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ORIGINAL ARTICLE

Analysis of recycling structures for e-waste in Vietnam

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Abstract E-waste management in Vietnam poses real challenges such as the lack of specific e-waste legislation, the strong involvement of "craft villages" and the missing of monitoring data. Many issues (e.g., pollution level, generated waste, health of workers and resident living at recycling sites) lead to the limited access to these craft villages. Thus, there is no comprehensive picture on e-waste management in Vietnam available today. This research focuses on the current situation of e-waste management. Sources of e-waste, collection and treatment in Vietnam are investigated by utilizing most available sources of information (published journals, unpublished works from projects and reports from institutes, ministry) together with the interviewed data from experts, collectors, workers and especially, biggest traders in the field. Based on this information, the processes applied in Vietnam, both in the formal and informal sector, have been analyzed systematically in terms of inputs, outputs, potential emissions and related risks for workers. From these aspects, a comparison in terms of legal frameworks, collection and treatment at both formal and informal sector between Vietnam and other countries in Asian region was undertaken. Thus, major challenges of e-waste management and relatively comprehensive image of e-waste management and treatment in Vietnam have been identified.

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Keywords Waste of electronic and electrical equipment (WEEE) · E-waste · Vietnam · Informal sector · Craft villages

Introduction

Waste of Electronic and Electrical Equipment or e-waste management in Vietnam poses real challenges for policy-makers, authorities (they belong to group of state management levels working on legislations and law enforcement) and even for collectors (who can be individuals, lowest level of traders, some are only in charge of e-waste collecting, and some are also involved in dismantling processes), traders, recyclers (including managers from recycling enterprises and dismantlers as they are a step closer to recycling processes) and waste processors (who treat residues from dismantling and recycling processes). Those challenges come from the geographical location of the country with long coastal line and contiguity with China and Cambodia that facilitates e-waste and used Electrical and Electronic Equipment (EEE) to be imported and exported [1]. Other challenges root in the lack of specific e-waste legislation and strict law enforcement and also from the domination of informal sector in e-waste collection, transportation and treatment with the involvement of many craft villages. As the handled e-waste is scattered among recycling craft villages [2], illegal importation and exportation activities exist [1, 3], and repair system is strong, up-to-date monitoring data are missing, they lead to inconsistence in the data that is a challenge for calculating and predicting e-waste generation of Vietnam.

Thus, there is a need for the investigation of e-waste sources, generated quantity, how e-waste has been treated and how the material flows from e-waste treatment activities could go, especially with the promulgation of the Decree No. 187/2013/ND-CP on the ban of import of used EEE and the Decision No. 16/2015/QD-TTg on the regulation of retrieval and disposal of discarded products which would be significant factors for change in e-waste management activities in Vietnam. This information shall highlight the particular characteristics of e-waste management and treatment activities in Vietnam. Under this point of view, a comparison in legal frameworks for e-waste management, e-waste collection and recycling activities from both formal and informal sectors between Vietnam and other countries in the Asian region has been made to evaluate the current situation of e-waste management and put an initial step for further improvement.

Materials and methods

Literature review

This study referred a wide range of published journals, reports from many projects and reports from cleaner production assessment at enterprises. In particular, the information sources were from previous studies of researchers. For example, Shinkuma and Huong [3] invested the e-waste illegal routes between Vietnam and China, and Vietnam and Cambodia; Nguyen et al. [2] provided the estimated data on e-waste generation; Hai et al. [4] provided the relationship among stakeholders involving in e-waste flow, e-waste recycling technologies and general diagram of the informal e-waste recycling in Vietnam. The information was also extracted from the reports of several projects implemented for a specific period. For example, Urban Environment One Member State-Owner Limited Company (URENCO) [5] presented the e-waste inventory in Vietnam in their report "The development of e-waste inventory in Vietnam", while the e-waste processing technologies can be found in unpublished work of the National Institute for Environmental Studies of Japan and the Institute for Environmental Science and Technology (INEST) [1]. The work focusing on "Development of Recycling Technique for Waste of Electrical and Electronic Equipment" was done as a joint project between INEST and Korea Institute of Geoscience and Mineral Resources—KIGAM in 2010. The data on processing of plastic and metals at craft villages were observed from the report of the "Scientific and realistic basic research for building up policies and solutions for environmental issues in craft villages of Vietnam" project [6]. Moreover, many cleaner production assessment reports at enterprises at craft villages had been used as sources for evaluating and crosschecking the processing benchmarks for plastic and metal recycling.

Interviews

In combination with the literature review, the interviews with experts (from INEST, local authorities and other experts in metal processing industries), workshop owners and workers at the craft villages (Bui Dau and Phan Boi village, Hung Yen province) have been conducted during a fieldtrip in November 2014. The most important source of data came from the interviews with the biggest e-waste traders in the North of Vietnam in November 2014, May 2015 and March 2016 with data on collected and processed Printed circuit boards (PCBs) from appliances. The quantity of processed PCBs is a valuable data because they have not been mentioned in many previous works.

Data using for calculation

It is important to state that data on e-waste in Vietnam are limited as the e-waste handled is scattered among recycling craft villages [2] and by illegal importation activities [1, 3]. Moreover, appliances sold at private service shops seem impractical to count because the shop owners tend to hide the business information to dodge taxes and the remanufactured appliances can be sold as fake new ones [7]. The above reasons, combined with the lack of a monitoring data system (such as responsible survey and material flow analysis), as commonly observed in developing countries [8], lead to the inconsistence in the data which is a challenge for calculating and predicting e-waste generation of Vietnam. The main data are from national projects and in most cases, they are unreliable and outdated [8] and absent alternative data [9]. The e-waste inventories in Vietnam came from works of URENCO [5] covering 7 types of appliances (additional batteries) and 1200 interview surveys in 7 major cities, and Nguyen et al. [2] covering 5 types of appliances with 1062 collected survey forms in 3 cities. One example showing the data gaps between two studies is that URENCO [5] estimated that about 742 thousand TV sets should have been discarded in 2010. But Nguyen et al. [2], using the combination with Weibull distribution, logistic function and population balance model, evaluated that these numbers were 2700 thousand. A team from INEST investigated and interviewed during their visits in major dismantling centers and presented in their report that approximately 1000 thousand TV sets were dismantled in only few craft villages per year in the Northern part of Vietnam, but there are some more dismantlers in other parts of the country [1]. The solution dealing with data difference had been suggested by NIES and INEST [1] which shows that it is possible that the data from URENCO [5] can be used as the lower bound and the data from Nguyen et al. [2] can be used as the upper bound. Additionally, we compared calculated data from URENCO [5] (as lower bound) with the e-waste generation data in Vietnam from Baldé et al. [10] for 2014. Thus, this study provided estimation data calculated from URENCO's data.

