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Innovating Collection Modes for Waste Electrical and Electronic Equipment in China

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Abstract: The huge amount of waste electrical and electronic equipment (WEEE) has aroused global concern with its importance of environmental performance for resources reutilization being recognized. The incomplete collection management system is required to be improved for a more environmental and orderly recycling way. Based on the public survey, field research and information search on the Internet, we present the existing framework and problems of WEEE collection in China, according to which four innovative WEEE collection modes are put forward: (i) Unified collection channels mode; (ii) Manufacturer alliance mode; (iii) Innovative enterprise self-built network platform mode; and (iv) Third-party integrated network platform mode. The characteristics, merits and deficiencies of the four modes are compared and analyzed, combined with which, we match the four modes with regions of different economic levels and Internet application. Third-party integrated network platform integrating online and offline resources is expected to be generalized under rapid development of information technology and e-commerce in China. The purpose of our research is to explore appropriate innovative WEEE collection modes and give suggestions for countries or economies whose WEEE collection situation or system are similar with China. Besides, government support and laws implementation are emphasized in mode promotion.

Keywords: waste electrical and electronic equipment; collection management system; extended producer responsibility; internet-based collection mode

1. Introduction

With the rapid development of information technology and increasing personalized demand by the public, the generation and upgrade rate of electrical and electronic equipment (EEE) such as mobile phones, computers and air conditioners is accelerated dramatically [1], resulting in an overwhelming volume of waste electrical and electronic equipment (WEEE). Since 2005, WEEE in the world has been estimated to increase at a rate of ~5% annually [2], which is three times higher than those of other wastes [3]. The yearly amount of disposed WEEE was ~40 million tons in 2014 [4] and it is predicted that the amount will surge to 50 million tons by 2018 [5]. In China, according to statistics provided by Ministry of Environmental Protection (MEP), WEEE has increased by a rate of more than 20% on average for the past 10 years [6,7]. The number of discarded mobile phones in 2013 was

~70 million units and in 2014, abandoned televisions, washing machines, air conditioners, refrigerators and computers (TWARC) are totally ~135 million units [8].

Not surprisingly, the tremendous amount of WEEE has leads to high probability of environmental pollution and human diseases [9,10]. Studies have found that ~70% of heavy metals, among which there is 58% lead, are from televisions and monitors ending up in landfill sites and that dumped computers cause 718 thousand tons of lead and 287 tons of mercury to flow into landfill sites around the world annually [11]. Generally speaking, there are three aspects of harmful effects that WEEE takes on the environment and human bodies. (i) If WEEE is handled by landfill or incineration, the heavy metals will permeate through soil, rivers and groundwater, giving rise to soil and groundwater contamination [12]. (ii) Hazardous gases including carbon monoxide, sulfur dioxide and dioxin discharged after incineration pollute atmosphere and take a toll on health [13]. (iii) Freon in disused air conditioners or other cooling equipment destroys ozone layer and aggravates greenhouse effect. Despite such contamination and damage mentioned above, some WEEE remains valuable as functions of them can be restored [14]. For instance, a good number of electronic products, especially computers and mobile phones, are discarded casually as a result of consumers' pursuit of more enhanced functional ones, speeding up the rate of products replacement consequently [15]. And the WEEE for which some of the components are damaged but the rest are in good condition can also be reutilized after repairing or replacing the worn parts. In addition, WEEE contains plenty of precious metals including gold (Au), silver (Ag), platinum (Pt) and palladium (Pd) that can be recycled through extraction. Usually the quantity of metals extracted from WEEE is much larger than that from ore of the same amount [16–18].

In order to address the environmental problems associated with the WEEE treatment as well as to take full use of the value, nations around the world have implemented laws and regulations on WEEE management. The European Union (EU) has released three main Directives, *Waste Electrical and Electronic Equipment* (WEEE, 2002/96/EC), *Restriction of the Use of Certain Hazardous Substances* (RoHS, 2002/95/EC) and *Energy-using Products* (EuP, 2005/32/EC), the first of which requires manufacturers and importers in the EU member states to take back their products from consumers for disposal by environmentally sound methods [11,19–21]. In 2012, the WEEE Directive was revised in target of improving collection, reuse and recycling of used electronic devices for waste reduction and more efficient use of resources [22]. In 2001, *Home Appliance Recycling Law* in Japan was promulgated, forcing producers to take back four types of household WEEE, that is, televisions, refrigerators, washing machines and air conditioners. In 2008, the law was amended to add LCD, plasma TVs and clothes dryers [23]. As the biggest EEE manufacturing and consuming country, the USA has no federal level legislation for WEEE recycling, while more than 20 states have already initiated WEEE management laws [24]. In response to the increasing volume of WEEE and their potential environmental impacts, Chinese government also has enacted a series of regulations and laws (shown in Table 1). In 2001, National People's Congress of China (NPCC) passed the *Clean Production Propel Law* to promote energy conservation, resources utilization and clean production of manufacturers [25]. At the end of 2014, *Guide for Standard Operation and Management of E-waste Dismantling and Disposal* was enacted, being conducive to guiding and supervising the WEEE collection and treatment from the aspects of management system, visual surveillance, disassembly standardization and so on [26]. *E-waste Disposal Catalogue* implemented in March 2016 increases the diversity of disposal WEEE ranging from TWARC to kitchen ventilators, electric water heaters, printers and so on and stipulates that (re)manufacturers use non-toxic and non-hazardous as well as recyclable materials for products in the catalogue [27,28]. In fact, existent regulations do not do well in providing a good guidance for WEEE collection implementation in China [29]. Three important factors that cause efficiency of existent WEEE collection system are considered: (1) The regulations in WEEE do not explicitly stipulate the responsibility of recycler and utilizer. Although the *Regulation on Management of E-waste Disposal* implemented from 2011 stipulates the WEEE processing fund system, there is no specific provision on responsibility for the government, manufacturer, sellers and consumers [30]; (2) The specific items

are not to be refined in detail. Extended Producer Responsibility is defined in *Circular Economy Promotion Law* issued in 2008 [31] but its specific implementation does not be provided. For example, payment mechanism is not included in this regulation, which causes the whole recycling system is difficult to be established and the law cannot be put into effect. (3) The existing legislation lacks incentive mechanisms for recycling entities and government financial support. To further promote EPR instrument, in 2017, the State council promulgated *China's extended producer responsibility plan* that emphasize the shifts of responsibility from the consumers to producers who should be responsible for the entire life cycle of a product, especially for the collection, dismantling and disposal at its end-of-life stage and set goals of EPR implementation by 2025 [32].

Most national laws and regulations on WEEE are about recycling that covers collection, dismantling, disposal and (re)manufacturing of end-of-life (EOL) products. As collection is the first recycling step that involves in the source and treatment method of WEEE, collection system plays a vital role in the whole recycling chain so that numbers of countries and regions are enthusiastic in promoting WEEE collection activities. In Germany, classification collection is well implemented by separating WEEE from household wastes and putting them into special containers or giving to municipal collection sites. For convenience, some municipal administrations also provide door-to-door collection service with a little charge [33]. The WEEE recycling system of Switzerland is based on EPR principles [23]. Every appliance retailer is a collection point which consumers can return the old appliances to and then the retailers deliver collected WEEE to the manufacturers for treatment [34]. To sustain the recycling system, when purchasing new products, consumers take the initiative to pay advanced recycling fees (ARF), some of which are for collection points establishment [35]. Similarly, in Japan, consumers are obliged to pay the transportation and treatment costs when discarding the four types of home appliances (TVs, air conditioners, refrigerators and washing machines), taken back by retailers or producers [36,37]. Japanese municipality requires manufacturers to purchase WEEE produced by themselves and many electric and electronic corporations set up collection points around the nation and deal with WEEE themselves [38,39]. Bahers and Kim (2009) demonstrate the regional approach of WEEE management in France and emphasize the roles of recycling operators, social economy companies and EPR compliance [40]. In the US, The Electronic Manufacturers Recycling Management Company (MRM), a joint company by Sharp, Toshiba and Panasonic, has launched a joint nationwide recycling program [23]. As for China, WEEE recycling industry at present is still at the hard beginning and a complete WEEE collection system has not yet been established. Although EU WEEE and ROHS Directives have been well recognized by most China's EEE manufacturers, Yu et al. identify that supply chain management is the most significant challenge for promoting environmental reform in WEEE recycling [41]. WEEE is mainly collected by informal collection entities who are the individuals and enterprises without government-issued recycling licenses (i.e., street peddlers, appliance repairing stores, waste collection stations and dismantling workshops). In a sense, their collection business is illegal but only a small amount of WEEE is collected by old-for-new retailers and professional WEEE recycling organizations [42,43]. The WEEE collection status in China is a major concern that has been widely studied. He et al. (2006) present the current status of WEEE and implementation of WEEE treatment and recovery strategies, based on which, they come up with problems that restrict the operation of qualified WEEE recycling enterprises in China [44]. According to Chinese WEEE flow and recycling status, Yang et al. (2008) argue that a special system focusing on how to transform or integrate existing informal recyclers into the formal recycling sector is necessary [45]. Also, Chi et al. (2011) take existing informal recycling sectors into consideration in setting up a new formal recycling system [15]. By a questionnaire survey and interviews with 20 manufacturing companies, Birkin et al. (2009) demonstrate the lack of sustainable development practices and emphasize the importance of establishing a new business model for sustainable development [46]. However, few studies in the literature consider the combination of the Internet and the formal recycling system establishment. In fact, with rapid advancement of the Internet and popularization of e-commerce, some corporations have set up WEEE collection websites such as Banana Peel [47] and Aihuishou [48] where people can

sell WEEE or purchase second-hand EEE. However, these platforms have not been widely used due to a lack of awareness raising campaign by corporations and the government and such WEEE recovery practices are confined to some big cities such as Beijing, Shanghai and Guangzhou [49].

Compared to the developed economics where WEEE collection systems have been comparatively mature, WEEE recycling in China started late. Extant laws and regulations about collection are just a framework where the payment mechanism, technical standards and evaluation system are unsettled. Being lacking in technology, finance and experience for WEEE collection, transportation and disposal, most producers fail to implement the EPR principles and establish collection stations. The consciousness of environmental protection and social responsibility are weak for businesses and consumers, for example, many enterprises have not fully realized that the products' design have an important impact on the environment and for most consumers, they are not clear how WEEE processed in informal way influences the environment and human health [50,51]. For most Chinese consumers, the reason for recycling WEEE is to get paid, thus polluter-pays principle is not feasible in China currently. The government is advised to give financial support to the manufacturers and enhances polluter pays awareness by some public campaigns and specific legislations. In light of discrepancies of economic development levels, residents' environmental consciousness and government systems among countries, China is supposed to establish its individual collection system in accord with actual national conditions rather than duplicate other countries' modes for WEEE collection.

