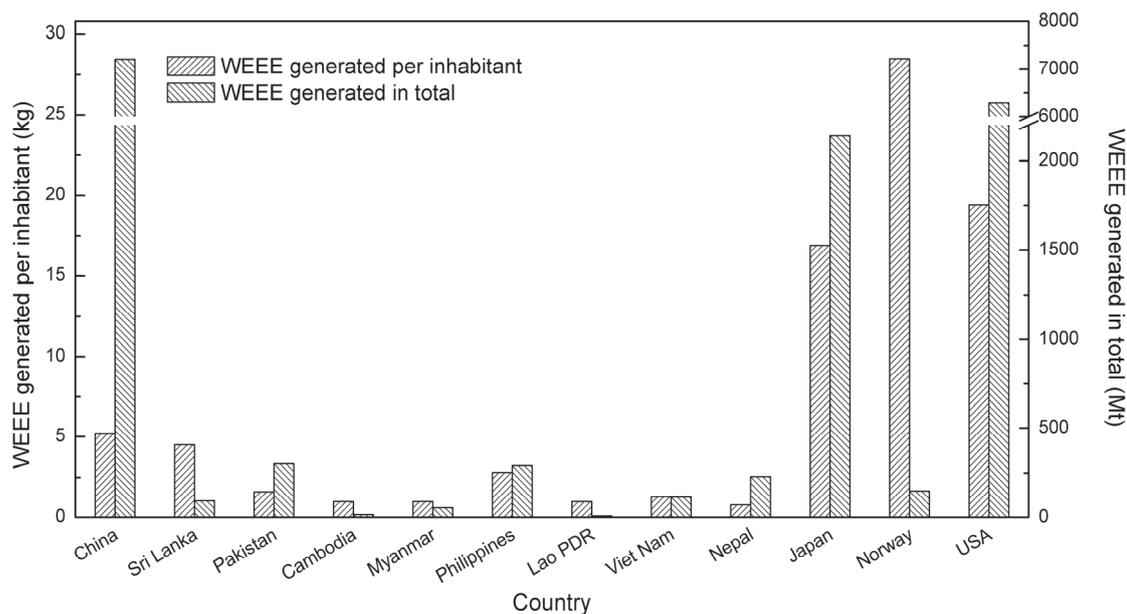


Fig. 1. The domestic WEEE generated per in habitant (kg) and in total (Mt) in some developed and developing countries in 2016

It also imports a large volume of used and discarded EEE such as CRT monitors, computers, televisions, printers, and scanners every year to provide usable components for its electronics industry (Imran et al., 2017; Li et al., 2013), and faces the issue of increasing WEEE amount.

2.2 WEEE Policy in China, Sri Lanka and Pakistan

China began formal management of WEEE in 2002, when the Law on Clean Production Promotion entered into force. Until now, a top-down legislative framework including a series of laws, administrative regulations, ministerial decrees, technical specifications and standards has been established. Provisions related to the green design and manufacture of EEE, WEEE collection, recycling and treatment are included. Table 1 lists the main laws and regulations focusing on WEEE management.

The state laws issued by the Standing Committee of the National People's Congress (NPC) are top-tier laws for WEEE management, which required that WEEE collection, recycling and treatment should be conducted in an environmentally sound manner. The Regulation on the Management of the Recovery and Treatment of Waste Electronic and Electrical Products (No. 551) (The State Council, 2009) serves as the governing umbrella for WEEE recycling and treatment in China. First, it authorizes Ministry of Commerce to take charge of the WEEE collection, Ministry of Environment Protection and Ministry of Industry and Information Technology (MIIT) to manage WEEE recycling and treatment. Other departments including Ministry of Finance (MOF), National Development and Reform Commission (NDRC), and National Standard Administration (NSA) provide support during policy formulation. Second, multiple mechanisms that

should be established for WEEE management are clearly put forward in the regulation. Among them, a WEEE catalogue, and matched licensing system and funding subsidies for enterprises, a multi-channel collection network and centralized treatment are key mechanisms. The Ministerial decrees and technical specifications issued by corresponding competent authorities (listed in Table 2) comprise specific measures to establish and run these key mechanisms. Furthermore, some standards listing technical requirements and guidelines also provide practical guidance on “recyclable” labeling, recycling and disposal equipment, information exchange practices between manufacturers and collectors, as well as dismantling operations and pollution control. The legislative framework has greatly promoted the WEEE recycling industry in China, and a resultant well-operated collection and recycling system involving dozens of qualified enterprises has been established.

It is worth noting that, currently, the licensing and funding subsidy mechanisms in China only cover the 1st batch of WEEEs listed in China's WEEE catalogue (TV sets, refrigerators, air conditioner, washing machine, and computers). The government has published the 2nd batch (9 more categories) of its WEEE catalogue, however the corresponding management operations still require time to be put into practice.

In Sri Lanka, the National Environmental Protection & Quality Regulations No.01 issued in 2008 (MENR, 2008a) prescribes specific types of WEEE as hazardous waste (discarded computers and accessories, discarded mobile phones, also called “scheduled waste”) under Schedule VIII, and regulates that only enterprises who obtain a License for Scheduled Waste Management (SWM License) can process these categories of wastes.