E-waste recycling structure in Vietnam

Sources of e-waste in Vietnam

E-waste generated in Vietnam originates both from the disposal of EEE, from importation of used EEE and e-waste, and from industrial processes at electronic industries. EEE are disposed at their end-of-life from domestic uses. Imported e-waste and used EEE are trans-boundaries from other countries (e.g., Cambodia, Japan) to Vietnam (Vietnam only imports used EEE from China, e.g., uninterruptible power supply—UPS, mobile phones) and they are re-exported mainly to China. These illegal activities result in the unquantifiable amount of e-waste from this source. The quantity of e-waste (as a part of hazardous waste) from e-waste-producing industries must be reported annually by industries generating hazardous waste themselves to Department of Natural Resources and Environment as regulated by Circular No. 36/2015/TT-BTNMT dated 30.06.2015 on Hazardous Waste Management, but there is no official report from authorities about the quantity of e-waste out of the quantity of hazardous waste from this type of source.

Products put on the domestic market

Vietnam imports both brand new and used EEE (although the government has banned the import of used EEE according to the Decree No. 187/2013/ND-CP, the largest amount of used EEE has been already transferred to Vietnam years before). Electronic enterprises operating in Vietnam also produce brand new EEE. In the report of URENCO [5], the quantity of products put on the domestic market for targeted EEE [TV, personal computers (PC), mobile phones, refrigerators, air conditioners and washing machine] has been estimated, as shown in Table 1. The amount includes both brand new and used EEE that are produced and imported, and minuses the exported units.

Table 1 shows the annual growth rate for 6 types of appliances in which the highest rate (21 %) is for air conditioners. TVs and PCs have the same rate at 20 %. It is noticeable that mobile phones have the lowest annual growth rate (1 %). The reasons for low annual growth rate of mobile phones with small numbers of mobile phones put on the domestic market provided by URENCO [5] can be from the high price of mobile phones and mobile service comparing to the income of inhabitants when the study was conducted. It also can be the behaviors of Vietnamese people so the mobile phones were transferred from one to another person. The data from World Bank [11] on mobile subscriptions per 100 people in Vietnam from 2007 to 2014 show that the highest increased mobile subscriptions were in 2008 with 65 % compared with that in 2007 [from 52.03 million (2007) to 85.7 million (2008)]. The increase percentage was 30 % in 2008, maintained around 12–13 % in 2009 and 2010, and reduced to 9 % in 2014. By the end of 2014, total number of mobile subscribers in Vietnam was 147.11 million. Thus, it is believed that the numbers of mobile phones put on the domestic market and the annual growth rate are supposed to be higher than those provided by URENCO [5].

Brand new EEE is produced from local manufacturers and exported from other countries (Japan, Taiwan). Specific types of used EEE can be mainly imported from a particular country during a period. For example, used refrigerators mainly went to Vietnam from Japan. Secondhand TV sets were almost brought into Vietnam during 1996–2006.

E-waste from domestic

URENCO [5] in their report estimated the quantity of used EEE discarded in Vietnam until 2020 using National Statically data of domestic sales and the collected data from surveys in the application of Weibull function. From those data, combined with the assumption that the e-waste

Table 1 The estimation of targeted domestic EEE in Vietnam from 2015 to 2020 (thousand units) [3]

	2014	2015	2016	2017	2018	2019	2020	Annual growth rate (%)
TV	14,848	17,800	21,338	25,609	30,756	36,960	44,442	20
PC	2132	2540	3030	3619	4326	5177	6200	20
Mobile phones	3498	3533	3569	3604	3641	3677	3714	1
Refrigerator	3481	4127	4900	5826	6937	8269	9869	19
Air conditioner	1367	1653	1998	2416	2921	3533	4272	21
Washing machine	3140	3674	4307	5060	5955	7022	8294	18

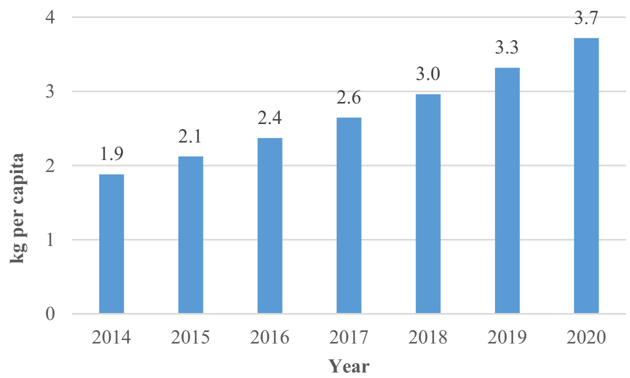

Fig. 1 E-waste generated from used EEE per capita in Vietnam from 2014 to 2020

from used EEE in Vietnam is mainly from TVs (average 30 kg per unit), mobile phones (average 0.1 kg per unit), refrigerators (average 45 kg per unit), PCs (25 kg per unit) [12], air conditioners (average 50 kg per unit) and washing machines (average 35 kg per unit) [5] and the average annual population growth rate during the period of 2014–2020 remains at 1.06 % [13], the e-waste from used EEE discarded per capita was calculated, as shown in Fig. 1. From 1.9 kg per capita in 2014, it is rapidly increased to 3.7 kg per capita in 2020. The e-waste generated rate is supposed to be higher if other e-waste sources can be counted.

E-waste from transboundary movement

Another source of e-waste is the illegal import–export activities among neighboring countries. If Vietnam is one of the central points for these activities, the routes of e-waste among Cambodia, Vietnam and China are detectable.

The northern part of Vietnam, as described by Shinkuma and Huong [3] and NIES and INEST [1] (Fig. 2), Mong Cai (Quang Ninh province), is the most suitable spot for e-waste trading because of its close distance to Hai Phong—the destination for temporary import for re-export cargoes, its specific regulation as an open economic zone and the presence of both sea and river ports. China and Vietnam banned the import of e-waste but both countries allow import for re-export and China allows secondhand EEE to be imported, rebuilt and then re-exported. Thus, e-waste can be imported to Vietnam, then exported to China to rebuilt and imported back to Vietnam illegally. This is possible because Vietnamese local authority also applies “the exemption to import of secondhand EEE that China does” [3]. Major types of e-waste exported to China consist of lead batteries, PC monitors, PCBs, and TV sets.

In the South of Vietnam, secondhand EEE and e-waste that are imported via Sihanoukville international port

Fig. 2 The route of e-waste among Cambodia, China and Vietnam. Map from © d-maps.com

(Cambodia) are smuggled into Vietnam through the border between two countries. A part of secondhand EEE is consumed within the Mekong Delta River, transported to Ho Chi Minh City for sale, and the rest, together with other e-waste, is moved to the North for exporting to China.