This paper is explorative in WEEE collection system that suits China. We establish current WEEE collection situation and find out problems by public survey, field research and information search on the Internet. Based on characteristics of informal collection channels and EPR instrument, we propose the unified collection channels mode and the manufacturer alliance mode respectively. Under the Internet era, some corporations probe into forming a collection system with information technology and several governmental agencies, such as NDRC and MEP, advocate combination of WEEE recovery and the Internet, on a basis of which, the innovative enterprise self-built network platform mode and the third-party integrated network platform mode are also put forward. To the best of our knowledge, there is very limited literature researching for new WEEE collection systems in accordance with China's national condition. In this paper, the four novel collection modes we proposed are combined with existing collection channels in China, aiming at providing recommendations for the government and enterprises to explore environmentally sound and practicable WEEE collection system. The paper is organized as follows: Section 2 presents our research method, current WEEE collection channels in China are analyzed and development strategies are recommended in Section 3, Section 4 illustrates four innovative collection modes, characteristics of each mode are described and their comparison is made in Section 5, conclusions and future work is given in Section 6.

Table 1. China's legislation on WEEE management.

Time	NPC ^a	State Council	Ministries & Commissions
July 2004		<i>Administrative Measure on Dangerous Wastes Operation Permit</i>	
April 2006			<i>Technical Policy on Pollution Prevention of Discarded Appliances and Electronic Products (by SEPA ^b)</i>
March 2007			<i>Measure on Management of Pollution Control of Electronic Information Products (by MIIT ^c)</i>
May 2007			<i>Measure on Management of Renewable Resources Recycling (by MOC ^d, NDRC ^e, MPS ^f, MOHURD ^g, SAIC ^h & SEPA)</i>
February 2008			<i>Measure on Management of Prevention and Control of E-wastes Pollution (by MEP ⁱ)</i>
January 2009	<i>Circular Economy Promotion Law</i>		
June 2009		<i>Circular on the Transmission of Measure for the Implementation of “Old for New” Policy for Home Appliance (GOSC ^j)</i>	<i>Measure for the Implementation of “Old for New” Policy for Home Appliance (by MOC, MOF ^k, NDRC, MIIT, MEP, SAIC & AQSIQ ^l)</i>
June 2010		<i>Regulation on Ozone-depleting Materials</i>	<i>Interim Measure on Remanufacturing Products Affirmation (by MIIT)</i>
November 2010			<i>Guide for Development Program of Disposal of E-wastes (by MEP)</i>
December 2010			<i>Industry Access to Integrated Utilization of E-waste (Exposure Draft) (by MIIT)</i>
January 2011		<i>Regulation on Management of E-waste Disposal</i>	<i>Administrative Measure on E-waste Recycling Enterprises Permit (by MEP)</i>
			<i>E-waste Disposal Catalogue (1st Batch) and Modified Provision (by NDRC, MPS & MIIT)</i>
August 2011			<i>Administrative Measure on Solid Wastes Import (by MEP, MOC, NDRC, GAC ^m & AQSIQ)</i>
April 2012		<i>Work-division Project on Building Complete Advanced Key Departments of Waste Goods Recycling System</i>	<i>Administrative Measure on Prevention and Control of Environmental Pollution by Electronic and Electrical equipment (Exposure Draft) (by MIIT)</i>
July 2012			<i>Administrative Measure on Tax Levy and Use for E-waste Recycling (by MOF, MEP, NDRC, MIIT, GAC & SAT ⁿ)</i>
			<i>Product Range of E-waste Recycling Tax Levy (by MOF & SAT)</i>
October 2012			<i>Administrative Provision on Prevention and Control of Waste Plastics Processing and Utilization (by MEP & NDRC)</i>
			<i>The 12th Five-year Plan for Prevention and Control of Dangerous Wastes (by MEP, NDRC, MIIT & MOH)</i>
May 2013			<i>Administrative Measure on Circulation of WEEE (by MOC)</i>
July 2013			<i>Circular on the Print and Distribution of “Old for New” Pilot Plan for Remanufacturing Products (by NDRC, MOF, MIIT, MOC & AQSIQ)</i>

Table 1. Cont.

Time	NPC ^a	State Council	Ministries & Commissions
August 2013		<i>Recommendation on Speeding up Development of Energy Saving and Environmental Protection Industries</i>	
December 2013			<i>Key Points on E-waste Disposal Catalogue Modification</i> (Exposure Draft) (by NDRC)
			<i>Circular on Policies Improvement for E-waste Recycling Tax</i> (by MOF, MEP, NDRC & MIIT)
December 2014			<i>Guide for Standard Operation and Management of E-waste Dismantling and Disposal</i> (Exposure Draft) (by MEP)
January 2015			<i>Long-term Planning on Construction of Renewable Resources Collection System (2015–2020)</i> (by MOC & NDRC)
			<i>Circular on the “Old for New” Pilot Plan for Remanufacturing Enterprises and Products</i> (by NDRC, MOF & MIIT)
January 2016			<i>“Internet +” Implementation Plan of Green Ecology</i> (by NDRC)
March 2016			<i>E-waste Disposal Catalogue (2014 Version)</i> (by NDRC, MEP, MIIT, MOF, GAC & SAT)
May 2016			<i>Measures on Promoting Transformation and Upgrading of Resources Recycling Industry</i> (by MOC, NDRC, MIIT & MEP)
January 2017		<i>China’s Extended Producer Responsibility Plan</i>	

(1) “Time” in this table indicates the implementation time. (2) Abbreviations of ministries list as follows. ^a NPC: National People’s Congress. ^b SEPA: State Environmental Protection Administration. ^c MIIT: Ministry of Industry and Information Technology. ^d MOC: Ministry of Commerce. ^e NDRC: National Development and Reform Commission. ^f MPS: Ministry of Public Security. ^g MOHURD: Ministry of Housing and Urban-Rural Development. ^h SAIC: State Administration for Industry & Commerce. ⁱ MEP: Ministry of Environmental Protection. ^j GOSC: General Office of the State Council. ^k MOF: Ministry of Finance. ^l AQSIQ: Administration of Quality Supervision, Inspection and Quarantine. ^m GAC: General Administration of Customs. ⁿ SAT: State Administration of Taxation. Specifically, the SEPA was renamed as the MEP in 2008, thus the SEPA and the MEP are the same ministry.

2. Methodology

To increase the level of WEEE collection, it is necessary to obtain a systematic collecting system. Our research project started in 2015 and is conducted in three phases: (1) Public survey on people's awareness and behavior on WEEE; (2) Field research on WEEE recycling enterprises; and (3) Information search on the Internet. We intend to find out WEEE collection status in China and propose feasible innovative WEEE collection modes to solve existing problems.

2.1. Public Survey on People's Awareness and Behavior on WEEE

In order to find out the public awareness on WEEE, questionnaire surveys taking family as a unit were conducted from August 2015 to February 2016. The questionnaires mainly include the following four categories:

- The public environmental awareness of WEEE;
- The ownership and treatment of WEEE in respondents' families;
- The respondent's attitude and tendency toward the collection of WEEE;
- The respondent's personal information.

A test was carried out to ensure the rationality and readability of the questionnaire before the formal survey. The formal questionnaire (Main questions in the questionnaire listed in the Supplementary data) came out after modified several times with the advices of respondents. Totally 1844 questionnaires are distributed in the public survey, including 1020 online questionnaires and 824 printed questionnaires. The results of printed questionnaires are mainly acquired by community and street interviews. Altogether, 1698 valid questionnaires are taken back with a response rate of 92.1%. Specifically, the questionnaires survey has strictly followed scientific methods for questionnaire design and research, to maintain authenticity, reliability and validity of the survey as far as we can.

In our survey, Zhejiang Province, Shandong Province, Guizhou Province and Sichuan Province were selected as the target regions. Zhejiang Province, with a population of 56.6 million and covering 40,733 square miles, is the most developed area of the Internet in China and has witnessed economic prosperity that the Internet advancement brings [52]. As the province with big population and strong economy, Shandong's GDP ranks third all over the nation [53]. Hunan and Guizhou belong to developing regions in the Midwest of China [54,55]. The specific geographical distribution of the questionnaire is shown in Figure 1.

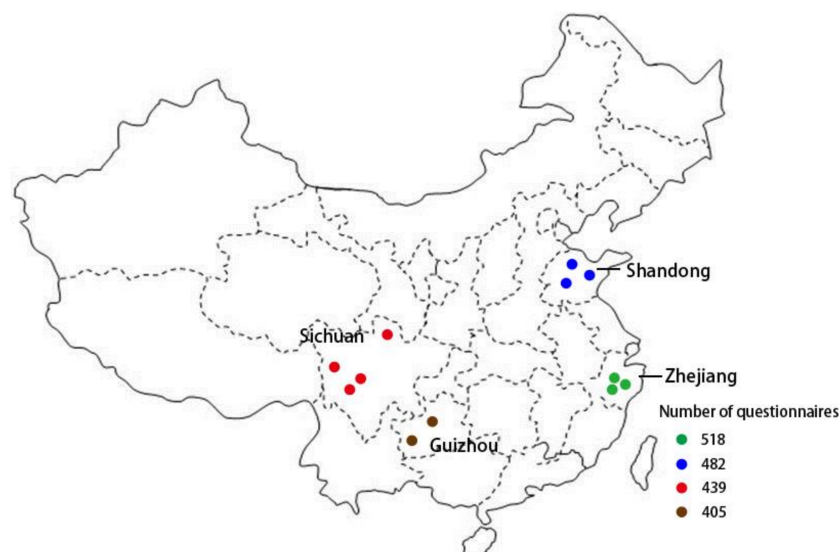


Figure 1. The geographical distribution of the questionnaire.

2.2. Field Research on WEEE Recycling Enterprises

In order to find out the environmental awareness and know about WEEE recycling process of the enterprises, our field visit covering those four different provinces in China were carried out from May 2016 to October 2016. We investigated 55 WEEE recycling enterprises including EEE manufacturers, WEEE collectors, dismantlers and disposers. Field research on these entities can reflect advantages and disadvantages of WEEE reverse logistics and management in China and promote us to provide significant recommendations to the enterprises and policy-makers.

Our field visit is conducted by interview and observations on processes related to WEEE management were made to material recycling facilities and disposal sites. Our research group consisted of 3 people, two of whom acted as note-taker and observer and the other researcher talked with the managers of enterprises (A table about questions for different entities in the interview is presented in the Supplementary data). Because they are compensated for their interview time, most respondents are active and the results are of high reliability. Field visit enables us to discuss with the managers of enterprises face to face for a better understanding of their attitudes toward WEEE recycling and strategies on WEEE recycling they adopt. The troubles in relation to their collection practice reflect the disadvantages of existing WEEE collection system and what aspect should be improved. The suggestions they propose are also conducive to the innovative collection mode establishment.