Table 1. The main laws and regulations focusing on WEEE recycling and treatment in China

<i>Hierarchies</i>	<i>Law/Regulation Name</i>	<i>Focus area</i>
State law	Law on the Promotion of Clean Production	Comprehensive
	Law on the Prevention of Environmental Pollution caused by Solid Waste (2004 version)	Comprehensive
	Law on the Circular Economy Promotion	Comprehensive
Administrative regulation	The Regulations on the management of Recovery and Treatment of Waste Electrical and Electronic Products (WEEE) (No. 551)	Core regulation for WEEE management
Ministerial decree	Administrative Measures on the Prevention and Control of Environmental Pollution by WEEE	Pollution control
	Administrative Measures on Renewable Resources' Collection	Collection
	Administrative Measures on WEEE Collection (Draft)	
	Administrative Measures on Qualification License of the Treatment and disposal of WEEE	License
	Administrative Measures on Collection and Use for Treatment Fund of WEEE	Subsidy Fund
Technical Specifications and standards	The Circular on Strengthening Environmental Management of Waste Electrical and Electronic Equipment	Disposal
	Announcement on Establishment of Information System and Guidelines for information submission by Treatment Enterprises of WEEE	Information plat-form
	Technical Specification on Pollution Prevention of Discarded Appliances and Electronic Products	Pollution Control
	The Catalogue for WEEE Treatment (1 st batch)	Catalogue
	Guidelines for Review the Subsidy Application from WEEE Treatment Enterprises	Subsidy Fund
	Environmental Protection Technical Specifications for Centralized District undertaking Disassembly, Utilization and Disposal of Waste Mechanical and Electrical Equipment (HJ/T181-2005)	Treatment facility
	General Technical Specifications of Recycling for Waste Electrical and Electronic Equipment (GBT23685-2009)	Recycling
	Technical Specifications of Pollution Control for Processing Waste Electrical and Electronic Equipment (HJ 527)	Pollution control
	"Recyclable" Labelling Requirements for Products and Accessories (GB/T23384-2009)	Labelling
	Standard Information Exchange Format between EEE producers and WEEE Treatment Enterprises (GB/T 29770-2013)	Information exchange
	Technical Requirements for Dismantling of Microcomputers. (GB/T 31371-2015)	Dismantling
	Technical Requirements for Dismantling of Printers (GB/T 31372-2015)	Dismantling
	Technical Requirements for Dismantling of Copiers. (GB/T 31371-2015, GB/T 31372-2015, GB/T 31373-2015)	Dismantling
	Technical Requirements for Dismantling of Plasma TV. (GB/T 31374-2015)	Dismantling
Technical Requirements for Dismantling of LED TV. (GB/T 31375-2015,)	Dismantling	
Technical Requirements for Dismantling of CRT TV. (GB/T 31376-2015)	Dismantling	

Table 2. Official WEEE recycling data during 2013-2017 in China

<i>Year</i>	<i>Amount (million units)</i>	<i>Weight (million tons)</i>	<i>Recycling value (billion dollars)</i>
2017	16370	373.5	N/A
2016	16055	366	N/A
2015	15274	348	N/A
2014	13583	313.5	1.27
2013	11430	263.8	1.13

Now, the Central Environment Authority (CEA), which was authorized to govern the environment management according to the National Environment Act No. 47 of 1980 (MENR, 2008b), is planning to amend the categories of schedule waste so that more types of WEEE can be included in the regulation. The specific laws on WEEE management in Sri Lanka have been drafted and the competent authority is in the process of finalizing the draft. Besides the existing or draft regulations, the

government is testing a subsidy mechanism for licensed formal recyclers to promote WEEE recycling and treatment.

The government of Pakistan, the government has not, to date, been involved in WEEE management. The Pakistan Environment Protection Act (PEPA) prohibits the discharge or emission of effluent into air, water or soil in excess of National Environment Quality Standards (NEQS). Except that, no general or specific legal requirements on WEEE collection and

recycling industry have been issued. The informal industry dominates the WEEE recycling market in Pakistan.

2.3. WEEE collection in China, Sri Lanka and Pakistan

In China, the Ministry of Commerce (MOC) is responsible for management of WEEE collection (MOC, 2015a). Currently, MOC has established a nation-wide collection network, integrating present individual collectors and developing new channels established through implementing regulations or projects.

The major formal collection channels in China include:

- Traditional collection chain: individual collector/second hand market/repair store to medium-sized or large scale collectors

- Collection channels and authorized collectors established as part of national “Home Appliance Old for New Rebate Program” from 2009-2011, which has proven to be highly efficient

- With the national “Home Appliance Old for New Rebate Program” project, consumers could receive a 10% discount to buy new appliances (of only the five categories listed in the 1st batch of the WEEE catalogue) if they sold their old electrical appliances to licensed collectors or recyclers (MOF, 2009).

- Collection network established by MOC: 1) 51550 pilot collecting points in typical cities---- 341 pilot sorting points-----63 pilot terminal markets (until 2014); 2) Novel collection channels in specific developed cities: including e-platform and self-service collection sites in Shanghai province.

- Further collection point and online collection networks established by recycling enterprises (Tian, 2017).

Based on the national multi-channel collection network, the recycling amount of 1st batch categories of WEEE as well as profits from the recycling process in formal sector is gradually increased from 2011-2017. As shown in Table 2, in 2017, over 16370 million units, totaling 373.5 million tons of 1st batch WEEE were recycled (MOC, 2014, 2015b, 2016, 2017, 2018).

Similar to China, Sri Lanka has also established an island wide collection system, combining widespread traditional collection channels like door to door collection with a further collection network promoted by the government. The collection system can be classified as follows:

- Widespread collection chain formed in the traditional sector, especially in rural regions.

- Collection centers established under the “National Cooperative E-Waste Management Program”

- As part of the Program, the CEA, in cooperation with 19 domestic telecommunication service providers, electronic vendors, and WEEE management companies as well as software

companies have promoted the establishment of a nationwide collection network, including transforming franchise shops or sales outlets into collection sites. Generally, telecommunications service providers only collect mobile phones and batteries, while WEEE management companies collect almost all types of WEEE.

- Regular or irregular drop off events are organized by formal collectors or partner organizations in the “National Cooperative E-Waste Management Program”. Generally, the events are held under the supervision of CEA.

- Collecting WEEE from commercial and industrial companies or factories through directly signing agreements with these establishments.

- Some electronic vendors, especially TV sets vendors, participate in an extended producer’s responsibility based collection mechanism. By handing over their waste electronic devices, consumers can receive a discount when purchasing a new similar electronic product in retail stores.

Over the years’ development, the formal collection system in Sri Lanka has greatly expanded. People’s awareness of the formal WEEE collection system has also improved, and presently a significant proportion part of the general public has the tendency to hand over their e-waste to collectors rather than throwing as municipal solid waste.