It is considered that the geographical location of the country shaped how smuggling activities happened. In the North, long border with China (complex mountain and forest areas, together with river ports) while in the South, the small river as a borderline, together with inland trade way between Vietnam and Cambodia make residents to illegally involve in importing and exporting goods. The transboundary movement of goods (and e-waste) has contribution from both the weakness of authorities and the facilitation of geographic location and terrains that smugglers have utilized.

In fact, the movement of e-waste and secondhand EEE among Cambodia, China and Vietnam is driven by the price. Shinkuma and Huong [3] pointed out that a secondhand set of PC gets the highest price in China, then Vietnam and lowest in Cambodia. So, PCs are moved from Cambodia to Vietnam, and then smuggled to China. Because secondhand TV sets have the highest price in Vietnam, they are illegally imported from China and Cambodia. Due to those activities considered as illegal and very sensitive, the data on the quantity of e-waste transferred among those countries are impossible to clarify [1].

Before the Decree No. 187/2013/ND-CP (signed on 20.11.2013, come into force on 20.02.2014) on the ban of import of used EEE, a large amount of imported products including a mixture of new, used and end-of-life products to Vietnam originated from Japan [14]. Only after Vietnam Ministry of Information and Communication issued the legal document No. 31/2015/TT-BTTTT (issued on 29.10.2015 and effective on 15.12.2015) as guiding articles of Decree No. 187/2013/ND-CP on the export and import of used information technology products, authorities and used EEE importers have practical legal framework on which types of used EEE are not allowed to be imported. As regulated by Decree and legal document, there are some exceptions to import used EEE for special purposes (e.g., scientific research, sampling). In fact, used EEE still can be imported to Vietnam by illegal ways (e.g., claiming as belongings of travelers in exceeded numbers of used EEE allowed per traveler, smuggling activities between the borders).

E-waste from electronic industries

E-waste generated from industrial production processes are considered as hazardous waste. Data on the amount of e-waste generated from this type of source are very limited and only data on PCBs from electronic enterprises have been observed by authors. The information gathered during the field trip in November 2014 by interview traders estimated that approximately 230 tons of PCBs from industries are generated per year.

E-waste treatment activities in Vietnam

Vietnamese e-waste recycling system has been described by URENCO [5], Nguyen et al. [2, 7] and Hai et al. [4] including collectors, junk shops, dismantlers, recyclers and exporters with the appearance of secondhand market and the involvement of craft villages. The collection and recycling of e-waste and used EEE in Vietnam rely on both the informal and formal sector but informality is predominated [2]. He et al. [15], Schluep et al. [12], Salhofer and Tesar [16], Wang et al. [17] have presented a recycling chain of e-waste in which three steps are included: (1) collection, (2) dismantling and processing and (3) end processing. There are several technologies and methods involved in those steps.

Formal sector

The formal sector is represented by enterprises licensed from the Vietnam Environment Administration because they are dealing with hazardous waste. E-waste from TVs, computers and other EEE containing several hazardous substances (mercury, lead, cadmium, brominated flame retardants) are belonging to this type of waste (regulated in Decision No. 155/1999/QD-TTg—Regulation of Hazardous Waste Management—and the Decision No. 23/2006/QD-BTNMT on the list of hazardous waste). Those companies are in charge of collecting, transporting and treating hazardous waste. There were about 15 (out of 150 certified enterprises working on this field) e-waste treatment systems [18], such as URENCO (waste collection, treatment and recycling), Hoa Binh Treatment and Recycling of Industrial Waste Joint-stock Company, Tan Thuan Phong Co., Ltd. (waste treatment and recycling), and others. These enterprises established from the demands of industries that generate hazardous waste have proper equipment for transportation and imported or self-developed technologies for hazardous waste treatment, such as incineration, pyrometallurgical technology, and solidification. For e-waste, the dismantling and sorting is done manually and the outputs have been classified into several categories such as PCBs, metals, plastics, glass and residues. For example, Thuan Thanh Environment JSC (retrieved from website: http://www.thuanthanhvn.com/Waste-Transportation-and-Treatment_2_66_10_0.aspx [19]) has dismantling capacity of e-waste at 375 kg per hour in conjunction with hydrometallurgical treatment to recover precious metals, gravity and magnetic technology for separating steel and an incineration plant to treat the residues. Tan Thuan Phong Co., Ltd. (Retrieved from website: http://tanthuanphong.vn/chi-tiet-tin/75-cong-ty-tnhh-tan-thuan-phong-thu-vang-tu-rac.html [20]) has operated at treatment capacity of about 10–20 tons per day for industrial waste (including e-waste). The company uses in-house-developed TTP-4/1 incinerator with four primary chambers and one secondary chamber for PCBs pyrometallurgical treatment. Hai et al. [4] describe the hydrometallurgical technology to treat PCB waste where copper and manganese had been recovered in sulfate form. The study also shows the recovery rate of copper and manganese sulfates in the solution was up to 95 % [4].

Informal sector

The informal sector has dealt with the larger amount of e-waste and is involved in all steps of the recycling chain. Reinhardt [21] suggested another step compared to common recycling chain, a "reuse and refurbishment" step, for the case of Agbogbloshie (Ghana). It is also applicable to Vietnam's context (Fig. 3). Within this context, the "reuse and refurbishment" step has been emphasized because of the behaviors of Vietnamese people.

Collection and transportation There are thousands of peddlers who collect disposed appliances from end users to service shops, dealers or collectors in Vietnam. They are seen as "saviors" for e-waste treatment in Vietnam who can guarantee nearly 100 % of e-waste from households transferred to recycling facilities and collectors. Using motorcycles, bicycles or even bamboo frame on shoulders, they go from house-to-house to buy e-waste (and other recyclable waste) and bring them to the places where those items can be sold at a higher price. The informal e-waste handling system is very active and successful [2].

Reuse and refurbishment After being collected, the appliances are classified by collectors, repairers and service shops. The disposed appliances can go through a simple repairing or refurbishing, then can be sold as fake new ones [7] or taken part in secondhand markets. The broken EEE can be repaired several times at repair shops till the repair is impossible. Nguyen et al. [7] considered secondhand markets as a "shadow market" because it is not fully controlled by the government and the business information, price, and taxes from subjects involving in this market are always hidden. The repairers and service shops can dissemble the useable parts from e-waste for reuse, and only broken EEE that is impossible to repair or does not pay off the cost for repair will be transferred to dismantling workshops. At those workshops, reusable parts (transistors, chips, parts) are collected for selling to repairers and service shops for part replacement during repair works.