2.3. Information Search on the Internet

We collect data from the literature review, book, article, newspapers and websites about the about WEEE recycling industry, WEEE collection status, regulations of WEEE and WEEE recycling management in China, India, America, Japan and European countries. The information is classified into four categories:

- The implementation of regulations and policies on WEEE collection in those countries;
- The recycling behavior of EEE manufacturers, collectors, dismantlers and disposers in those countries;
- Public awareness and behavior on WEEE collection;
- Online recycling platforms in China.

Most information is acquired from literature review that is organized to be able to describe the existing WEEE collection system around the world. Besides, we get information and materials from representatives of authorities and experts on WEEE recycling through mail enquiries or personal visit. Personal notifications and real-life experiences are also for reference as we describe current situation of WEEE collection in China.

3. Status Quo of WEEE Collection in China

In China, the volume of WEEE is growing at a rate of 20% per year [56]. Appropriate collection methods are as the premise of reutilizing resources of EOL products. On the basis of classification of collection channels, we conclude the flow path of WEEE by the public survey, field research and information search on the Internet, as shown in Figure 2. In the following, we elaborate collection entities of informal recycling channels and formal recycling channels, respectively.

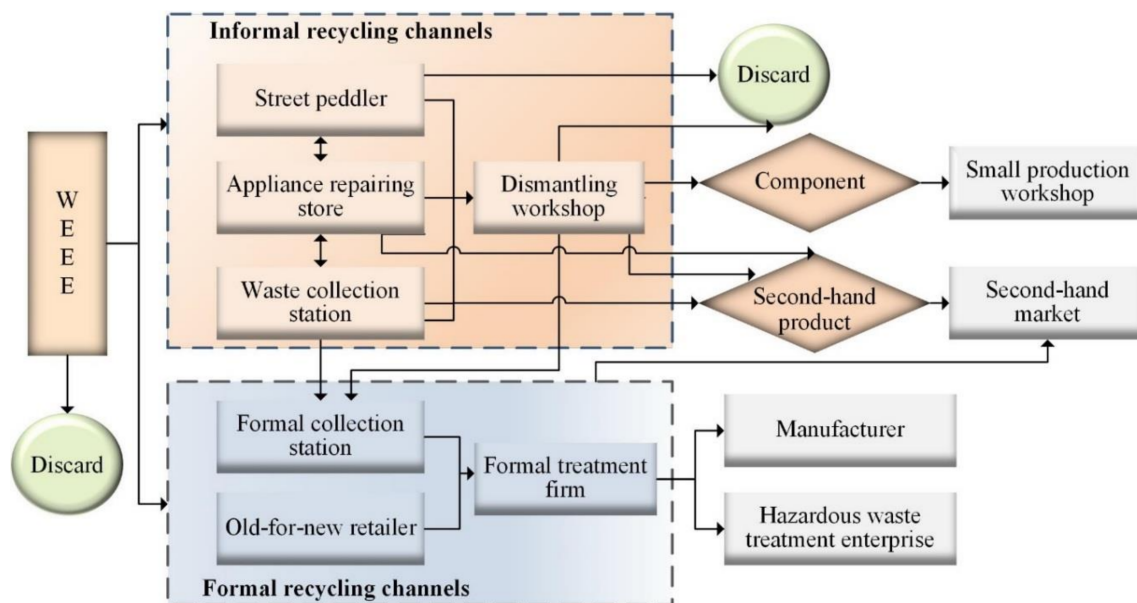


Figure 2. WEEE recycling mode in China currently.

3.1. Informal Collection Entities

At present, the main informal collection entities in China are street peddlers, appliance repairing stores, waste collection stations and dismantling workshops, as shown in Figure 3.



Figure 3. Informal WEEE collection entities in China.

3.1.1. Street Peddlers

In China, it is common that street peddlers ride tricycles along the street in communities to provide door-to-door WEEE collection service. Being dominant in WEEE collection channels, the peddler-collection mode recovers most WEEE, accounting for more than 80% of total wastes collected [57].

Driven by profit motive, the street peddlers seldom transfer the EOL products to formal collection and treatment corporations but deal with them in random ways. (i) For the repairable WEEE, they send them to appliance repairing stores, waste collection stations or dismantling workshops; (ii) Street peddlers simply separate the useless wastes into different categories. The useful components (e.g., transformers, motors), metals, glasses, plastics and so on are sold individually while the other parts and materials are disposed of by incineration or landfill. Due to the large number, and wide distribution, of street peddlers, it is difficult for the government to regulate and supervise them as well as control WEEE pollution from the source. Thus it is necessary for the street peddlers to be regulated and educated how to handle hazardous waste.

3.1.2. Appliance Repairing Stores and Waste Collection Stations

In appliance repairing stores, a large amount of WEEE is directly from consumers and a part comes from street peddlers. Typically, appliance repairing stores and waste collection stations cooperate

with street peddlers. Peddlers sell WEEE that are slightly damaged or still reusable after repairing to appliance repairing stores while appliance repairing stores sell the non-reused second-hand products to street peddlers at low price [58].

Apart from working on WEEE collection, waste collection stations collect all kinds of metals (e.g., copper, iron and aluminum), plastic, glasses and so forth. The major difference between waste collection stations and street peddlers is that the former possess their own storefronts. They get EOL products from consumers at a certain payment or purchase from street peddlers and appliance repairing stores, thus to some extent, waste collection stations and street peddlers are cooperators and competitors. Most of WEEE collected by waste collection stations finally flows into informal dismantling workshops and only a minority is delivered to formal WEEE treatment stations.

Both appliance repairing stores and waste collection stations recycle some reusable appliances back into second-hand market, which takes a threat to consumers' health because the appliances that are not tested to be qualified professionally give a rise to short service life, poor stability, easy leakage of electricity and high burning accident rate. And the completely valueless products collected by appliance repairing stores and waste collection stations are usually delivered to informal dismantling workshops or disposed of in other illegal ways, causing serious safety issues and being detrimental to the environment.

3.1.3. Dismantling Workshops

The WEEE of dismantling workshops are supplied by street peddlers, appliance repairing stores, waste collection stations and consumers, viewed as the continuation of street peddlers' work. They dismantle the collected WEEE mainly in three ways: (i) After being reconditioned, the reusable or repairable WEEE are recycled back into market of second-hand products; (ii) The reusable component, for example, electric machines, compressors, extracted from the non-reusable WEEE, are recycled into second-hand material market; (iii) The valuable metal and plastic of the non-recycled are sorted out and the useless parts are discarded at will.

A large majority of dismantling workshops are family-run who generally use primitive technologies such as manual dismantling, acid etching, incineration and landfill to handle WEEE, which causes low recycling rate and local pollution. In particular, the informal backyard treatment poses a health risk—for example, headache, tetter, nausea and conjunctiva congestion—to workers in dismantling workshops [13,59].

3.2. Formal Collection Entities

3.2.1. "Old for New" Retailers

"Old for new" refers to EEE replacement scheme whereby consumers receive subsidy for buying new products including TWARC if they resell the same sort of used ones to stores, namely, old appliances are as discount coupons. On 28 June 2009, the *Measure for the Implementation of "Old for New" Policy for Home Appliance* was promulgated [60,61], its implementation process is as follows: After consumers resell EOL products to a retailer and get an "old-for-new" voucher from the collector who are sent to collect the old products by the retailer, they can buy a new electric and electronic product at a lower price by the voucher. The retailer get subsidy from the government with sales invoice and "old-for-new" voucher and give a part of the subsidy to the manufacturer. WEEE is transported to and handled by WEEE treatment firm who should advance the transport subsidy to collectors and submit voucher to the government. After checking the voucher, the government subsidize the treatment firm for transporting and dismantling WEEE [62,63]. The operating process is presented in Figure 4.

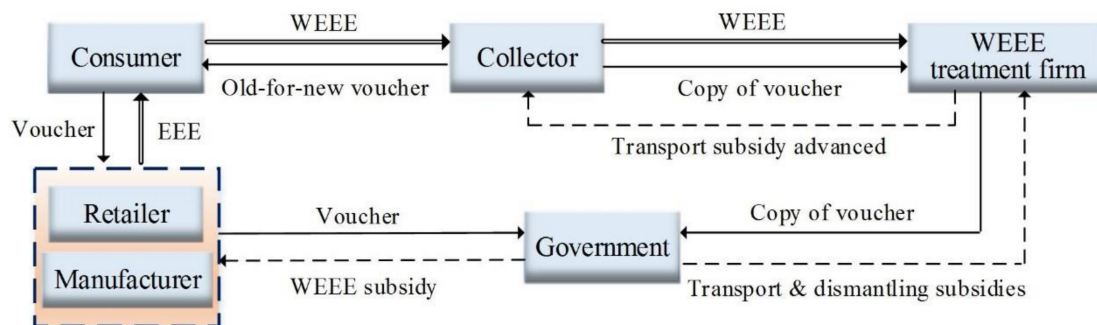


Figure 4. Operating process of “old-for-new” activity.

On 1 January 2012, the “old-for-new” policy that had been implemented for 2.5 years came to an end [64]. In recent years, in order to promote new products, some producers, such as Haier and Gree, carry out “old-for-new” activity 2–3 times annually and usually lasts 10–14 days every time, even though it may increase costs and the difficulty of storage control. Fees of collection, storage, transportation, treatment are so high that it seems unwise to carry out “old-for-new” activity from the perspective of economic benefit. But this activity, in a sense, stimulates consumer demand as more new appliances are sold as the EOL products are collected. More importantly, the collected WEEE is handled by formal treatment corporations for environment pollution reduction and resources conservation.

With the development of e-commerce, some e-commerce giants such as Amazon.Com, BestBuy.Com, Jingdong, Gome Online, Suning Tesco, and so forth, offer an “old-for-new” service in order to retain regular customers and increase sales. Unlike traditional “old-for-new” activity, the consumers send the WEEE to these B2C platforms by mail, going to the brick-and-mortar stores or door-to-door service. After checking and evaluating the used product, the platform gives consumers gift card (GC) and cash card (CC) that can be used to deduct the price of products that consumers purchase later [18,65]. This online “old-for-new” pattern can also be adopted by some network collection platforms.

3.2.2. Formal Collection Stations

Formal WEEE collection stations are licensed entities who engage in collecting WEEE from individuals and corporations. In spite of low recovery price, consumers can be reassured that the WEEE they deliver to the formal sectors are coped with safe treatment meeting with “3R” principles [52]: “Reuse”—WEEE of good function can be sold as second-hand products and reused; “recover”—WEEE with slight damage are sold again after refurbishment and repair; and “recycle”—the scrapped WEEE is handled by formal corporations in environmental friendly way.