The WEEE collection system in Pakistan is completely driven by market forces (through the informal sector) at present. WEEE is bought by individual junk buyers at different prices, and then flows to dismantling and recycling workshops. Although the collected WEEE is not recycled in an environmentally sound manner, such an informal collection system nevertheless increases awareness of individuals on WEEE-related issues.

2.4 WEEE recycling and treatment in China, Sri Lanka and Pakistan

In general, China, Sri Lanka, and Pakistan share similar processes for WEEE management both regarding the formal and informal sectors, as shown in Fig. 2. After collection, WEEE are transferred to dismantling site. Then the dismantled products are sorted and valuable materials such as reusable components, metals, and plastics are recycled through physical or chemical treatment. Components will not normally be recycled if hazardous materials are involved. However, due to differences between technology that are used and the capacities of existing facilities, the recovery rate and the pollution conditions vary significantly among the three countries. This section therefore focuses on the recycling and treatment operations ongoing among these three countries.

At present, in China, there are 109 licensed enterprises qualified to handle any or all of the five primary categories listed as the 1st batch of the WEEE catalogue (MEP, 2015). The nature of the treatment of WEEE in the formal sector is based on its category.

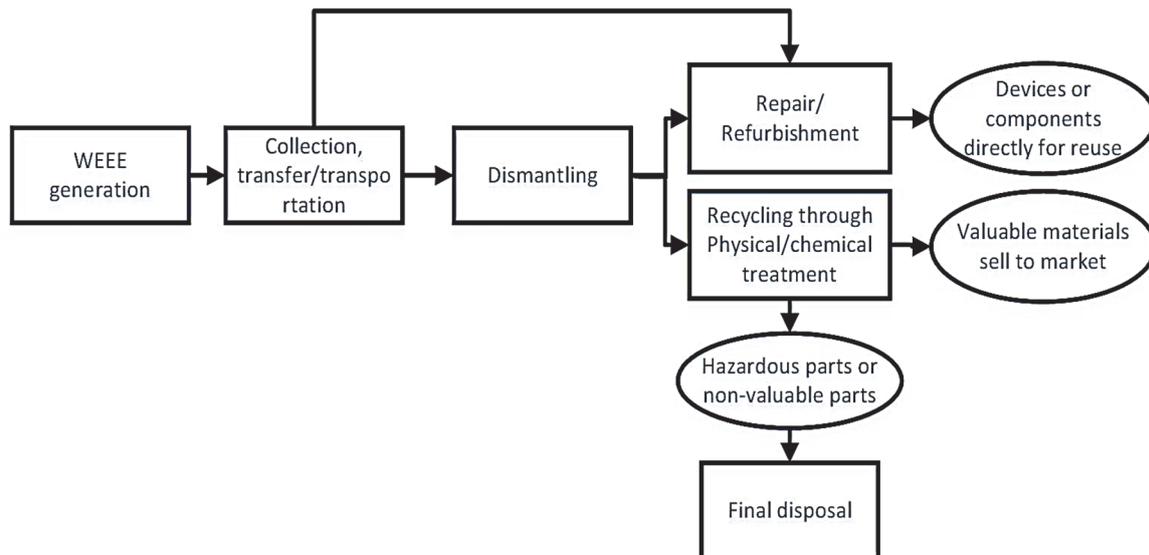


Fig. 2. The general flow of WEEE management in China, Sri Lanka and Pakistan

After sorting, weighing and labelling, specific WEEE are fed into corresponding manual/mechanical disassembly lines. On the line, the components or devices are disassembled in sequence through manual dismantling coupled with mechanical assistance. The dismantling products are then classified and sent to further processing lines. For example, for televisions and computer monitors, the Cathode Ray Tube (CRT) is removed with heated wire under negative pressure to separate the cone-glass from the funnel glass, and the vacuum aspiration method is used to capture fluorescent powder.

Printed Circuit Boards (PCBs) are commonly treated through mechanical shredding and then hydrometallurgical recovery to recycle precious metals, copper and other nonferrous metals. For cooling and freezing equipment, automatic and hermetic treatment systems are installed to capture the coolants. The plastic components are crushed and separated as Propene Polymer (PP), Acrylonitrile Butadiene Styrene (ABS), Poly Styrene (PS) granules. Polyurethane foam is separated through crushing and winnowing. Base board is recycled through crushing and sorting technologies to separate copper metal and non-metallic materials.

At the endpoint of the dismantling and recycling process in the formal sector, precious metals, ferrous and non-ferrous metals (copper, aluminum, magnet, various alloys etc.) and plastics are the most sought-after materials. Usually, plastic granules are used for remanufacturing. CRT glass is used for glass tube remanufacture. Material or components including fluorescent powder, polyurethane foaming, collected dust, batteries are sent to hazardous waste treatment enterprises for centralized disposal. The main materials flow during WEEE recycling can be seen in Fig. 3.

According to legal requirements, most facilities in the formal sector in China have installed emission control or pollution control equipment, such

as dust collectors and ventilation equipment. Workers are required to wear protective equipment. Some enterprises, however, continue to not value pollution control and worker safety, and therefore more supervision from government is needed.

In Sri Lanka, formal dismantling enterprises need qualify for a Scheduled Waste Management License (Hazardous Waste Management License). Currently, there are 7 formal enterprises engaged in WEEE collection and recycling (CEA, 2017). In the formal sector, WEEE is manually dismantled to separate PCBs, plastics and other metal components. After dismantling, some devices or components are repaired for reuse if they are in good working condition; the plastic parts are crushed and prepared for manufacturing electric switches, plugs, shoe sole and heels; metal parts are sold to smelters to extract metals through normal technologies; and some valuable components like CRTs and PCBs are sold to qualified facilities in other countries. Under normal circumstances, materials with no value are disposed of through open-burning or dumping. About 2-10 trained workers are placed in each dismantling operation. Fig. 4 summarizes the materials flow for formal WEEE recycling in Sri Lanka.