Dismantling and pre-processing The purposes of this step, as mentioned by Schluep et al. [12] and Wang et al. [17], are to separate materials and prepare for further treatment. The characteristics rural areas in Vietnam are the formation of craft villages—"villages with a profession that is separated from agricultural activities for an independent manufacturing/processing and that profession attracts the workforce of the village and creates main income for the habitants" [22]—where residents not only produce agricultural products but are also involved in industrial activities. Thus, the craft villages play an important role in rural economic development as they provide work for residents of neighboring villages. There are 27 % of farm households earning income from both farming and other careers while 13 % of rural households being professionally engaged in careers rather than farming [5]. They have also attracted about ten million full-time workers (approximately 30 % of workers in rural areas) [23]. The e-waste treatment was counted for approximately 30 craft villages handling e-waste recycling [18] out of 90 waste recycling villages mainly from the North [23] in total more than 3000 craft villages in Vietnam. At those villages, e-waste is dismantled and sorted manually into parts by workers working at no or with a low level of protective equipment. Workshops at e-waste dismantling craft villages have been specialized by types of appliances. For example, some workshops only buy and dismantle refrigerators and washing machines, some only collect CD and DVD players, and some are in charge of plastic collecting and grinding. After dismantling, the tradable parts are classified for further treatment or sale. The processes of open burning of copper wires to extract copper, chipping and melting plastic parts, discharging residues to fields and riverbanks or ponds are common.

The current situation of e-waste dismantling and pre-processing has led to many serious issues related to environment and human health of not only workers at those workshops, but also residents living close to workshops. Study of Tue et al. [24] showed the accumulation of polychlorinated biphenyls and brominated flame retardants in breast milk from women living in e-waste recycling site (Bui Dau in Hung Yen province) at very high levels of polybrominated diphenyl ethers and hexabromocyclododecanes; Tue et al. [25] found the polychlorinated biphenyl and brominated flame retardant contaminants in indoor dust and air at informal e-waste recycling site that were significantly higher than in urban house dust. The soil was

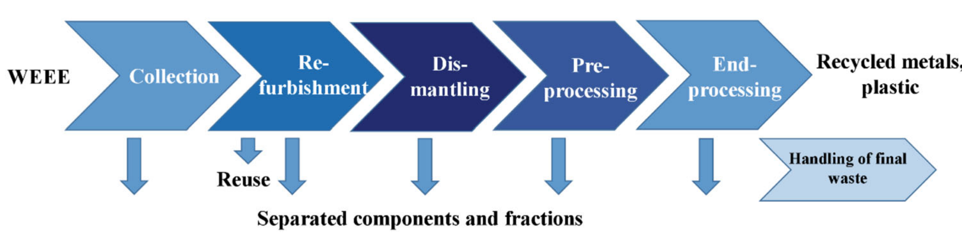

Fig. 3 E-waste recycling chain. Adapted from [12, 17, 21]

also contaminated by flame retardants in soils of e-waste recycling sites (near workshop and open burning places) [26]. Their formation was originated by the influence from high-temperature processes [27] such as open burning of copper wires and plastic recycling process using conventional extruders.

It is difficult to estimate, monitor and record how much e-waste is transported to and processed at craft villages in Vietnam. The data of e-waste are rough and based on estimation by interviewing people from craft villages, experts and traders in the field and, therefore, impossible to clarify with certainty. The processes of dismantling and pre-processing by type of appliances and estimated data collected during the fieldtrip in November of 2014 are presented in Table 2. In case of a craft village in Hung Yen province: the e-waste dismantling amount of the whole village has fluctuated from 1 to 10 tons per day (depending on the buyers). The output capacity from dismantling and sorting of e-waste is 40–50 tons per month in average.

Table 2 shows that in some appliances, such as electric fans, PCs, laptops, radio and DVD/CD players, washing machines, cell phones during dismantling processes, only dust can create critical health problem to workers. While the dismantling work of air conditioners and refrigerators is considered a real threat to the environment. Especially, the case of dismantling CRT glass bodies with the release of fluorescent powder and lead-acid batteries with acid handling can result in the critical issue for both workers and environment. Moreover, this table also provides data from those dismantling and pre-processing processes such as the capacity per dismantler for specific types of appliances, estimated amounts on PCBs collected from dismantling works of appliances.

Steps of pre-treating PCBs include several methods: (1a) manual dismantling of electronic components (ICs, transistors, metal and plastic parts) or (1b) treating PCBs in a vertical rolling equipment with heat provided (240–280 °C) to separate solder, transistors, capacitors and circuit boards. Then, (2) electronic components are collected and sorted for sale or reuse purposes or export to China for further treatment. In addition, (3) circuit boards (PCBs without electronic components) are ground for export purpose or treated to recover copper.

Because the outputs are mainly collected for exportation to China, the capacity, operation time, number of workers, etc., of this sector in Vietnam mainly depend on buyers from China. For example, the significant reduction of metal prices on international markets in 2016 has led to the fact that Chinese buyers have less interest in buying materials from e-waste. Thus, the lower amounts of e-waste (in form of shredded plastics, PCBs) from Vietnam have been exported to China.

End processing Currently, the outputs from dismantling and pre-processing steps are mainly exported to China. But, it is worth to present the available infrastructure for end processing even just a small amount of outputs is treated within Vietnam territory. The strict enforcement of both the Decree No. 187/2013/ND-CP on the ban of import of used EEE and the Decision No. 16/2015/QD-TTg on the regulation of retrieval and disposal of discarded products shall force the recycling of pre-processing outputs inside the country in near future. The end processing step consists of the metal recovery/recycling from the pre-processing step and final treatment of the residues. Because different types of e-waste are dismantled and sorted at dismantling craft villages, this section will present the current technologies applied to corresponding output materials. The end processing of output materials from dismantling and pre-processing steps is shown in Table 3.

By comparing the current plastic and metal processing with older cleaner production assessment reports from Vietnam Cleaner Production Center (VNCPC) for plastic, aluminum, steel making industries, Green Credit Trust fund application of plastic and steel making submitted to VNCPC for technical assessment and approval, reports from other institutes (such as Vietnam Steel Association, INEST), Cleaner Production guidelines for steel sector from Cleaner Production Component—Ministry of Industry and Trade, etc., the current technologies and consumption (materials, energy, water) to produce each ton of final products were not changed considerably. For example, to produce each ton of steel billets under Induction Furnace technology, 750–1300 kWh of electricity, 1.08–1.30 ton of scraps, 0.2–0.3 ton of coal are needed [28–33]. The copper smelting processes mainly at some traditional craft villages with many know-hows are passed from one to another generation and many measurements are based on experiences result in difficulties in monitoring inputs and outputs for each ton of final product and emission (approximately 1053–1070 ton copper scraps, 1.1–2.5 ton of coal need to be consumed) [6, 34, 35]. The use of obsolete technologies and limited investment for technology upgrade are the reasons for many problems: occupational health and safety for workers and surrounding-site residents, pollutions to environment and waste of natural resources. The monitoring of air, water and soil quality, and diseases of workers and residents at craft villages had been mentioned in the reports of MONRE [23, 36].