However, a number of formal collection stations have gone out of business without sufficient WEEE. Rather than set up in downtown, they are mostly in less populated suburb and the recovery price of them is usually lower than that of street peddlers, while the peddlers are widely distributed and dominant in collection field, some of who even pay fees to residential property for monopolizing WEEE collection. Consumers would rather sell WEEE to the peddlers as a result of their higher payment and more convenient collection service. Also, unlicensed dismantling workshops tend to pay more to street peddlers than formal collection stations pay, so the former is a prior choice for most peddlers to recycle WEEE they have collected. For these reasons, the common challenge for sustainable running faced by most formal collection stations is how to get abundant WEEE.

3.3. Development Strategies for WEEE Collection in China

As can be seen from aforementioned collection entities in China, lower-cost informal sector has held back development of formal collection entities, made a horrendous waste of resources and taken threat to the environment. Both processes of informal and formal collection channels currently are nontransparent so that the public know little about WEEE information such as whereabouts of

the EOL they resell and market recovery price. Besides, environmentally harmful and even illegal recycling behaviors driven by economic interests of informal collection entities are difficult to be supervised and controlled. It is of great importance to set up a comprehensive WEEE collection system, which desperately needs the support of government and the efforts of enterprise promotion due to imbalanced regional economic development, the relatively weak environmental awareness of residents and a recycling market dominated by informal channels. We come up with the following suggestions for establishing WEEE collection system.

(1) Improve laws on WEEE collection

First of all, formulating and improving laws and regulations of WEEE collection system should be viewed as primary tasks owing to the WEEE law inadequacy in China compared with some developed countries such as Germany, Japan and Switzerland. What responsibilities consumers, manufacturers and franchisers must undertake on WEEE collection ought to be defined officially. Regulatory functions of MEP, MIIT and NDRC should be enforced to supervise WEEE collection process and punish violators. Only with legal protection can a new WEEE collection system be set up with guarantee.

(2) Support formal WEEE collection corporations

Formal collection corporations are supposed to improve technology for WEEE collection, import advanced equipment and pay higher labor costs than informal collection, requiring large investment and gaining returns before long. To alleviate the fund pressure and reduce the barriers to entry of formal recycling, the government could enact preferential policy, take some sort of subsidy and tax relief on formal collection corporations, which also contributes to the establishment and improvement of WEEE collection system.

(3) Broaden WEEE collection channels

Through reward and subsidy by the government, WEEE collection and treatment corporations are inspired to enlarge collection scale, improve dismantling and disposal technology. Taking the allocation of regional resources into account, the collection corporations could establish WEEE collection sites and control the scale of regional collection industry in a reasonable range. For instance, each district can set up a WEEE collection site and each city depending on its size builds several WEEE collection and treatment branches. Producers are required to manage and collect their EOL products so that they will pay more attention to environment factor in design of products.

(4) Set up a sound WEEE collection system

Most WEEE is collected by private traders informally and whereabouts of the WEEE are uncontrollable, followed by a series of environmental problems. The actions of setting up a sound WEEE collection system are categorized into three aspects. (i) Integrate all kinds of collection channels to command where the WEEE collected are to go, a way to settle the matter from the source. (ii) Set up a system considering producers alliance as a subject that makes EEE manufacturing, WEEE collection and treatment are processed in the system. (iii) Under the Internet era, firms are expected to realize that WEEE is recycled through a greener “Internet + recycling” system.

4. Exploration on Innovative WEEE Collection Modes

Based on the existing WEEE collection system in China and strategies of WEEE collection development in Section 3.3, we introduce and analyze four WEEE collection modes. Our exploration on these innovative WEEE collection modes is motivated by several considerations:

- The collectors or other recycling entities tend to be scattered and small-sized;
- The collection behaviors are seldom monitored by government;

- How to combine the network platform and brick-and-mortar collectors;
- How to make full use of existing resources such as transporting, informal collectors.

Construction and operating processes of the modes are presented in the following.

4.1. Unified Collection Channels Mode (Mode I)

At present, the characteristics of WEEE recycling in China are “dirty” (i.e., discard and dismantle WEEE at random), “messy” (i.e., too many decentralized collection channels) and “small” (i.e., collectors mainly consist of individual hawkers). The widespread and numerous informal collection entities undertaking most WEEE collection should be managed and fully made use of, thus we propose to integrate them by setting up a unified WEEE collection system.

4.1.1. Mode Construction and Operating Process

To control chaotic WEEE collection entities, the government funds and establishes the integrated collection company incorporating decentralized street peddlers, waste collection stations, appliance repairing stores and “old-for-new” retailers. This state-owned enterprise control and manages both the formal and informal collection entities in its management area. Regional WEEE collection station is also established by the company in each city or town and for big cities every district can own a collection station, responsible to gather and pre-dispose WEEE.

The operating flow of Mode I is shown as Figure 5. Consumers sell WEEE to street peddlers, appliance repairing stores, waste collection stations or “old-for-new” retailers, all of which send the collected WEEE in enough number to the regional WEEE collection station. Or more directly, consumers sell WEEE to the regional station whose responsibility is collection, classification, pretreatment for the WEEE in its territory. Some of the WEEE is sent to producers as raw material or remanufacturers for the main components of remanufacturing, while the others are transported to the formal treatment enterprises to be dismantled and disposed of.

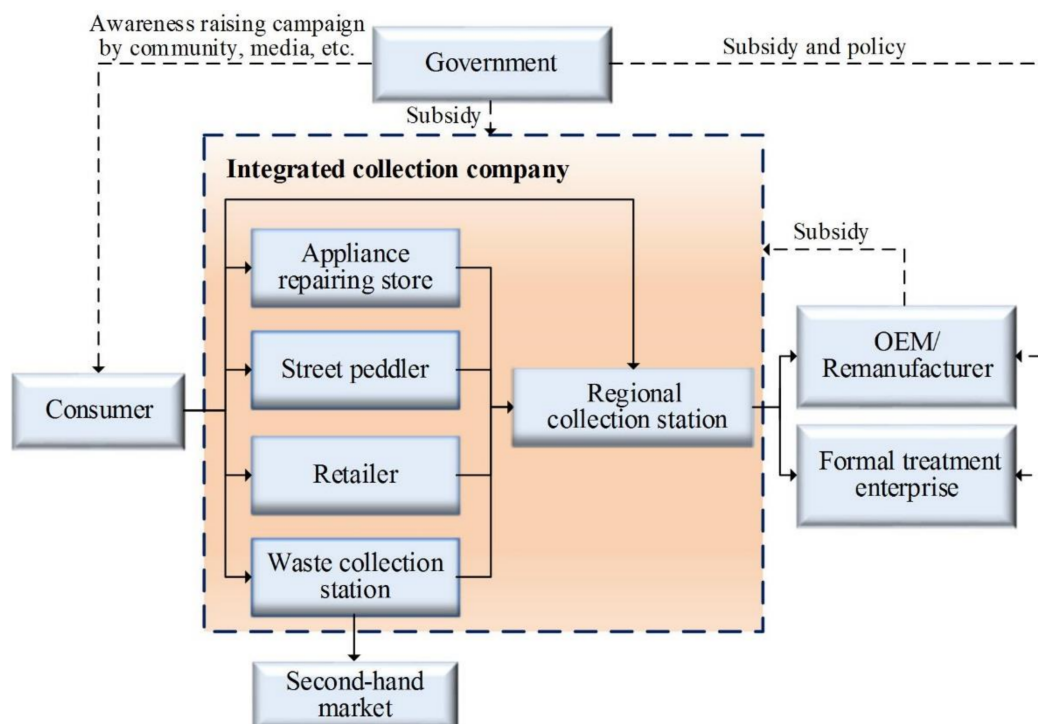


Figure 5. Operating process of unified collection channels mode (Mode I).

The early implementation of this mode needs policy support and subsidy from the government. When OEMs and remanufacturers receive WEEE, they subsidize the integrated collection company for collection and transportation cost, followed by which, the enterprises (OEMs, remanufacturers and formal WEEE treatment companies) apply to the government (e.g., Ministry of Finance) for subsidy through submitting invoices. This subsidy form was applied in “old-for-new” activity in China from 2009 to 2012 [66]. Besides, the government is supposed to subsidize integrated collection company whose construction and running in the beginning stage takes much capital.

4.1.2. Analysis of Responsibilities and Rights

A large number of the self-employed without licenses occupy WEEE collection market in China. It is the unified collection channels mode’s purpose as well as a great challenge for integrated collection company that how to organize and guide the behavior of individual collectors by centralized management system. In the mode, the integrated collection company is as a liability body and the government’s supervision and incentive mechanism is to be emphasized for improving the environmental compatibility of WEEE collection activities. The description of their roles and responsibilities is shown.

- The integrated collection company

The integrated collection company is to integrate the WEEE collection entities and carry out operation programs. It organizes environmental awareness raising campaign, provides professional training for the informal sectors and prevents less environmentally friendly behavior of WEEE treatment. For inspiring existing collection entities to participate in the integrated collection system, the company gives the collectors rewards according to WEEE volume they have collected. The whole WEEE management system also requires the integrated collection company to choose qualified (re)manufactures and WEEE treatment corporations.

- Government agencies

Government agencies give support to integrated collection company and formal WEEE treatment enterprises by financial subsidies and preferential policies like tax relief and preferential procurement of government office supplies. For incorporating and managing various collection entities, the integrated collection company are faced with great operation and financial pressure at initial phase. The processors are in trouble in insufficient WEEE, financial stress, upside down take-back prices (i.e., recovery price is higher than the selling price of the component dismantled). All of the problems are expected to be solved with the aid of the government, who is also capable of publicizing the unified collection channels mode through communities and media.

4.2. *Manufacturer Alliance Mode (Mode II)*

EPR requires that producer be not only responsible for production but also the product’s entire life cycle, especially for collection and disposal of the EOL [67]. In this mode, EEE manufacturers in manufacturer alliance are responsible for their product’s entire life cycle including production, collection and treatment.

4.2.1. Mode Construction and Operating Process

Manufacturer alliance consists of EEE manufacturers who produce homogeneous products or adopt similar production specification. The manufacturers invest and set up the WEEE recycling alliance center, in which WEEE collection station collects WEEE produced by the EEE producers in alliance or their sub-corporations from consumers, retailers and third-party collectors and WEEE treatment enterprise dismantles and disposes of the WEEE. The government levies recycling fund or tax from EEE manufacturers and subsidizes WEEE recycling alliance center, who reallocate the subsidy

to collection stations and treatment enterprises according to their WEEE collection and treatment separately. Specifically, the total revenue and expenditure of the government is balanced but for each manufacturer alliance, the recycling fund levied to the government and the subsidy gained from the government is generally unbalanced because the manufacturers are subsidized based on categories and quantities of WEEE they collect.