In Pakistan, the collected WEEE are dismantled and sorted manually into fractions in small workshops, and no ventilation and pollution control equipment are specially provided. Among dismantled products, components in good working order are sold for reuse; components containing metals are either burned or "backyard smelted" to extract metals. Components without resale or reuse values are openly burnt or disposed of through open dumping (Imran et al., 2017; Umair et al., 2015). Due to a lack of protective working conditions and advanced treatment technologies, the toxic substances or fugitive emissions released and wastes with strong acid after-treatment pose great risks to the environment and human health.

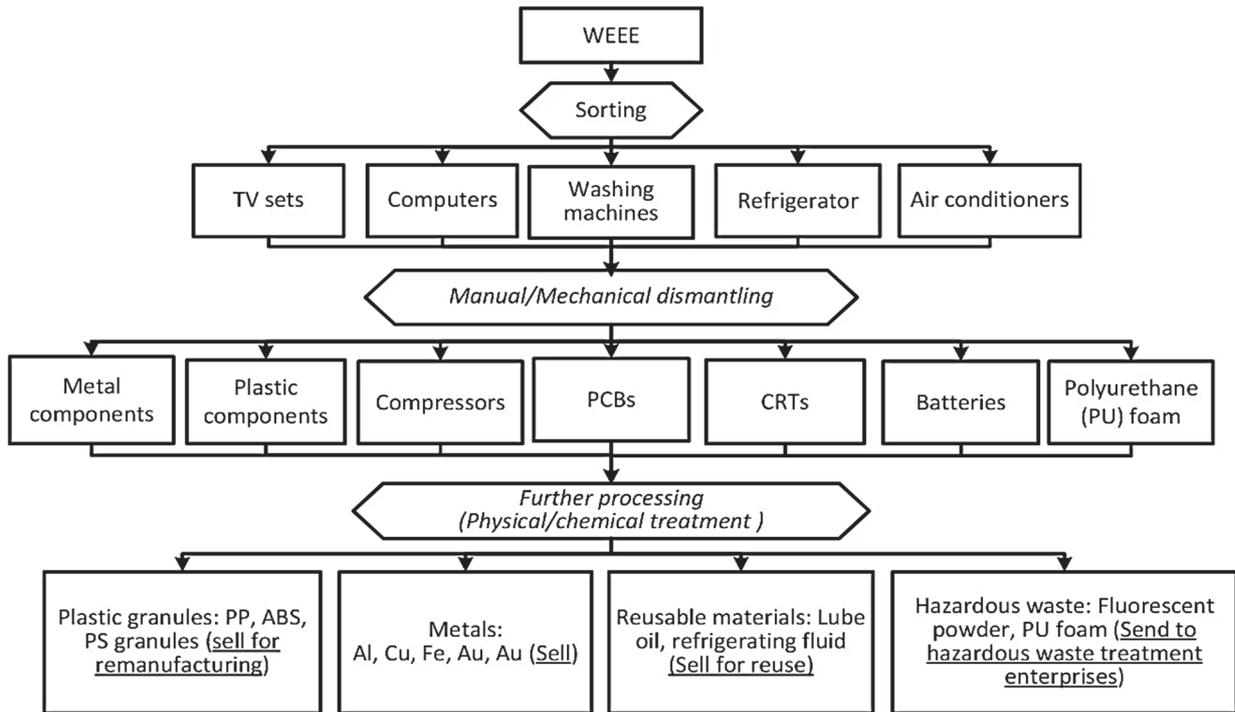


Fig. 3. The general material flow for the formal WEEE recycling process in China

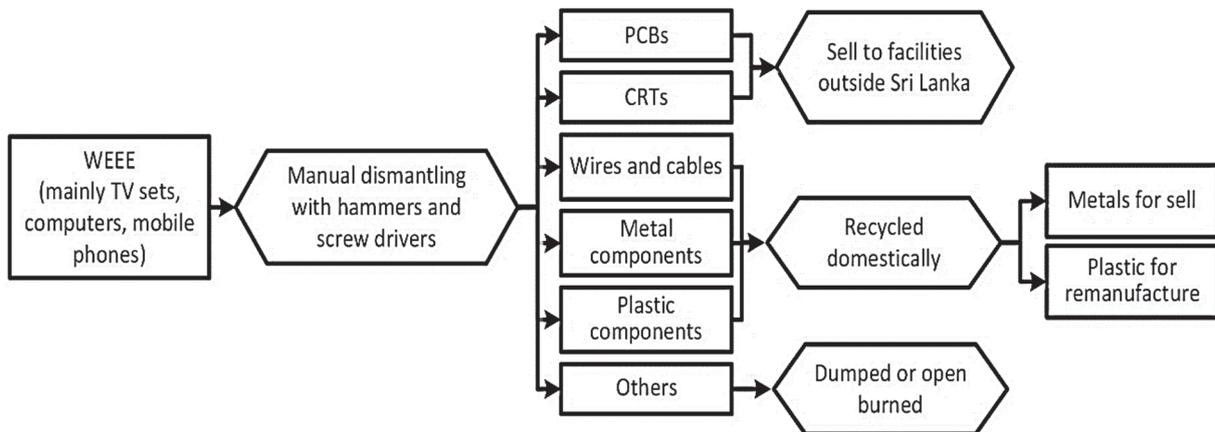


Fig. 4. The general flow for the formal WEEE recycling process in Sri Lanka

3. Results and discussions

3.1. SWOT analysis

SWOT analysis (alternatively SWOT matrix) is a structured planning method that aims to identify the key internal factors (strengths and weaknesses) and external factors (opportunities and threats) to achieve the objectives or strategy of a project, a process or an organization. After identifying both internal and external factors which have effects on the performance of the said project/process/organization, a clearer vision of possibilities regarding success and failure can be achieved. As a result of a well-executed SWOT analysis, activities and objectives can be confirmed and modified accordingly. Normally, areas identified as “strong” need to be enhanced and sustained, areas identified as “weak” need to be fixed

or eliminated; external “opportunities” need to be realized, and “threats” need to be prepared for and/or avoided (Jaber et al., 2015). SWOT analysis is primarily used in the field of economics, however it has been increasingly applied in various fields, including environmental research (Beloborodko et al., 2015; Chen et al., 2014).