As seen from Table 3, the most critical recycling process is count for lead smelting. As a result of lead recycling activities under basic technology, adults and children living in lead-acid recycling craft villages have suffered diseases from lead recycling activities as they got high levels of lead in their blood. All children living in Dong Mai lead-acid battery recycling craft village taking part in the study of Daniel et al. [37] had high blood lead level (BLL) in which 40 % had BLL $\geq$45 µg/dL and they need urgent exposure

Table 2 The dismantling and pre-processing of e-waste from different appliances at craft villages in Vietnam

Appliance	Dismantling and pre-processing	Outputs	Emission and residues	Estimated data
Air conditioner	Manual dismantling to separate fan, housing, compressor, condenser and evaporation coils, copper wires, PCBs and other components (valve, controller, filter, …). Reusable parts (housing parts, motor, coils, …) can be reused. PCBs, metals and plastics are sold for exporting or recycling. Refrigerants are discharged to environment	PCBs Copper Aluminum Ferrous metal Plastics	Dust, refrigerant emitted into the air. Untradeable plastics	
Cathode ray tube (CRT) TV	Manual dismantling to separate plastic housing, power supply, copper wires, PCBs and CRTs. Copper wires are burned or scrapped to extract copper. Plastic parts are partly ground and sold. CRT tubes are dismantled and sorted into ferrous, copper and glasses The CRT glass body is broken manually that leads to the release of fluorescent powder. Ferrous parts go to craft villages (e.g., Da Hoi craft village) and the glass is crumbled into 3 × 4 cm pieces then exported	PCBs Copper Aluminum Ferrous metal Plastics	Dust Fluorescent powder Untradeable plastics	30 TVs/dismantler.day (17″ CRT TV) About 20–25 % are crumbled
Electric fans	Manual dismantling to separate electric motor, copper, copper wires, housing, PCBs and plastic fan, buttons. Reusable parts (motor, plastic parts, …) can be reused. PCBs, metals and plastics are sold for exporting or recycling	Copper Aluminum Ferrous metal Plastics PCBs	Dust Untradeable plastics	
Lead-acid batteries	Lead-acid batteries are recycled at few craft villages in Vietnam. They are dismantled manually into plastic housing (cleaned and ground, then sold for plastic exporting or recycling), acid (discharged to environment) and lead electrodes	Plastic Lead electrodes	Acid	Recycling capacity: 60 tons of lead-acid batteries per day in the North of Vietnam and 120 tons of lead-acid batteries per day for whole country
Personal computers (PCs) and laptops	Manual dismantling to separate power supply, fans, housing, copper wires, hard disk, PCBs and other components (LCD, CD/DVD drivers, sound and video card, mouse and keyboard). Reusable parts (main board, sound card, video card, DVD driver, transistors, …) can be reused. PCBs, metals and plastics are sold for recycling	PCBs Copper Aluminum Ferrous metal Plastics	Dust Untradeable plastics	
Radio, CD/DVD players	Manual dismantling to separate power supply, housing, copper wires, PCBs and other components. Reusable parts (main board, motor, display, transistors, …) can be reused. PCBs, metals and plastics are sold for exporting or recycling	PCBs Copper Aluminum Ferrous metal Plastics	Dust Untradeable plastics	50–70 kg/dismantler.day
Refrigerator	Manual dismantling to separate compressor, housing, heat exchanger, copper wires, PCBs, insolation material and other components. Reusable parts (housing parts, compressor, plastic trays, … can be reused. PCBs, metals and plastics are sold for recycling. Isolation material is collected and sold or dumped. Refrigerants are discharged to environment	PCBs Copper Aluminum Ferrous metal Plastics	Dust Refrigerant emitted into the air Untradeable plastics	

Table 2 continued

Appliance	Dismantling and pre-processing	Outputs	Emission and residues	Estimated data
Washing machine	Manual dismantling to separate motor, drum, housing part, PCBs, pump, copper wires and other components (valve, hose, etc.). Reusable parts (control board, housing parts, motor, pump, … can be reused. PCBs, metals and plastics are sold for exporting and recycling	PCBs Copper Aluminum Ferrous metal Plastics	Dust Untradeable plastics	1–2 pieces/dismantler.day
Other appliances (phones, cell phones, mosquito racks, photocopy machines, barcode readers, etc.)	Manual dismantling to separate power supply, housing, copper wires, PCBs, ferrous parts (trays, net), plastic parts and other components. PCBs, metals and plastics are sold for exporting and recycling	PCBs Copper Aluminum Ferrous metal Plastics	Dust Untradeable plastics	500 kg of PCBs from phones and cell phones per day 1.2 tons of PCBs from photocopy machines and barcode readers per day 1 ton of PCBs from scanners per year 10 tons of PCBs from TV displays, phone power parts and electrical mosquito rackets per day

reduction and remediation. This study also found high level of lead levels in surface and soil at all tested homes, even with no recycling history. While recycling processes of metals (steel, copper and aluminum) are under critical pollution from air emissions, the process of gold recovery from PCBs discharges toxic chemicals into environment. In addition, it is not recommended that the residues from PCB treatment for copper recovery can be used for plywood or ultralight brick making due to the presence of flame retardants. For plastic recycling, it is concerned about the quality of the products.

E-waste recycling activities in Vietnam in comparison with other countries in Asia

Legal framework

Asian countries are distinguished from 2 groups: (1) industrialized economics (such as Japan, Korean, Taiwan) and (2) emerging countries (such as Cambodia, China, India, Lao, Thailand, Vietnam). The conventional laws and regulations on environmental protection were developed to cope with the linear model of economy while the economy is switching to the circular model to value the nature conservation. That leads to the necessity of new environmental policies which require the integration of stakeholder's responsibility with their products in respect to product's life cycle. From that point of view, the term of extended producer responsibility (EPR) has been introduced and showed its successful application in many developed countries. OECD [38] defines "EPR as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". Thus, it is very important to emphasize the development and implementation of EPR in Asian countries as the main aspect for comparison which is presented in Table 4.