The operating flow of mode II is shown in Figure 6. WEEE recycling alliance center pre-establishes specific urban collection stations that collect WEEE in two ways, one of which is from consumers directly and the other is that individual hawkers, material collection companies, “old-for-new” retailers transport WEEE collected from consumers to the stations. The collected WEEE are temporarily stored in the specific collection stations and then sent to the regional WEEE treatment enterprise that the manufacturer alliance sets up. WEEE recycling alliance center adds or updates information of the WEEE recycling system about the list of manufacturers, product categories, recovery prices, conditions of WEEE treatment to share with suppliers, collection entities and the government.

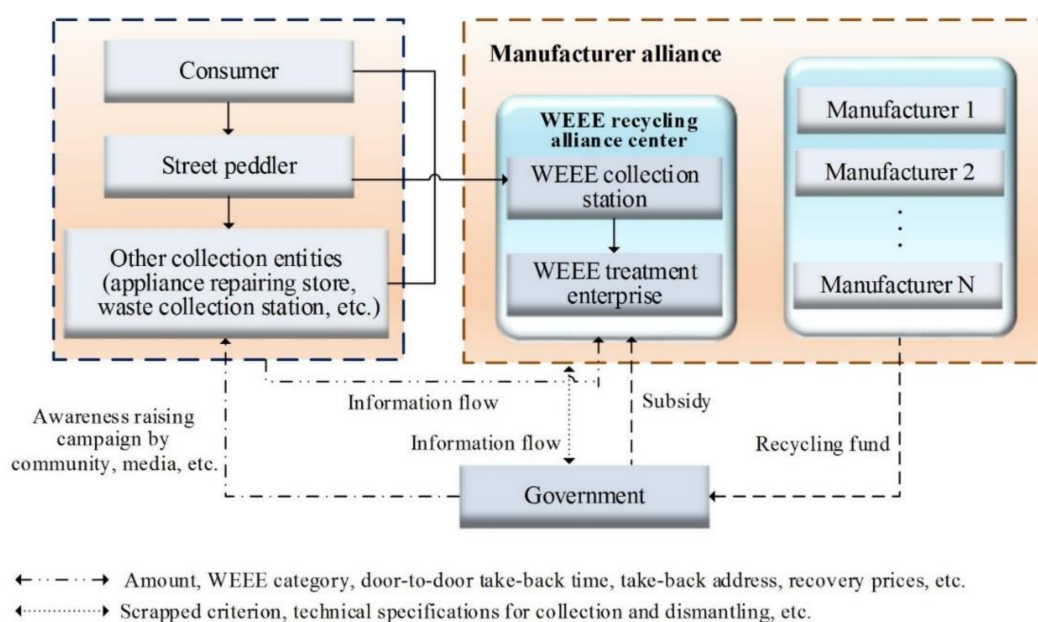


Figure 6. Operating process of manufacturer alliance mode (Mode II).

If consumers want to discard an EOL product, they can make an appointment with WEEE recycling alliance center, sell them to peddlers or in other ways. They get paid after giving WEEE to the alliance employees or peddlers who provide door-to-door collection.

4.2.2. Analysis of Responsibilities and Rights

Manufacturer alliance is a consortium made up of EEE manufacturers and occupies a decisive position in this WEEE collection system. It is in charge of transferring WEEE from consumers to the OEMs to share risk and revenue among members in alliance and expand scale of WEEE collection.

Invested and set up by manufacturers, WEEE recycling alliance center manages WEEE collection and treatment, introduces green technology for dismantling and disposal. The collection station makes a centralized control of the EOL products generated by the manufacturers in alliance and handled by the treatment enterprise through environmentally sound procedure. One of the main tasks for manufacturers is that some useful components or restorable EOL products are separated to be remanufactured. The center also engages in EEE return and exchange that includes after-sales services of products produced by manufacturers in the alliance. This alliance is conducive to consolidate various resources of corporations, for example, production technology of manufacturers, dismantling

and disposal processes, managerial personnel, logistics vehicles. Thus, a WEEE recycling logistics network covering the whole country to collect and dispose a variety of EOL products is more likely to be built.

For government agencies, they take responsibility for supervising and supporting the manufacturer alliance and collection entities. Policies and regulations for supervision and management are formulated to support the system running, for example, WEEE recycling fund levied from manufactures is subsidized to WEEE recycling alliance center by an allowance distribution system; firms are promoted to establish environmental performance evaluation system as well as a WEEE collection and treatment standard system on WEEE classification, scrapped criterion and technical specifications. The lawbreaking act, for example, vendors handle WEEE by acid leaching and incineration, must be punished by the Environmental Protection Law-enforcing Department (EPLD). Popularization of this mode also should be supported by the government through communities and media.

4.3. Innovative Enterprise Self-Built Network Platform Mode (Mode III)

With the Internet universal, a minority of WEEE collection or treatment enterprises have built their own network platform for WEEE collection to collect WEEE online. Both the existing and innovative enterprise self-built network platform modes are to be introduced.

4.3.1. Existing Enterprise Self-Built Network Platform Mode

The existing network platforms are divided into three types, type A—self-built network platform of formal WEEE treatment corporations, type B—self-built network platform of WEEE collection enterprises and type C—self-built network platform of sanitation groups. In the whole operating system, information (e.g., WEEE amount, WEEE category, recovery price) is exchanged online and goods transportation is taken offline simultaneously.

Figure 7 shows the operating processes of the three types of enterprise self-built network platforms. The platform is informed of categories and volume of WEEE, door-to-door take-back time from consumers and all information should be checked. Once confirming the information, the customer-service personnel inform collectors to collect WEEE door-to-door and the collectors pay consumers when receiving the right WEEE. Finally, consumers evaluate the entire transaction process over phone or website. Table 2 introduces these three types from the perspectives of liability entity, source of vehicles, collectors, logistics, settlement, etc.

According to investigation, this enterprise self-built platform run and managed by the enterprises who regulate WEEE categories, specifications and prices exists some problems. (i) Because of low recovery prices for some WEEE like electric fans, rice cooker and CRT TV, the companies usually give consumers payment after several transactions. (ii) The collection of one platform is limited in a specific region or one city. (iii) Collection companies tend to establish logistics on their own so they are in trouble of great pre-investment and high operating costs. (iv) Delayed consumers' evaluations, payment for consumers and WEEE door-to-door collection service cannot satisfy consumers.

In view of the above problems and increasingly popular e-business application, we put forward an innovative enterprise self-built network platform mode.

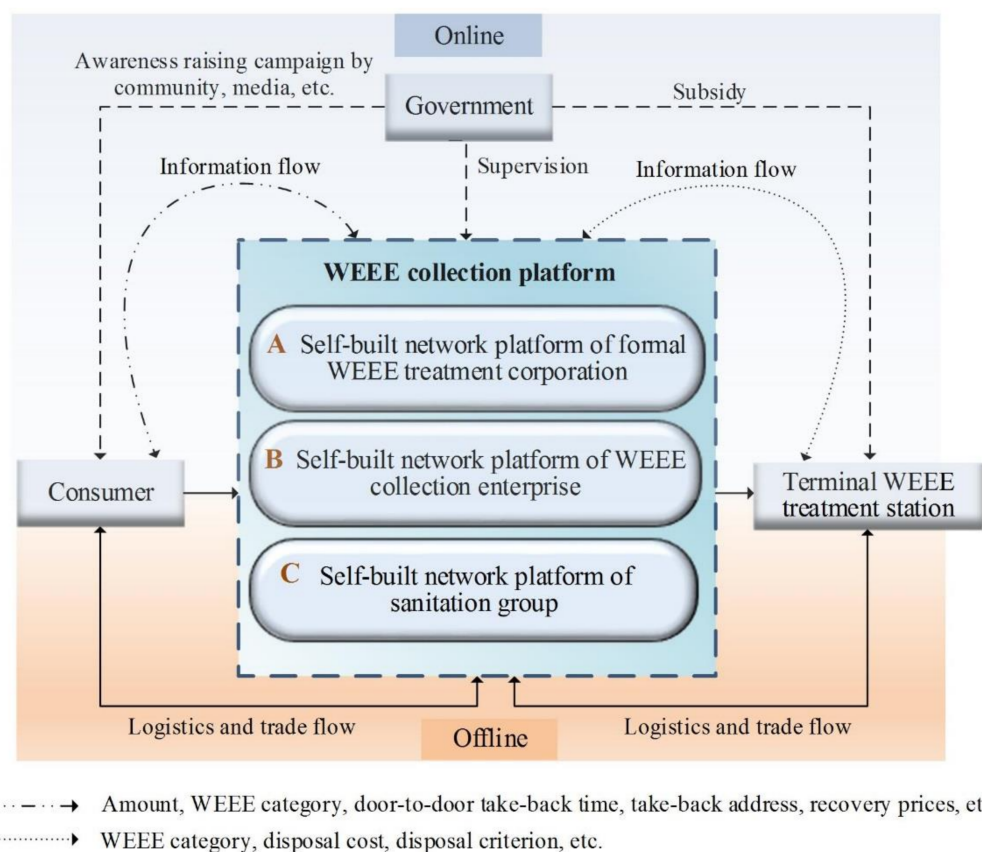


Figure 7. Operating process of existing enterprise self-built network platform mode.

Table 2. Comparison of existing enterprise self-built network platforms.

	A	B	C
Liability entity	Formal treatment enterprises	WEEE collection companies	Urban sanitation group
Vehicles for collection	New Vehicles	New Vehicles	Sanitation vehicles
Collectors	New collection groups	New collection groups	Sanitation workers
Representative platforms	Huge Recycle [68]	Ala [69]	Classification & Clean App [70]
Establishment time	November 2015	August 2011	January 2016
Enterprises attached	Jiucang, Zhejiang Province	King Bridge, Shanghai	Hangzhou Environmental Group
Collection scale	Urban region in Hangzhou, Zhejiang province	Shanghai	Urban region in Hangzhou, Zhejiang province
Categories	TWARC, clothes, shoes, cap, bag, quilt	Appliance, battery	Book, paper, plastic bottle, glass bottle, metals
Settlement	Cash and coupon	Cash for large appliances, coupon for small pieces	Coupon
WEEE treatment mode	On their own	Transfer to WEEE treatment corporations	Transfer to WEEE treatment corporations
Characteristics	Integrate WEEE collection and treatment instead of entrusting third party, collect WEEE in five districts in certain time every month	Self-build logistics and information network to constitute recycling system, large investment for layout of recycling logistics system in the early stage	Sanitation workers participate in WEEE collection, adequate labor and vehicles distribute widely

4.3.2. Operating of Innovative Enterprise Self-Built Network Platform Mode

Based on C2B (consumer to business) mode, the innovative enterprise self-built network platform integrates information technology and WEEE recycling industry through the Internet and e-commerce.