Tables 3-5 represent the SWOT analysis of the formal WEEE collection and recycling systems in China, Sri Lanka and Pakistan, respectively. The internal factors refer to elements that a well-planned formal system should contain, such as legislation, facilities, etc. The external factors refer to the outside-the-system factors that will promote or restrict the development of the formal system. One should note that a single factor may be classified both in terms of strengths or weaknesses, opportunities or threats due to different national conditions.

Among the opportunities, all countries face same WEEE-related situation. Increasing amount and types of WEEE are being generated each year, creating significant environmental pressures and a high potential realizing profits from recycling. This situation catalyzes governments and relevant

stakeholders to take action. Secondly, as WEEE has become a global issue, it becomes more promising for developing countries to receive more technical assistance and financial support from international society through funds or cooperation projects.

Table 3. SWOT analysis of the formal WEEE collection and recycling scheme in China

<p>Strengths:</p> <ul style="list-style-type: none"> a. Implemented systematic laws and regulations; set up comprehensive standards. b. Established a well-operated license mechanism for WEEE recycling and treatment. c. Traditional collection (informal sector) and collection under the national policy guidance constitute a multi-channel collection system. d. Established a WEEE treatment fund to subsidize the dismantling and processing of WEEE. e. Dozens of licensed enterprises are well-operated. Relative environmentally sound recycling and treatment technology and equipment has been placed in formal sector. f. Established an effective manual/mechanical disassembly line. g. Almost all components of WEEE are properly disposed. 	<p>Weaknesses:</p> <ul style="list-style-type: none"> a. Currently, only computers, TV sets, refrigerators, air conditioners, washing machines and a very small part of defective appliances are recycled adequately in the formal sector. b. Lack of a competitive and cost-effective system to collect WEEE: 90% of WEEE that is collected by licensed recycling enterprises are from traditional large-scale collectors, which procured WEEE from a multiplicity of small-sized informal collectors. c. Transportation and labour costs greatly increase the collection cost.
<p>Opportunities:</p> <ul style="list-style-type: none"> a. The government highly values the environment protection industry, including the WEEE recycling industry. b. More knowledge, techniques, and equipment for dismantling, in-depth recycling, final disposal and emissions control have been put into action in recent years, bringing about an improvement in practical operations. c. Increasing volumes and categories of WEEE are generated every year, resulting in greater potential economic profits for the WEEE collection and recycling industry. 	<p>Threats</p> <ul style="list-style-type: none"> a. Licensed facilities face shortages of WEEE for recycling. A competitive and cost-effective collection system to further diminish the informal sector should be established. b. Some informal collectors still tend to deliver collected WEEE to informal recyclers, leading to improper recycling and treatment. c. More types of WEEE will be included in formal sector, which may need more specific technologies, and a larger scale for the industry.

Table 4. SWOT analysis of the formal WEEE collection and recycling scheme in Sri Lanka

<p>Strengths:</p> <ul style="list-style-type: none"> a. A nation-wide collection system including a collection network has been established under national projects, and the informal collection system is well-operated. b. An effective mechanism to collect WEEE from relevant generators has been established, for example, through the signing cooperative agreements. c. A licensing system for collectors and recyclers has been established. d. Subsidies are provided to licensed recyclers for WEEE recycling and treatment. 	<p>Weaknesses:</p> <ul style="list-style-type: none"> a. Lack of a systematic legal framework for WEEE management. b. Dismantling processes that depend on manual operation without pre-sorting are less effective and less productive. c. More formal sector collectors and recyclers are needed to handle the increasing volumes of WEEE. d. Lack of in-depth recovery facilities for some valuable components (i.e., PCBs, CRTs.). No facilities are available for the final environmentally-sound dispose of hazardous wastes. e. Lack of advanced knowledge, experience, technology and equipment for WEEE dismantling, treatment, recycling and final disposal.
<p>Opportunities</p> <ul style="list-style-type: none"> a. The government is finalizing targeted laws for the WEEE industry. b. With increased economic development, the increasing amount of domestically-generated WEEE and imported WEEE provide sufficient raw materials for the WEEE recycling industry. c. As WEEE management has become a global issue, more international cooperation and technical assistance will be available. 	<p>Threats</p> <ul style="list-style-type: none"> a. Awareness of environmental management of WEEE among the general public is still low, especially in rural areas. b. A large proportion of informal collectors tend to deliver collected WEEE to informal recyclers, leading to improper recycling and treatment. c. Limited support for in-depth recycling, pollution control in the WEEE industry.

Table 5. SWOT analysis of the formal WEEE collection and recycling scheme in Pakistan

<p>Strengths</p> <p>a. An effective and nation-wide informal collection system exists.</p>	<p>Weakness</p> <p>a. No relevant legislation in place</p> <p>b. No formal system including licensed enterprises and effective mechanisms for collection and treatment have been established</p> <p>c. Lack of knowledge, experience and technologies for the systematic and proper recycling of WEEE.</p>
<p>Opportunities</p> <p>a. WEEE recycling remains a new market, no formal recyclers are involved.</p> <p>b. As WEEE management becomes a global issue, more international cooperation and technical assistance will be available.</p>	<p>Threats</p> <p>a. Low awareness on environmentally sound management of WEEE among the public restricts the development of the formal collection and recycling system.</p> <p>b. Limited support for the development of WEEE industry.</p> <p>c. Significant numbers of persons rely on the WEEE collection and recycling in the informal sector.</p>

Additionally, the efforts of governments to formulate and enact relevant laws, catalyze research and development into relevant technologies, as well as to provide financial support through subsidies also creates significant opportunities for the development of formal systems. On the contrary, a lack of government involvement may be translated into significant threats or weaknesses, especially for countries like Pakistan, which has not yet established a formal collection and recycling system.