As presented in Table 4, the first group, Japan is considered as one of the first countries in Asia to promulgate EPR (since 1991) with the Law for the Promotion of Effective Utilization of Resources and the Law for Recycling Specified Kinds of Home Appliances [39, 40] but it was limited to 4 types of appliances (2 more types of appliances were added in 2009). The recycling fee from end users that is only practical in Japan till present best practices in collection and separation of materials, step-by-step dismantling and most advanced treatment technology [41] of "well-established and legally based EPR" [42]. In South Korea, since the EPR Law was introduced and effective (since 1992) in which disposed EEE must require official recycling [43], the rate of recycling of electrical

Table 3 The end processing steps for different input materials during e-waste recycling at craft villages in Vietnam

Inputs	Processing	Outputs	Emission and residues	Estimated data
PCBs	Gold fingers and gold-containing chips are treated by hydrometallurgical process for gold recovery (few small-sized workshops scattered in Bac Ninh and Hai Phong) PCBs without electronic components go through the fine grinding step, then separating using vibration screen under water flow. The residues (epoxy resin) after mechanical process are sold for producing plywood or ultralight bricks or dumping	Gold Copper	Residues (epoxy resin) Wastewater with toxic chemicals (acid)	NA
Iron and steel	Recycled at some craft villages in which the technologies can be (1) coal furnace (traditional furnace) that was used for a very long time, and (2) electrical furnace (induction furnace), mostly comes from China to produce steel billets From steel billets, there are other processes to produce iron wires, construction steel, etc., and they decide the shape of steel billets (square or flat) during the casting step	Steel billets	Air emissions (CO_2, SO_2, NO_x, dust) Solid waste (slags) Waste water	Demand for steel scrap in Vietnam is about 2 million tons per year in which 600,000 tons are from domestic sources [4] There is no estimation on proportion of the ferrous scraps from e-waste because all ferrous parts from e-waste have been mixed with other scrap sources and sold to collectors
Copper	Recycled at several traditional copper craft villages to make products for decorating and worshiping purposes (flowers, vases, and jars), copper statues such as Dai Bai village, Quang Bo in Bac Ninh province, Ngu Xa village in Hanoi, and several villages in the South The copper scraps used as input materials are a mixture of coppers from e-waste, used gears, faucets, and wires from domestic sources	Copper products	Air emissions (CO_2, SO_2, NO_x, metal fume, dust) Solid waste (coal slag) Waste water Wasted clay (from molds)	About 5000–6000 tons of copper scrap are recycled at the craft villages [4]. Before 2010, when PCBs were used directly at copper smelters, the copper scrap coming from e-waste source has a proportion of 30–50 % of the total mass recycled [4]. Currently, this proportion is insignificant
Aluminum	Recycled at several craft villages (Binh Yen village in Nam Dinh province, Man Xa village in Bac Ninh province, etc.) to produce motorcycle parts, cooking pots,… from aluminum scraps (equipment parts, wires, cans, etc.) as technology at craft villages are used small coal furnace in batch	Aluminum ingots Aluminum products	Air emissions (CO_2, SO_2, NO_x, metal fume, dust) Solid waste (aluminum slag, coal slag) Waste water containing chemicals for surface treatment processes	To produce one ton of aluminum ingot, 1.18–1.25 tons of aluminum scraps [4, 22, 23]. There is no estimation on proportion of the aluminum scraps from e-waste
Lead	Recycled mainly from lead-acid batteries. At craft villages (e.g., Dong Mai craft village in Hung Yen province), leads are melted using coal furnace to make the lead ingots. Only few smelters have an off-gas treatment system (settling chamber, filter bag) to recover dust	Lead ingots	Air emission (lead dust, lead fume, CO_2, SO_2, NO_x, etc.)	Recycling capacity: 60 tons of lead-acid batteries per day in the North of Vietnam and 120 tons of lead-acid batteries per day for whole country (interview data)

Table 3 continued

Inputs	Processing	Outputs	Emission and residues	Estimated data
Plastics	Recycled at Khoai village, Minh Khai village (Hung Yen province) and many other Small and Medium-Size Enterprises Each plastic recycler recycled only 2 or 3 types of plastics. The rest of plastics are sold to other workshops at the same craft villages or to other craft villages Plastics are treated via 2 processes: (1) making secondary plastic pellets from plastic parts as plastic pellets are the main inputs to make final products and (2) producing final products from the plastic pellets Depending on the final products, the original plastic pellets and color-making plastic pellets are added and they decide which technologies are used such as blow molding to produce plastic bags, injection molding to produce machine parts, plastic sinks, plastic chair; spinning for plastic fiber making; etc	Secondary plastic pellets, Plastic products	Dust Burned plastics Solid waste Wastewater	Capacity of producing reproduced plastic from a plastic recycling craft village in Hung Yen province in November 2014 (pellets and products) are about 20 tons per day and the quantity of plastics exported to China is about 10–12 tons per day (interview data)

home waste equipment rapidly increased; for example, the volume of PCs recycled was from 6 to 50 % of estimated waste PCs [44].

In developing countries, generally, the law and regulations do not fulfill the requirements for e-waste management and treatment. In Vietnam's case, the country has developed legislative and institutional frameworks for waste management (Law on Environmental Protection 1994 and the Amended Law on Environmental Protection 2005, Decision No. 155/1999/QD-TTg on Regulations of Hazardous Waste Management, the Decree No. 59/2007/ND-CP on Solid Waste Management) and initially regulates the electrical and electronic manufacturers and consumers via Decision No. 16/2015/QD-TTg on the regulation of retrieval and disposal of discarded products. Cambodia and Philippines have Laws and Regulations on waste management but a specific legal framework for e-waste does not exist [2, 45, 46]. Malaysia is working toward EPRs for e-waste [42]. China and Thailand have some enforcement on EPR [45] but only China has one decree direct items about e-waste, the Collection and Treatment Decree on Waste of Electrical and Electronic Equipment, that was approved in 08.2008 and enacted in 01.2011 [47]. India, Indonesia and Sri Lanka have a lack of real e-waste registration and will issue and are expected to bring that legal framework into enforcement in the near future [40–42].

In the cases of Lao PDR and Cambodia, both countries have expressed interest in EPR but are limited by insufficient regulatory capacity [48].

From Table 4, it is obvious that Vietnam has started EPR since 2013 while Japan and Korean have already applied EPR since early 1990s. The others (except Cambodia and Lao PDR) issued several EPR-related regulations around 2007 and 2008. With a larger gap in issuing and implementing EPR, the second group of Asian countries can utilize the experiences from the first group. In fact, with the domination of informal sector, there are many obstacles to bring EPR into reality (competitiveness between both sectors, how taking-back system can be operated, etc.). It is believed that strictly applying regulations via prohibition and fines to informal recyclers cannot stop their involvement to e-waste treatment, because their operation creates income for millions of poor residents [40].