The Internet realizes instant communication and provides people for more ways to obtain information in short time. The consumer's right can be enhanced through the interactivity in the transaction. This novel WEEE collection platform acts as a guarantor in transactions between consumers and collectors and aids the government to implement regulation effectively.

The operating process of innovative enterprise self-built network platform mode is presented in Figure 8. Using Internet technology, the corporation in mode constructs information exchange website where consumers can search for or input basic information about their WEEE to be collected, for example, WEEE categories, aging degree and price. The platform self-built and run by the corporations estimates recovery prices in the light of the information offered by consumers. If consumers are satisfied with the price, they submit orders that contain WEEE basic information, door-to-door take-back time, take-back address and telephone number. Otherwise, they can bargain with the platform or cancel the order.

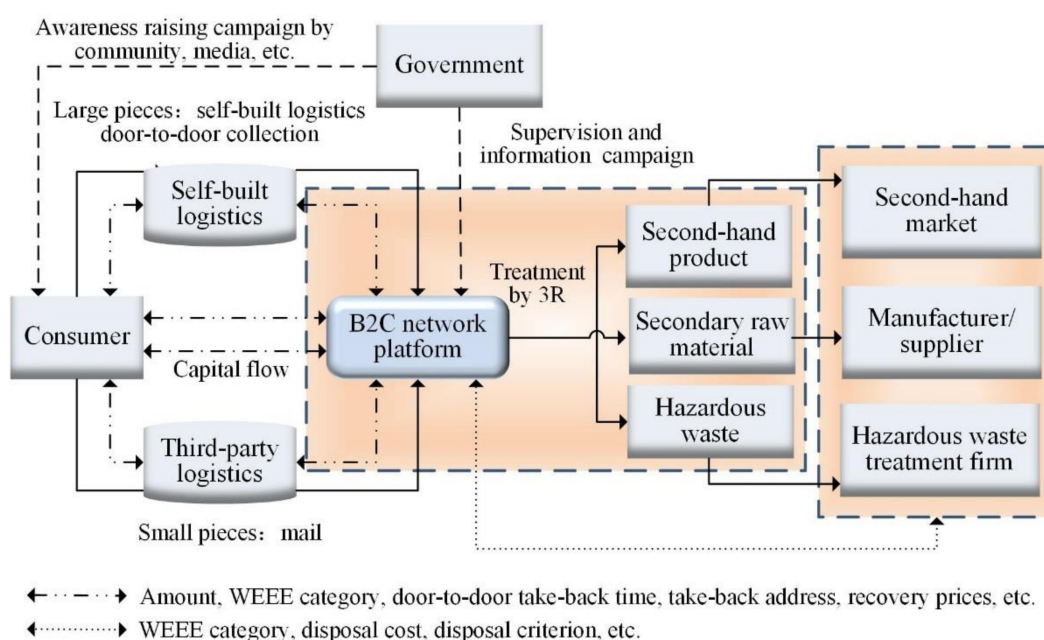


Figure 8. Operating process of innovative enterprise self-built network platform mode (Mode III).

Once the order is generated, staff from the platform call consumers to check the appointment time, address, WEEE information and other details, after which, collectors are informed and vehicles are arranged to reclaim the EOL products if the items are in large pieces, while the small pieces are mailed to the platform through third party logistics. After confirming the WEEE, the collectors pay consumers by cash, online bank or third-party payment platform, or reward them coupons by which consumers enjoy a discount if they buy the same type of new product. Likewise, for the mail collection, the platform will return corresponding cash and discount coupon to consumers after receiving and confirming the WEEE.

When finishing a transaction, consumers can evaluate the collection price, the attitude of the collector, or whether the door-to-door service is on time and when they receive the payment on an evaluation section of platform. In the end, collected WEEE is transported to downstream enterprises to deal with the waste in the environmental method according to the 3R principles. The logical operating of the collection process is shown in Figure 9.

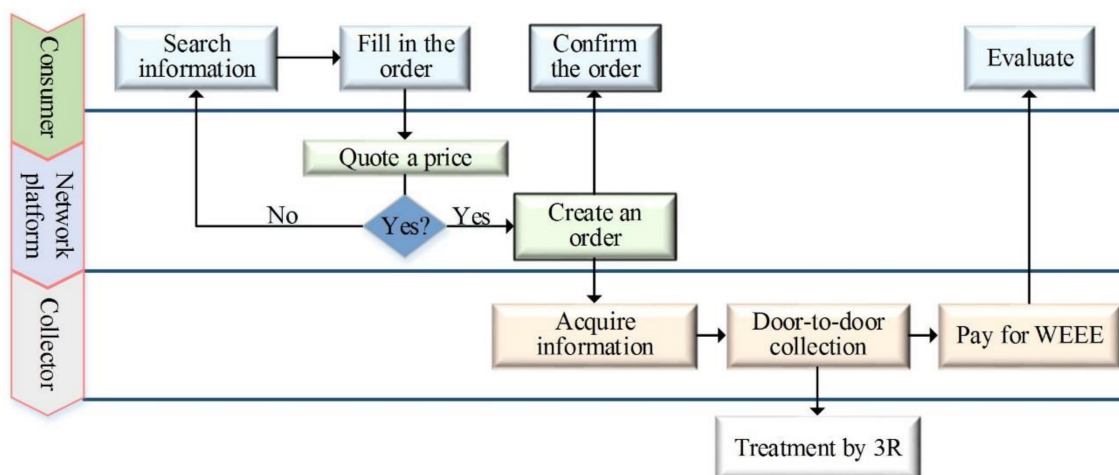


Figure 9. WEEE collection process of innovative enterprise self-built network platform mode.

4.3.3. Novelties of Innovative Enterprise Self-Built Network Platform Mode

In comparison with existing enterprises self-built network platform modes, the innovative ones make great improvement on logistics, collection scale and consumer satisfaction with a focus on C2B network platform.

- The enterprises need lots of funds to self-built logistics, yet some third-party logistics fail to satisfy the consumers on punctuality of receiving WEEE or attitude of staff. Hence, combination of self-built and contract logistics is proposed in the innovative enterprise self-built network platform mode to improve consumer satisfaction on recovery service, reduce logistics cost and capital investment of transportation compared to self-built logistics only.
- Consumers have self-determination on WEEE recovery price, door-to-door take-back time and whether to submit the WEEE collection order, so they are more likely to join in WEEE collection in this mode.
- Compared with the existing mode merely carried out in a specific region, the new one establishes joint pattern that absorbs third-party logistics and cooperates with producers and WEEE treatment enterprises to expand its service scope covering one province and even several provinces.
- Further utilization of IT accelerates customer response to the transaction, reduces intermediate links, cuts down transaction costs and improves the benefits of both consumers and businesses. In addition, the transaction becomes more convenient with e-commerce application.

4.3.4. Analysis of Membership

In the innovative enterprise self-built network platform mode, consumers have more options for recovery prices and free transaction time attracts more consumers to participate in WEEE collection to realize efficient coordination of online and offline. To better understand manipulation of this platform, we give a description for the relationships among the members involved in the mode.

(1) Cooperation and competition coexist in enterprises' network platforms. To be specific, cooperation is reflected in their need to promote this innovative network mode, cultivate consumer habits of online transactions and environmental friendly handling of EOL products and popularize WEEE collection in this way. It is a task not one business platform can take, instead, only the corporations cooperate with each other can they promote and publicize the mode.

The competition among the network platforms is considered from two aspects that are price competition and service competition. For the former, owing to consumers' consciousness on environmental protection in China is still relatively weak, to some extent, the price is the main driving force to determine their collection behaviors. So besides taking the bid with formal channels

into account, the platforms must have an advantage on price over street peddlers to enable obtain more customers to join in the network. For the latter, network operating mode emphasizes the consumer experience so the key to win consumers is to offer convenient and reliable service, which drives some consumers to ignore the price factor.

(2) The main relationships between consumers and network platforms are information exchange and trading. During WEEE transactions, the communication involves WEEE and collection information, the pattern of payment consumers choose, evaluation by the consumers and so forth. For example, after consumers place orders online, the staff need to take the initiative to contact consumers to confirm the order information and home delivery time; consumers evaluate the platform when the transaction ends; payment and settlement can be conducted online.

(3) Among consumers mainly transfers information flow, for example, recovery price, service attitude of collectors, operating process, appraisal of the operating mode. Before transaction, consumers are able to communicate with others through the interactive section of the website to know about whether the transaction is reliable and to further understand its processes.

(4) The relationship between formal treatment businesses and network platforms is also about transaction. In addition to consumers, formal treatment corporations are another objects collection platforms service to. The platforms should choose qualified treatment enterprises including formal hazardous waste treatment firms who environmentally handle part of hazardous waste components, for example, cone-glasses, cathode-ray tube (CRT) and batteries, which are pretreated by corporations that build the platforms.

(5) The government gives policy support and supervision to the platforms. The government ought to enact policies and measures to ensure the WEEE be transferred to enterprise's platform instead of vendors and strengthen the awareness raising campaign of the platforms. At the initial stage, by policy and financial support, the formal recycling chain including enterprises with the platform and WEEE treatment corporations are supposed to be subsidized to maintain stable and sustainable operation. Moreover, the platform is prevented from non-formal WEEE collection and monitored to be in legal operating by the government.

Innovative enterprise self-built network platform mode has its own merits and convenience that the environment and society benefit from but the processes of reverse logistics are suggested to be improved and optimized, for example, self-built logistics system, the repeated construction of enterprise information network. Therefore, we propose a third-party integrated network platform mode to further lower WEEE collection cost and improve the efficiency of collection.

4.4. Third-Party Integration Network Platform Mode (Mode IV)

Because of the ever-accelerated development of Internet application technology, we attempt to construct a third-party integration network platform mode where people, materials, funds are all connected. With fast information communication and automatic monitoring for WEEE recycling normalization, this mode integrates online and offline resources, viewed as one of the promising explorations to solve the problem of WEEE collection at present. It is quite possible to become a brand-new business mode and be prospective in application. Herein we elaborate on this new third-party integration network platform mode.

4.4.1. Mode Construction and Operating Analysis

The third-party enterprises invest and build this network platform that integrates WEEE, consumers and enterprises, on which, WEEE basic information, door-to-door take-back time and prices, WEEE logistics information and so forth are visible. Communication among consumers and evaluation of collection service are also realized by the platform and WEEE treatment enterprises cooperated with the platform should post messages of disposal process, criterion, fee and so forth. The operating process of the third-party integration network platform mode is shown in Figure 10.