Regarding threats for these countries, the key threat is informal recycling. China, Sri Lanka and Pakistan all have widely-distributed informal collection sites which motivate the public to deposit WEEE for recycling rather than dumping WEEE as common waste. However, some collectors tend to deliver their collected WEEE to informal recyclers, which leads to the improper treatment of WEEE and poses great risk to human health and the local environment. Lower awareness of the environmentally sound treatment of WEEE among stakeholders (especially the public) will restrict the development of the formal system. For example, if the public doesn't use a formal collection system, the possibilities for WEEE flowing to the informal sector will be increased. For China, with the development of licensed recycling facilities, the formal collection network has already failed to provide enough WEEE as raw materials for recyclers. Therefore, how to keep a sufficient volume of WEEE flowing to licensed collectors and recyclers is an issue to be resolved.

Among strengths and weaknesses, government management including legislation and supporting mechanisms are fundamental and essential elements for formal systems to be a success. After the legal framework is put into place, effective enforcement and government supervision can maintain the operation of the legal framework. China has established a relatively complete management system for WEEE collection and recycling in the formal sector, however further supervision by government is required to keep the system effectively implemented. Further improvements need to be made to ensure a more cost-

effective and streamlined formal system continues into the future. For example, clarifying the relative responsibilities of the producers and the public, establishing mechanisms to encourage the public and informal collectors to transfer WEEE to formal recyclers, etc. is needed. For Sri Lanka, which is developing (but has not yet enacted) legislation on WEEE treatment, and Pakistan, which lacks a specific WEEE policy, such shortcomings need to be urgently addressed.

The second weakness of concern for all three countries are the categories of WEEE covered by the formal system (WEEE scope). In China at present, only 5 categories of WEEE (1st batch) are covered in the formal industry. For other types of WEEE, only a small proportion of defective products are recycled by licensed facilities. Therefore, additional categories of WEEE (including the 2nd batch of WEEE) need to be handled in the formal sector. This may require specifically a more adaptable subsidy mechanism, and the introduction of relevant technologies and facilities. In Sri Lanka, the main WEEE categories currently recycled are waste computers and mobile phones. Sri Lanka, therefore, also faces the challenge posed by increasing the number of WEEE categories to be recycled in an environmentally sound manner in the near future. The lack of a cost-effective formal collection system to compete with widely-distributed informal collectors is also a major weakness in the three countries. Licensed recyclers still depend on supply of WEEE from large-scale collectors, who collect WEEE from bottom-level collectors. The complexity of the collection chain increases traffic and labor cost, leading to high costs for recyclers. All three countries should accelerate the formalization of informal collectors and streamline the collection chain.

Another essential part of the formal system are advanced and environmentally sound technologies, and matched equipment, facilities and trained staff. In this regard, China and Sri Lanka both need additional advanced technologies to optimize the formal system. Pakistan needs to establish relevant facilities and to apply advanced technologies.

3.2. Identify general concerned factors and priorities

In summary, the factors that are important for the effective and environmentally sound recycling of WEEE are unique to the three countries' situations. Among these factors, government involvement, legislation, functional mechanisms, advanced technologies and facilities are basic factors that should be primarily focused upon during the establishment of a formal system. Other factors such as law enforcement, WEEE categories covered by the system, awareness among stakeholders, and the involvement of producers and the public are areas that should be further strengthened after the fundamental factors are satisfied. Countries with differing WEEE management status therefore need to focus on such specific, targeted areas when formulating relevant strategies.

Since the WEEE collection and recycling industries of China, Sri Lanka and Pakistan are at different stages of development, the priority areas of focus are different, and point the way forward to the implementation of differing future development strategies. For China, the most important areas to be addressed can be summarized in three aspects: 1) how to make the system handle more categories of WEEE; 2) how to prevent WEEE flow to informal sectors; and 3) how to make legislation 100% implemented (including effective enforcement). For Sri Lanka, priority issues at present are executing specific WEEE legislation and policies to guide the industry's development, putting into place effective facilities for recycling all of WEEE components, and enhancing pollution control when processing WEEE. For Pakistan, the priority is to strengthen the government involvement and policy intervention. The government should focus on formulating WEEE policies, and establishing qualified formal collectors and recyclers. Pakistan may then need to seek more technical assistance through participating in international projects or ensuring cooperation with other countries.

3.3. Recommendations

Based on the priorities identified for China, Sri Lanka and Pakistan, general recommendations are proposed for developing countries with similar WEEE issues. The recommendations are listed as follows:

(1) Enhance government management

Government management is an indispensable tool, which will guide and foster the formalization of the WEEE industry. Basically, a specific competent authority responsible for WEEE collection and recycling should be designated. A national strategy and systematic laws on WEEE collection and recycling should be established. Action plans for WEEE collection and recycling, a clear division of responsibility among stakeholders (especially for producers and the public), supporting mechanisms for collectors and recyclers, and technical standards for operations should be included in the legal framework. Relevant experiences of developed countries (for

example, Europe Union countries) can be referred to when establishing national legislation, strategies or action plans. In addition, governments can undertake national pilot projects, taking the experiences gained and replicating them country-wide. This approach can effectively promote the development of the formal WEEE industry. An evaluation mechanism should also be placed to promote the government supervision and ensure the effective implementation and enforcement of legislation.

(2) An effective mechanism to ensure adequate supply of WEEE

In many countries, informal collectors have dominated the collection market, and a significant proportion of collected WEEE flows to informal recyclers that improperly handle WEEE. Such conditions not only create significant risk to the environment and human health, but also limits the development of formal recyclers through lessening the volume of WEEE delivered to them. To improve the situation, the following recommendation are proposed:

- Incentives should be provided for informal collectors who deliver WEEE to licensed collectors or recyclers. The incentives can be provided through a fund jointly established by the government, licensed recyclers or EEE producers. Informal collectors can apply for the subsidy based on the amount of WEEE they sell to formal collectors or recyclers.

- Governments should encourage the licensed recyclers or large-scale collectors to establish community-level and village-level centralized sites. It will therefore be more convenient for nearby residents to hand over WEEE.

- The public should be encouraged/motivated to deliver WEEE to formal collectors and recyclers through strengthened publicity on WEEE issues and providing incentives (discount coupons, for example). Such incentives should be offered by formal collectors and recyclers.