Sources of e-waste

The estimation of e-waste generation in Vietnam can be seen in Fig. 1 and the comparison with e-waste generated per country in Asian region is present in Table 5. As observed from Table 5, the top e-waste generators are Japan and Korea and the end-list goes for Cambodia, Lao

Table 4 EPR development and implementation in Asia

Country	Development of EPR	References
Cambodia	–	
China	2004: Draft of Ordinance on the Management of Waste Household Electrical and Electronic Products Recycling and Disposal came to public	[34–38]
	2006: Measures for Administration of the Pollution Control of Electronic Information Products (China RoHS) was enacted (became effective in 03. 2007)	
	2006: Technical Policy for the Prevention of Pollution from Waste Electrical and Electronic Products came in force	
	2007: Administrative Measures for the Prevention of Environmental Pollution by Electronic Waste was enacted (effective in 01.2008)	
	2009: Regulation on the Administration of the Recovery and Disposal of WEEE (China WEEE) (effective in 2011)	
	2012: Regulatory Measures for Collection and Disposal Fund of Waste Electrical Appliances and Electronic Products was public	
India	2008: Management of e-Waste, Guidelines	[25, 38]
	2010: E-waste management and handling rules was promulgated (effective in 2011)	
Indonesia	2008: Solid Waste Management Act 18/2008 was enacted. A specific article on EPR is under preparation under this Act	[32, 34]
Japan	1991: Law for the Promotion of Effective Utilization of Resources was promulgated	[25, 26, 35, 39]
	1995: Law for the Promotion of Separate Collection and Recycling of Containers and Packaging (Packaging Recycling Law) was enacted	
	1998: Specified Home Appliance Recycling Law (SHARL) was enacted (and came into force in 2001). Targeted home appliances were Air conditioners, TV sets, electric refrigerators and freezers, electric washing machines and clothes dryers (Flat-screen TV sets and clothes dryers were added in April 2009)	
Korea	1992: waste deposit–refund system was introduced. TVs and washing machine were included	[30, 35, 40, 41]
	2003: EPR system was enforced. Primary targets: TVs, PCs, refrigerators, washing machine and air conditioners	
	2005: mobile phones, fax machine, printers, copiers and audio equipment were added	
	2007: “the Act on the Resources Recycling of WEEE and End-of-Life Vehicles” (WEEE Act) was adopted	
Lao PDR	–	
Malaysia	2007: Solid Waste and Public Cleansing Management Act 2007 was enforced with a specific article on take-back and deposit–refund	[34, 38]
	2010: Classification of Used Electrical and Electronic Equipment, Guidelines (2nd Edition) was public	
Thailand	2007: WEEE Strategic Plan was promulgated. The Act on Economic Instruments for Environmental Management (EI Act) was drafted	[34, 42]
Vietnam	2013: Decision No. 50/2013 of the Prime Minister on prescribing retrieval and disposal of discarded products was approved and took effect	[2, 34, 38]
	2015: Decree No. 38/2015/ND-CP dated 24.04.2015 on Waste and Scrap management	
	2015: Decision No. 16/2015/QD-TTg on the regulation of retrieval and disposal of discarded products, take effect from 01.07.2016	

PDR, India and Vietnam. These can be considered as proof for the applied technological tendency, life standards and possibly, the behaviors of end users at those countries.

There is a difference in the domestic e-waste generation (kg per inhabitant) in Vietnam from the data of URENCO [5] (1.9 kg/inh) and Baldé et al. [10] (1.3 kg/inh) that can be explained by different methods for data collection. Baldé et al. [10] calculated e-waste generated based on empirical data and statistical routines whilst URENCO [5] estimated the quantity of used EEE discarded in Vietnam based on National Statically data in combination with interview surveys.

The increase in quantity of e-waste from PCs in several Asian countries is shown in Table 6. China, India and Vietnam have fast rise of e-waste from PC in which Vietnam has the highest percentage. These can be from the fast increase rate of PC in the past years and with the contribution of technology innovation, PCs are substituted

Table 5 Domestic e-waste generated per country in Asian region in 2014 (Baldé et al. 2015) [43]

Country	E-waste generated (kg/inh.)
Cambodia	1.0
China	4.4
India	1.3
Indonesia	3.0
Japan	17.3
Korea	15.9
Lao PDR	1.2
Malaysia	7.6
Thailand	6.4
Vietnam	1.3

Table 6 The predicted increase percentage of e-waste from PCs

Country	Percentage of increase	Period	References
China	200–400	2007–2020	[66]
India	500	2007–2020	
Vietnam	1000	2006–2020	Calculated from [5]

Table 7 The increase of e-waste generated from TV sets, MPs and RFs by different factors in future

Source of e-waste	Country	Factor	Period	References
TV sets	Cambodia	6	2009–2019	[3, 9, 45]
	China	1.5–2	2009–2020	[9]
	India	1.5–2	2009–2020	[9]
	Vietnam	13	2006–2020	[3]
Mobile phones	Cambodia	4	2009–2019	[3, 9, 45]
	China	18	2007–2020	[9]
	India	7	2007–2020	[9]
	Vietnam	7	2007–2020	[3]
Refrigerators	Cambodia	3	2009–2019	[3, 9, 45]
	India	2–3	2007–2020	[9]
	Vietnam	17	2006–2020	[3]

by other devices (laptops, tablets) and CRTs are replaced by LCD screens.

The quantity of generated e-waste from TV sets, mobile phones and refrigerators will increase by different factors of 1.5–18 by 2020 as seen in Table 7. Vietnam still has high factor in generated e-waste from TV sets and refrigerators comparing to those of Cambodia, China and India. The results might come from the new technology development that lighter weight and more modern of TVs (lower factors for India and China) and refrigerators were put in the markets at a low increase rate (lower factor for India) [12]. E-waste generated from mobile phones is the highest in China as the country with very high rate of subscribers, followed by India and Vietnam as number of mobile phones have highly increased in the past years [12].

E-waste importation from developed countries is also a main source and the illegal import–export activities among these countries that create "the large gaps between statistical data and facts" [3]. Among Asian countries, Japan and South Korea are two e-waste exporters. The rest, Cambodia, China, India, Indonesia, Malaysia, Philippines, Thailand and Vietnam, are known destinations or suspect as destinations for e-waste [1, 3, 49] from the United State, European Union and Australia. Fuse et al. [14] provided information on used CRTs from Japan that went to Vietnam, Philippines and Hong Kong (61 % of all exported) while other used EEE moved to Taiwan, South Korea, Thailand, China, India [50]. Various import–export methods of smuggled e-waste have been discovered by governments in this area, such as being declared as raw materials, materials for reconditioning/reuse, for charity, or declared as other types of materials or scraps [46].