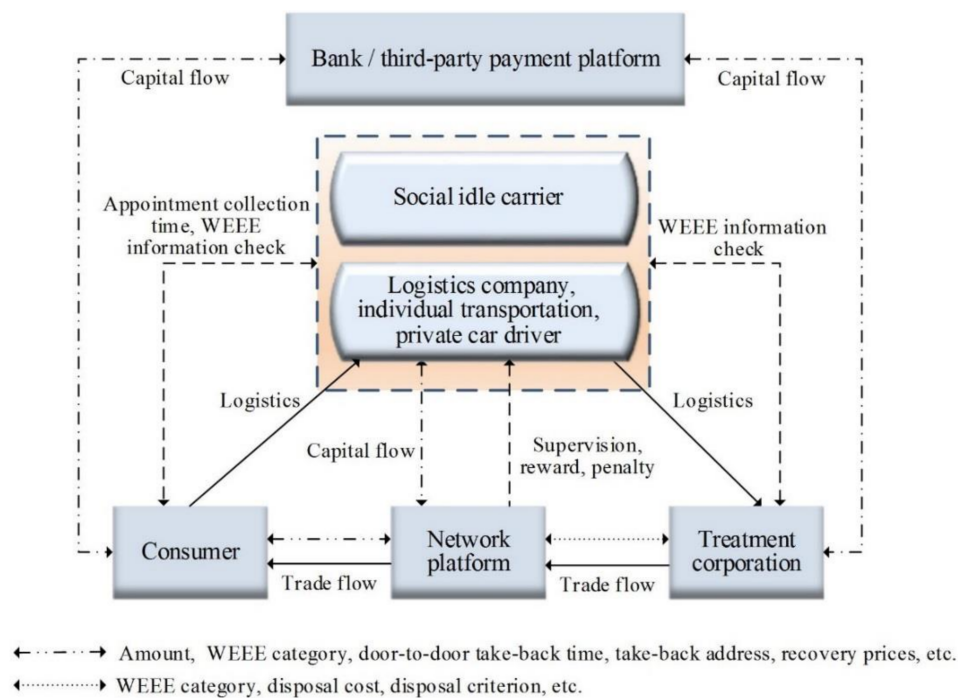


Figure 10. Operating process of third-party integration network platform mode (Mode IV).

After logging in the collection network platform, consumers have access to browse the WEEE specifications, recovery prices and so on. They post the WEEE door-to-door take-back time, take-back address and WEEE basic information, for example, WEEE condition, WEEE category, photos of WEEE and so forth to the platform. Similar with the innovative enterprise self-built network platform, this platform automatically estimates the recovery price based on information provided by consumer.

The orders consumers submit are shown in the network platform and the social idle carriers, that is, logistics companies, individual transportation, private car drivers who just have spare time to take this collection task are as collectors. The one who first gets the order obtains the collection chance and is required to confirm the order information again.

According to the appointed time and address, the collectors provide door-to-door service on time and pay for consumers through the third-party payment platform. The payment is not directly transferred to consumers' account, it is temporarily reserved in collection platform. After the WEEE is sent to pre-determined disposal site and checked, the payment will be released to the consumer's account, in the meantime, the collector will receive corresponding rewards. When transaction ends, collectors' service is evaluated by consumers and fed back to the collectors who likewise make appraisals of consumers about whether the WEEE messages they post coincide with the EOL products offered, the attitude to collectors and so forth.

Advancement of network platformization improves users' experiences as well as accelerates scale economy in the WEEE industry. To be more understandable for the operating system, operational logic of this network platform is shown in the flow chart Figure 11.

As a critical object of the mode, network platform attracts the social idle carriers and logistics transportation personnel to meet large demand on door-to-door collection and greatly reduce logistics costs. This system also ensures WEEE to be assigned to the qualified treatment enterprises and payment to be given to consumers or carriers as soon as the platform confirms the WEEE.

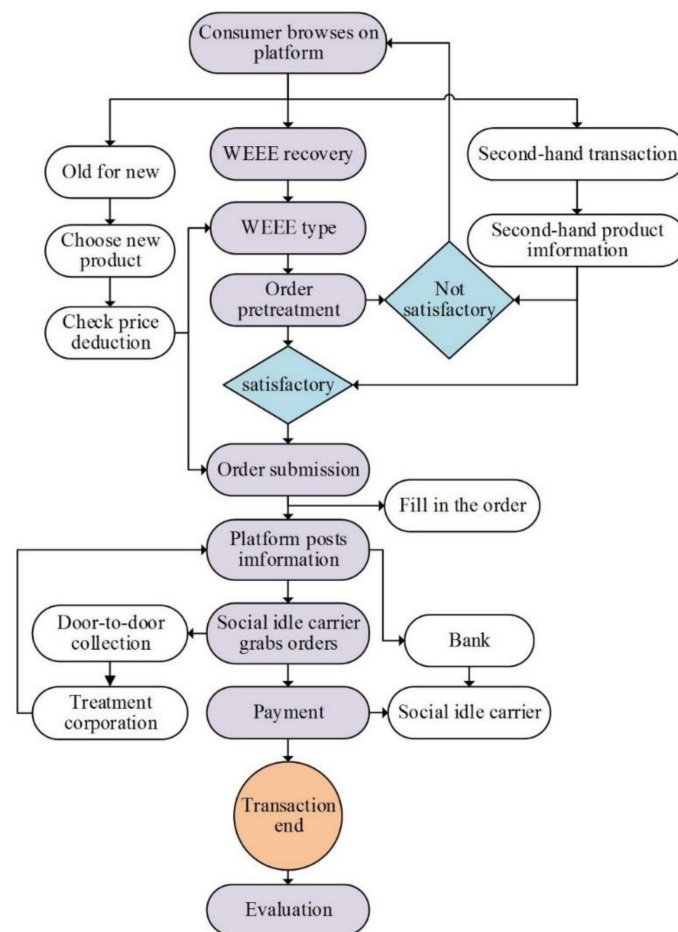


Figure 11. WEEE recycling process of third-party integration network platform mode.

4.4.2. Analysis of Responsibilities and Rights

In existing collection system, the informal collection entities as WEEE collection main forces are of scattered distribution and small scale, causing hard supervision and management mechanism of government. The transaction information is non-transparent and asymmetric aggravates difficulty in gathering enough WEEE from consumers. The third-party integration network platform mode integrates consumers, social idle carriers and formal WEEE treatment corporations to normalize collection channels and increase the public engagement. On the platform, WEEE demand of treatment corporations can be met because WEEE categories consumers supply and treatment corporations require are opening. Herein, the responsibilities and roles of the network platform and other participants are discussed.

(1) Responsibilities of the network platform

(i) Integrate consumers. In the existing WEEE collection channels, it is impossible for consumers to trace the flow of collected WEEE and obtain other valid information such as market prices of WEEE, profit margins of collection enterprises, qualified enterprises of WEEE collection, dismantling and treatment. Conversely, the third-party integration network platform mode provides consumers with an information flow collection channel: Put wastes online, take logistics offline (That is, consumers place orders on the platform for WEEE collection; the trade between consumers and the platform is completed by online bank; all the collection processes are proceeded online except that the WEEE transportation by social idle carriers is offline). Absorbing consumers into the collection platform, this mode enables consumers to clearly know where the WEEE is to go and how to be dealt with,

improving the public participation in environmental recycling and monitoring handling process of WEEE treatment corporations.

(ii) Integrate social idle carriers. Apart from consolidation of personnel of waste collection stations, individual collectors and other existing collectors, this mode integrates other social idle carriers like urban dustmen and couriers. Especially, the high Internet awareness of young group is conducive to advancement of WEEE collection industry. About logistics, not only the vehicles of WEEE collection corporations should be integrated but the personal vehicles are also, so as to play their roles of universality and initiative for better serving WEEE collection system.

(iii) Integrate all corporations. WEEE treatment corporations and collection corporations are integrated by the network platform to get more waste resources and market share. The cooperation between (re)manufacturers and raw material suppliers gives remanufacturers and raw material suppliers second-hand components and raw materials, provides return channels and sales channels for manufacturers.

In addition to integrate all the resources, the platform needs to strengthen their own business.

- Since there are a variety of brands and types of WEEE, it is vital to build a comprehensive database for the EOL products, so that the system can conduct accurate statistical processing to estimate reasonable prices for any WEEE consumers submit.
- As for various types of information including collection messages posted by the consumers, collectors who grab orders and their collection progresses, how the WEEE are dealt with and so forth, the platform updates them as quickly as possible to form a real-time and accurate information service system. In general, the whole WEEE collecting and treatment processes are going to be fully networked and transparent.
- It is imperative for the platform to formulate the reward and punishment mechanism. The collectors, WEEE treatment corporations and consumers who participate actively are supposed to be rewarded such as extra bonus for collectors and treatment corporations and coupons for consumers. Problems in operation—for example, the actual WEEE information on consumers is not in line with what they submit to the system, the collectors fail to collect goods in a timely manner—should be strictly investigated and coped with to ensure efficient running of the platform.

(2) Other participants' responsibilities

(i) Individual consumers. In this mode, increasing numbers of consumers turn into being collectors by registering in the platform. Meanwhile, publicity of this collection platform and environmental collection among collectors need to be strengthened to encourage more residents to participate in WEEE collection, facilitating more pieces of WEEE being handled through this mode.

(ii) The government. Government agencies ought to take obligations for publicizing this mode and the network platform to inform people of formal WEEE collection channels and guide people to handle waste products appropriately. The relevant laws and regulations are essential to be issued by the government so as to restrict informal collection acts, resolutely crack down and punish illegal recycling activities.

(iii) Formal WEEE treatment enterprises. Based on standardized processing technique and principles and to achieve more amount of WEEE, formal treatment enterprises conduct environmentally and should keep communication with the platform so as to acquaint themselves with market demands.

(iv) Manufacturers. The manufacturers are stimulated to adopt eco-design in favor of comprehensive utilization of resources and innocuous treatment of WEEE with reduction or prohibition on the utilization of toxic and hazardous substances, green production technology adoption and consideration of disassembly and recycling.

5. Discussion

The four modes are different in operation, logistics, enterprise organization, government support, technology application and so on. Herein, the characteristics of each mode are analyzed and compared, based on which, we also discuss the selection in collection mode for regional developing disparities in China.

5.1. Analysis of Each Mode's Characteristics

5.1.1. Unified Collection Channels Mode (Mode I)

With a newly formed integrated collection company as the liability subject, unified collection channels mode has two major features.

- Make full use of existing WEEE collection entities

Through combination of peddlers, waste collection stations, appliance repairing stores and so on, the unified collection channels mode has merits of wide distribution and convenient WEEE collection for consumers, being favorable to improve current disordered WEEE collection status. Existing informal WEEE collection individuals or corporations, under strengthened guidance and management, are permitted to continue to work so that they can play a greater position in the integrated network and get a better economic income because of the increasing scale of WEEE collection.