- Local governments should enhance the supervision of and penalties for informal recyclers.

- Informal sector recyclers should be trained and participate in the formal collection and recycling system through programmes and incentives.

(3) Licensed facilities should be established using advanced technologies, equipment and properly trained workers

Licensed facilities should at least be equipped with advanced and relative environmentally sound technical processes, pollution control equipment and protective environments for workers. Properly trained workers can improve work efficiency and avoid accidents. WEEE can therefore be recycled and treated in a less harmful manner.

Governments should guide the industry and academic community to promote the research and development of environmentally sound technologies and equipment, and should encourage them to apply best available technologies, to provide funded projects, offer tax relief, and undertake technology transfer from other countries. It should be compulsory for licensed enterprises to train their workers. National

standards, technical guidance, and training materials should be developed for enterprises to use.

(4) Raise awareness among stakeholders

Raised awareness regarding the economic benefits and environmental effects of WEEE recycling among stakeholders will greatly facilitate the development of the WEEE industry. For countries with formal collection and recycling systems at the “primary” or “zero”-stage, the government should be the first target for awareness-raising. Officials from these countries should participate in related international training courses. Awareness within the industry can be raised through mandatory regulations and training courses organized by government. For the public, the most common method is to use publicity materials and advertisements. It is recommended to publicize the formal recycling concept of WEEE at the community level. In addition, the concept of formal recycling of WEEE into schools’ education curricula will serve to gradually increase awareness among the public in the future.

(5) Seek international cooperation with experienced countries and organizations

For developing countries with formal WEEE collection at the “zero” stage, cooperating with experienced countries and international organizations for technical assistance, financial support or best experience can be very useful. Countries (including developed countries) with well-operated formal systems, or developing countries with relative well-operated formal systems are both suitable categories of candidates for cooperation. Specifically, developing countries with a similar WEEE status and management history can provide a more adaptable experience and relevant lessons. For developing countries in Asia-Pacific Region, regional cooperation between countries at different WEEE management levels can be conducted to balance the regional development of WEEE management.

4. Conclusions

China, Sri Lanka and Pakistan represent different levels of formal WEEE management. China has established a relatively well-operated formal system covering WEEE collection, recycling, treatment and final disposal; Sri Lanka has established a formal WEEE system equipped with a collection network and some licensed facilities for WEEE recycling; while in Pakistan, a formal WEEE management system has not yet been established. After analyzing the strengths, weaknesses, opportunities and threats of formal systems through the SWOT model, the influential factors (basic-level and improvement-level) and priority areas that should be focused on can be identified.

In summary, the basic-level factors include government involvement, legislation, functional mechanisms, advanced technology and facilities; the improvement-level factors include law enforcement, WEEE categories covered by the system, awareness among stakeholders, and the involvement of producers

and the public. Moreover, for countries with different WEEE management conditions, governments should focus on specific priorities. For China, further categories of WEEE should be addressed, maintaining WEEE flow to the formal recycling sector, and enhanced law enforcement are priorities. For Sri Lanka, implementing specific WEEE legislation and policies, placing effective facilities for recycling all the components of WEEE, and enhancing pollution control for WEEE processing are priority issues. For Pakistan, the priority is to strengthen government involvement and policy interventions.⁶

Based on these priorities, five recommendations are proposed for developing countries with similar WEEE issues, including: 1) enhance government management; 2) establish an effective mechanism to keep WEEE flowing to formal recyclers; 3) establish licensed facilities with advanced technologies, equipment and trained workers; 4) raise awareness among the stakeholders; 5) seek for international cooperation with experienced countries and organizations.

In the future, research will focus on screening available management experiences from countries with developed management on WEEE, Best Available Technologies (BAT)/Best Environmental Practices (BEP) on WEEE recycling and treatment. Further recommendations can then be proposed regarding legislation, technologies and equipment for countries like China, Sri Lanka and Pakistan.

Acknowledgements

We would like to thank the financial support from the National Social Science Fund of China (No. 16ZDA071).

References

- Amato A., Rocchetti L., Beolchini F., (2017), Evaluation of different strategies for end-of-life liquid crystal displays (LCD) management, *Environmental Engineering and Management Journal*, **16**, 1651-1657.
- Awasthi A.K., Li J., (2017), Management of electrical and electronic waste: A comparative evaluation of China and India, *Renewable and Sustainable Energy Reviews*, **76**, 434-447.
- Baldé C.P., Wang F., Kuehr R., Huisman J., (2015), The Global E-waste Monitor - 2014 quantities, flows and resources, On line at: <http://i.unu.edu/media/ias.unu.edu-en/news/7916/Global-E-waste-Monitor-2014-small.pdf>.
- Baldé C.P., Forti V., Gray V., Kuehr R., Stegmann P., (2017), The Global E-waste Monitor – 2017 quantities, flows and resources, On line at: <https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx#FullReport>.
- Beloborodko A., Romagnoli F., Rosa M., Disanto C., Salimbeni R., Karlsen E.N., Reime M., Schwab T., Mortensen J., Ibarra M., Blumberga D., (2015), SWOT analysis approach for advancement of waste-to-energy cluster in Latvia, *Energy Procedia*, **72**, 163-169.
- CEA, (2017), Licensed Collectors of Electronic Waste Management in Sri Lanka, Central Environmental Authority, Sri Lanka, On line at:

- http://www.cea.lk/web/images/pdf/whats/Licensed_Collectors_of_Electronic_Waste_Management_in_Sri_Lanka_WEB.pdf.
- Chen W.M., Kim H., Yamaguchi H., (2014), Renewable energy in eastern Asia: Renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, SouthKorea, and Taiwan, *Energy Policy*, **74**, 319-329.
- Gurauskiene I., Stasiskiene Z., (2018), Model for regional management of electrical and electronic waste (WEEE) flows, *Environmental Engineering and Management Journal*, **17**, 135-145.
- Herat S., Agamuthu P., (2012), E-waste: a problem or an opportunity? Review of issues, challenges and solutions in Asian countries, *Waste Management & Research*, **30**, 1113-1129.
- Ikhlayel M., (2018), An integrated approach to establish e-waste management systems for developing countries, *Journal of Cleaner Production*, **170**, 119-130.
- Imran M., Haydar S., Kim J., Awan M.R., (2017), E-waste flows, resource recovery and improvement of legal framework in Pakistan, *Resources, Conservation and Recycling*, **125**, 131-138.
- Jaber J.O., Elkarmi F., Alasis E., Kostas A., (2015), Employment of renewable energy in Jordan: Current status, SWOT and problem analysis, *Renewable and Sustainable Energy*, **19**, 490-499.
- Kumar A., Holuszko M., Espinosa D.C.R., (2017), E-waste: An overview on generation, collection, legislation and recycling practices, *Resources, Conservation and Recycling*, **122**, 32-42.
- Li J., Lopez B. N., Liu L., Zhao N., Yu K., Zheng L., (2013), Regional or global WEEE recycling. Where to go? *Waste Management*, **33**, 923-934.
- Maheshi D., Steven V.P., Karel V.A., (2015), Environmental and economic assessment of 'open waste dump' mining in Sri Lanka, *Resources, Conservation and Recycling*, **102**, 60-67.
- Mallawarachchi H., Karunasena G., (2012), Electronic and electrical waste management in Sri Lanka: Suggestions for national policy enhancements, *Resources, Conservation and Recycling*, **68**, 44-53.
- MENR, (2008a), National Environmental Protection & Quality Regulations, Notification No.1534/18 dated in 01.02.2008, Ministry of Environmental and Natural Resources of Sri Lanka, On line at: <http://www.cea.lk/web/images/pdf/Gazette-Notification-No-1534-18-dated-01-02-2008.pdf>.
- MENR, (2008b), National Environmental Act No 47 of 1980, Ministry of Environmental and Natural Resources of Sri Lanka, On line at: <http://www.cea.lk/web/images/pdf/Gazette-Notification-No-1534-18-dated-01-02-2008.pdf>.
- MEP, (2015), The Distribution Map of licensed WEEE treatment enterprises in China, (in Chinese), Ministry of Environment Protection of the People's Republic of China, On line at: <http://weee.mepsc.cn/Index.do?method=flow>.
- MOC, (2014), The 2013 development report for the recovery industry of renewable resources, (in Chinese), Ministry of Commerce of the People's Republic of China, On line at: <http://ltfzs.mofcom.gov.cn/article/ztzzn/an/201406/20140600629599.shtml>.
- MOC, (2015a), The mid-long term plan for the recovery industry of renewable resources during 2015-2020, (in Chinese), Ministry of Commerce of the People's Republic of China, On line at: <http://ltfzs.mofcom.gov.cn/article/ztzzn/an/201501/20150100878083.shtml>.
- MOC, (2015b), The 2014 development report for the recovery industry of renewable resources, (in Chinese), Ministry of Commerce of the People's Republic of China, On line at: <http://ltfzs.mofcom.gov.cn/article/date/201505/20150500965258.shtml>.
- MOC, (2016), The 2015 development report for the recovery industry of renewable resources, (in Chinese), Ministry of Commerce of the People's Republic of China, On line at: <http://ltfzs.mofcom.gov.cn/article/af/201605/20160501325666.shtml>.
- MOC, (2017), The 2016 development report for the recovery industry of renewable resources, (in Chinese), Ministry of Commerce of the People's Republic of China On line at: <http://ltfzs.mofcom.gov.cn/article/ztzzn/an/201705/20170502568040.shtml>.
- MOC, (2018), The 2017 development report for the recovery industry of renewable resources, (in Chinese), Ministry of Commerce of the People's Republic of China On line at: <http://ltfzs.mofcom.gov.cn/article/date/201806/20180602757116.shtml>.
- MOF, (2009), The Measures on Home Appliance Old for New Rebate Program, (in Chinese), Ministry of Finance of the People's Republic of China, On line at: http://www.mof.gov.cn/zhengwuxinxi/caizhengxinwen/200907/t20090702_175325.htm.
- Morris A., Metternicht G., (2016), Assessing effectiveness of WEEE management policy in Australia, *Journal of Environmental Management*, **181**, 218-230.
- Premur V., Vucinic A.A., Melnjak I., Radetic L., (2018), Reuse of the recycled nonmetallic fraction from waste printed circuit boards in pavement industry, *Environmental Engineering and Management Journal*, **17**, 2719-2729.
- Rucevska I., Nellemann C., Isarin N., Yang W., Liu N., Yu K., Sandnæs S., Olley K., McCann H., Devia L., Bisschop L., Soesilo D., Schoolmeester T., Henriksen R., Nilsen R., (2015), *Cross Border Movement and Routes*, In: *Waste Crime – Waste Risks: Gaps in Meeting the Global Waste Challenge. A UNEP Rapid Response Assessment*, Birkeland Trykkeri AS, Norway, 53-54.
- State Council, (2009), The Regulations for the Administration of the Recovery and Disposal of Waste Electric and Electronic Products, (in Chinese), The State Council of the People's Republic of China, On line at: http://www.gov.cn/flfg/2009-03/04/content_1250844.htm.
- Salhofer S., Steuer B., Ramusch R., Beigl P., (2016), WEEE management in Europe and China - A comparison, *Waste Management*, **57**, 27-35.
- Tian H., (2017), The 2016 white paper on WEEE-recycling industry in China, (in Chinese), On line at: http://www.weee-epr.org/uploads/20170914092945_cuskiq.pdf.
- Umair S., Björklund A., Petersen E.E., (2015), Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines, *Resources, Conservation and Recycling*, **95**, 46-57.
- Yoshida A., Terazono A., Ballesteros F.C., Nguyen D.Q., Sukandar S., Kojima M., Sakata S., (2016), E-waste recycling processes in Indonesia, the Philippines, and Vietnam: a case study of cathode ray tube TVs and monitors, *Resources, Conservation and Recycling*, **106**, 48-58.