Among developing countries in this region, the transboundary activities of e-waste are vigorous and mainly smuggled. The routes of e-waste among Cambodia, Vietnam and China are from Cambodia to Vietnam, from Vietnam to China and from China back to Vietnam. E-waste from the nearest ports (Singapore and several cities of Malaysia) entered the Indonesian territory and once passed the international ports, it continues to travel illegally to other islands of the country [46]. Research of Borthakur and Sinha [51] shows that India has faced a fast increasing rate of e-waste both from domestic generation and illegal imports. China is in the same situation concerning illegal imports of e-waste from overseas and neighboring Asian countries and becoming the largest e-waste dumping site of the world [52, 53].

E-waste treatment activities

Asia has both co-existing formal and informal e-waste recycling sectors. The developed economies witness the differences in resident's behaviors, collection and treatment systems in comparison with the developing ones.

Formal sector

In this region, Japan operates a system in which consumers pay a fee for recycling, retailers take those used EEE back and recyclers are in charge of recycling [41, 54]. Korea combined between a free take-back and the use of agreed collection channels that pushed the collection and recycling rate to a higher rate than Japan [54] as the recycling rate was 27 % in Korea [55] and 24 % in Japan [10] in 2013. Whist, the formal sector in developing economies is fewer in number and lower in capacity and has more disadvantages in operation cost and collection ability. China has formed the formal sector via four national pilot projects for e-waste recycling and National Voluntary Collective Initiatives [47, 52, 56–58] and 106 e-waste recycling plants have been established by mid of 2015 and the treatment capacity has reached 1.458 mio.t in 2014 [59]. India has about two authorized treatment facilities related to e-waste at the full capacity of 5 tons per day and only two formal e-waste dismantling facilities [51]. Malaysia has 138 full e-waste recovery licensed facilities as of 2009 [45]. Thailand has about 30 formal e-waste recycling facilities [60]. In Vietnam, the formal sector is licensed hazardous waste treatment enterprises and e-waste dismantling and treatment are just a small part of their business (see Sect. 3.2.1). The common features of formal sector in developing countries are that they are facing the problem of insufficient inputs, operate at much higher cost comparing to informal sector and are not capable to collect e-waste from door-to-door [47, 48].

Informal sector

On the contrary to the industrialized economies, in emerging economies, the informal sector dominates. The reasons for the existence and development of informal sector in e-waste recycling are summarized in the research of Hicks et al. [61] and Chi et al. [52] that came from the unwillingness of consumers to return and pay for disposal of old EEE, lack of awareness in the potential hazards of e-waste, lack of funds and investment in improving e-waste recycling technologies, absence of appropriate e-waste management or absence of e-waste-specific legislation. It is important to point out the resident's behaviors to e-waste and used EEE in Asian region, in which, they (1) keep them at home or seldom disposing used EEE because they might be useful in future or sold [60, 62, 63], (2) have their appliances repaired, upgraded or refurbished [2, 62], and (3) prefer in buying secondhand or used EEE [52, 64–66]. Thus, the market for secondhand EEE is inevitable and being expanded [17, 51, 52, 67]. The informal collecting system in which old and malfunctioning EEE from households can be sold to individual collectors is very effective [2, 41, 52].

The e-waste treatment activities including dismantling, sorting and final processing (metal, plastic, part recycling) at small workshops under obsolescent technologies are mainly manual. Those crude technologies have been described in the study of Chi et al. [52] and Zhang et al. [53] for China's case. The studies from NIES and INEST [1], Fujimori et al. [65], Sothun [64], Oliveria et al. [66] and many others also mentioned the low and no protective equipment for the workers at e-waste treatment workshops and their low salaries. In case of Vietnam, the treatment of e-waste normally takes place at craft villages scattered throughout the whole country in which each craft village can deal with a specific type of e-waste or concentrate to a step in the recycling chain, such as Dong Mai craft village (Hung Yen province) focuses on Lead-Acid batteries, Te Lo village (Vinh Phuc Province), Trang Minh village (Hai Phong City) work on e-waste dismantling, and Ngu Xa village (Hanoi) is mainly for copper recycling. Thailand initially formed the recycling communities at farming villages of Kalasin Province [68]. In China, large informal recycling centers have been formed, such as Guiyu, Taizhou [52], as seen in India's case (Dehli and Bangalore) [53].

Conclusions

E-waste in Vietnam is generated from discarding of end user and imported new and secondhand products (in both illegal and legal ways), transboundary e-waste and industrial sources. A large amount of e-waste is collected and treated by informal sector (with the presence of repair shops, secondhand market, small workshops and craft villages).

E-waste recycling in Vietnam relies on craft villages. They are specialized in e-waste dismantling, plastic recycling, aluminum, copper smelters, lead recycling, and steel recycling. It forms a chain in which the output from dismantling villages will be transferred and become the inputs for other craft villages. There is specialization among workshops at e-waste dismantling craft villages in which each workshop deals with specific types of appliances. The same situation has been seen at plastic recycling craft villages.

Currently, outputs from e-waste dismantling and sorting processes are mainly sold to traders then exported to China. This leads to the dependence of the e-waste recycling sector in Vietnam on Chinese buyers.

The infrastructure for e-waste recycling existed but the technologies are basic and obsolete: manual dismantling works, manual and experience-based metal recycling processes. PCBs are mostly exported (only copper from PCBs is recovered at one workshop and gold is extracted at small workshops with small capacity). Other precious metals and rare earth elements are not recovered.

Those recycling technologies with lacking care of environment and health issues result in serious problems threatening worker's health and surrounding communities' lives as well as the environment (air, water and soil). With the profit orientation, those workshops at craft villages focus on how to maximize their gains rather than investment back for treatment systems or applying some methods for pollution reduction and waste minimization. Currently, the most critical processes go for the dismantling of CRT tubes (with florescent powder), refrigerators and air conditioners (with cooling agent or refrigerant), lead-acid batteries (with acid), and for the recycling of lead-acid batteries.

In Asia, it is distinguished between industrialized economies and emerging ones, in which the first group is with the activeness of formal sector and comprehensive e-waste regulations while the second one has the informal sector dominated and no or low level of e-waste regulations. The developing countries in Asia are the destination for e-waste from developed countries and face the problem of e-waste smuggling across the borders and within the country. They share the same end users' behaviors to e-waste and used EEE, the common features in which the secondhand market is popular and expanded, obsolescent technologies have been used for e-waste treatment, and even share the common consequences dealing with e-waste management and treatment using those technologies. Among compared countries, the highest e-waste generation rates belong to developed countries (Japan and Korea). Driven by technology innovation and the increase of appliances put on the market, China has the highest factor for e-waste generated from mobile phones, while the highest factor in e-waste from TV and refrigerator source belongs to Vietnam.

Thus, those developing countries in this region are in the need for the cooperation and support from other countries over the world to cope with e-waste in strengthening the regulation framework and law enforcement, capacity building for authority staff, and technology transfer.

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