- Policy support and supervision of government as a guarantee for implementation

The government funds the integrated collection company and inspires the collection entities to join in the company, reducing financial pressure in constructing the collection system and alleviating the hardships of collection channels' integration in the early stage of implementation. For the formal treatment corporations, the government guide and encourage them to recruit excellent management and technical personnel, import advanced WEEE dispose equipment to raise WEEE processing technology level. Meanwhile, supervised by the government, the activities of all collection entities in the system should obey the integrated collection company's management and the treatment for WEEE confirms to national standards.

5.1.2. Manufacturer Alliance Mode (Mode II)

EEE manufacturers in manufacturer joint alliance mode, as the liability subject, form manufacturer alliance who invest and build specific WEEE collection stations and formal treatment corporations to deal with waste resources environmentally and get economic benefits. The characteristics of this mode are mainly reflected in the following three aspects.

- Information sharing for improvement of WEEE collection efficiency

From the perspective of the whole collection processes, the management in alliance is able to reduce transaction costs on collecting WEEE, since information sharing and resources complementarity are among manufacturers, specific collection stations, WEEE treatment corporations in manufacturer alliance. Each alliance establishes a unified logistics service for WEEE collection that reinforces the coordination mechanism.

- Reduction on collection cost for enterprises' common progress

The management in alliance allows the cooperative producers to learn from each other and reduce the cost of unnecessary competition. The WEEE recycling alliance centers should be much more committed to collecting, dismantling and disposing WEEE because the government subsidize them by the amount and treatment capacity of the WEEE collected. The cooperation of entities can reduce repeated construction of recycling network, avoid personnel waste and improve the ability to deal with the uncertainty of the market environment.

- Support and supervision by government

The government agencies develop WEEE classification standards, dismantling technical specifications and formulate a WEEE recycling fund levy and subsidy distribution system. Meanwhile, non-formal collection or treatment behaviors must be severely penalized to ensure that more WEEE flow into the WEEE recycling alliance center.

5.1.3. Innovative Enterprise Self-Built Network Platform Mode (Mode III)

For innovative enterprise self-built network platform mode, the entities who undertake primary obligations are bricks-and-mortar companies, including WEEE collection corporations, WEEE treatment enterprises and EEE remanufacturers. The characteristics are as follows.

- Rationalization of WEEE recovery price

Consumers are able to know the recovery prices and bargain over the price to get satisfied payment in the enterprise's network platform since the transaction messages are transparent and the problem on unreasonable transaction prices caused by information asymmetry is figured out.

- Facilitation in WEEE collection

Consumers make an appointment with collectors who provide door-to-door collection at appointed time, which avoids difficulty in information transmission and cross-regional trade for offering consumer timely and convenient WEEE collection service.

- Standardization of WEEE collection

This network platform renders WEEE collection process flattening and transparent, simplifies operating flows of collection, presents clear WEEE classification to attract consumers to take part in formal collection and provide consumers with an environmental and safe collection channel.

Apparently, compared with the two former collection modes, Mode III shows more superiorities but it brings the enterprises who build network platform extra website construction and maintenance costs. In addition, the enterprises equipping with self-built logistics system, affiliated vehicles and staff take relatively high operating cost, all may restrict development of the mode.

5.1.4. Third-Party Integrated Network Platform Mode (Mode IV)

Focused on standard treatment and reutilization of EOL products, WEEE collection is to meet the requirement of both environmental protection and resources reutilization. Chinese central government has underlined concept of "Internet +" to motivate all kinds of traditional industries to combine with the Internet so as to realize the transformation and upgrading of the industry. Third-party integrated network platform mode is essentially an "Internet + WEEE collection" mode, the characteristics of which are mainly reflected in the following aspects.

- More efficient WEEE collection service

This Internet-based and customer-centric WEEE collection platform overcomes and breaks the original geographic limitation, shortens the distance between consumers and formal collection entities. The role of traditional collection entities is weakened by the Internet platform where consumers can make WEEE collection transaction at home and get good returns. Consumers are also offered high-quality service unattainable for traditional collection modes, to a large extent, stimulating their enthusiasm to engage in collecting and transporting WEEE, for the sake of prompting formal WEEE recycling industry development.

- More transparent WEEE collection and treatment information

Information about WEEE is transparent for members in this mode. Consumers pass information of their own EOL products through the network platform and social idle carriers can quickly get opportunities for collection by grabbing orders from the messages popping up in the platform, that is, the information of the WEEE consumers offer and collectors who get the order is transparent. The costs of purchasing WEEE from consumers and paying for collectors are also known by both consumers and collectors who have access to acquire recovery price of the WEEE or service tips, which gives a chance for consumers to determine whether to place the WEEE order and for collectors to see their remuneration in advance. What's more, consumers inquire whereabouts of their WEEE timely on the platform and the government know about the condition of WEEE treatment, both of who are capable of supervising the WEEE collection and treatment process clearly.

- More complete Collection system

With collection scale enlarging, in this mode, more standardized collection procedures are and more extensive scope collection channels cover. Based on the Internet technology, the network platform owns a comprehensive database and information management system to monitor the collection procedures and regulates the collection channels, thus the traditional collection approaches lose core competitiveness, original "dirty, small and scattered" collection status will be broken and an efficient collection system is built up.

- Increasing environmental protection benefit

Abundant EOL products, through multitudinous traditional collection channels that collect and handle WEEE at random, flow into non-specialized small workshops that generally are not supervised strictly, causing environmental pollution and waste of resources. In contrast, under this new mode, pollution is controlled from WEEE collection and the WEEE is ensured to delivered to formal treatment corporations, greatly enhancing environmental benefits.

Overall, this mode relying on the Internet connects fragmented idle resources and personnel, provides efficient and low-cost services, to achieve creative development in WEEE collection industry. It does have plenty of outstanding merits but owing to its high degree of integration and subversiveness, some problems emerge in practice, for example, the initial financing of third-party platform [71], mode's awareness raising campaign in the early stage. According to our investigation, there is no company doing this project over the world, meaning application of this mode in WEEE collection is a challenge but also an opportunity. We could try to create and implement an innovative business pattern on the basis on this mode to better solve problems in the WEEE collection.

5.2. Comparison of the Modes

To further analyze the characteristics and differences of the four modes, a comparison among the modes concerning liability subject, collection and treatment approaches, consumer participation, the role of government, etc., is further made, as shown in Table 3.

Table 3. Comparison of the four modes.

Mode	I	II	III	IV
Liability Subject	The integrated collection corporation newly formed.	WEEE recycling alliance center co-financed by the EEE manufacturers in the manufacturer alliance.	WEEE recycling enterprises that self-build network platforms.	Newly formed corporations that build third-party network platforms.
Collection standardization	Many informal collection entities participate in.	Self-built collection system, allow part of informal collection entities to participate in.	Formal collection, mainly collected by staff of collection companies.	Allow informal collection entities even consumers to participate in but the WEEE eventually flows into formal WEEE treatment enterprises.
Source of collection personnel	Very extensive, collectors of informal channels and formal channels self-built by the integrated collection corporation.	Very extensive, staff of formal channels, that is, WEEE collection stations and collectors of informal channels.	WEEE recycling company's own staff.	Very extensive, staff of formal and informal channels, consumers.
Consumer participation	Few consumers participate in, they just sell WEEE to the collection entities.	Few consumers participate in, they just sell WEEE to the collection entities.	Some consumers participate in, they can clearly know about whereabouts and the final treatment of WEEE.	Numbers of consumers participate in, they can sell WEEE to the collection entities or become WEEE collectors and delivers.
Whereabouts of WEEE	Formal WEEE treatment enterprises, remanufacturers.	WEEE recycling corporations self-built by manufacturer alliance.	Formal WEEE treatment enterprises, remanufacturers, raw material suppliers.	Formal WEEE treatment enterprises.
Correlation between product design and WEEE recycling	Correlation is general. The integrated collection company keeps trading relationships with downstream WEEE treatment companies and remanufacturers.	Correlation is strong. Take full account of the convenience of WEEE recycling and component remanufacturing properties in the EEE design stage.	If WEEE recycling companies are collection corporations or disposal corporations, the correlation is general; if WEEE recycling companies are manufacturers or remanufacturers, the correlation is strong.	Correlation is weak. Mainly keep relationships with downstream WEEE treatment companies and consider the WEEE reutilization properties.
Logistics mode	Mainly transported by non-formal collection entities, a small amount is transported by the company.	Partially transported by non-formal collection entities, the others are by specific collection stations.	Large pieces are transported by logistics system self-built by WEEE recycling companies, small pieces are by express companies.	Social idle carriers including individuals and firms as long as they have registered and been validated in the platform.
Settlement method	Offline. Collectors pay for consumers in cash.	Offline. Collectors pay for consumers in cash	Offline or online. Collectors pay for consumers in cash or by e-commerce platform.	Online. The third-party payment platform pays for consumers.
Government financial and policy support	Support is required to ensure that all types of collection entities deliver WEEE to the integrated collection company.	Strong support is needed, including WEEE recycling fund levy and subsidies, as well as the supervision for WEEE treatment.	A certain support is needed in the initial stage to guarantee increasing amount of WEEE collected.	Support is needed in the initial stage to increase the amount of WEEE collected by the third party and popularize network platform.
Source of government financial subsidy and objects being subsidized	Subsidies granted by MIIT and Ministry of Finance (MF) are issued to the integrated collection company through manufacturers, remanufacturers and formal collection companies.	Levy WEEE recycling funds from EEE manufacturers and those are subsidized to WEEE recycling center.	Subsidies granted by MIIT and MF are issued to the recycling corporations on self-built platform in the initial stage.	Subsidies granted by MIIT and MF are issued to corporations establishing third-party network platform in the initial stage.

Combined with Table 3, we make a few complementary explanations.

(1) Construction and development of WEEE collection entities. Mode I makes full use of existing collection entities both formal and informal while Mode IV explores new collection and transportation entities including consumers. As for Mode III, existing collection entities are supposed to be strengthened. In addition to the original collection entities, the manufacturer alliance establishes new collection stations in Mode II.

(2) The relationships among all entities during WEEE collection and treatment. In Mode I, WEEE collected by all collection entities is gathered to the integrated collection company, who then transport the WEEE to the formal WEEE treatment corporations that it has contracted with. Both collection stations and treatment corporations are set up by manufacturer alliance in Mode II. The relationship between WEEE collection entities and treatment entities in Mode III is determined by characters of the corporations who build their own network platforms. For instance, if the enterprise works on WEEE treatment, it undertakes the job both in WEEE collection and treatment. But for Mode IV, the sources of collectors are very extensive and the WEEE are delivered to the contracted WEEE treatment enterprises.

(3) Government support. Mode I incorporating all collection entities into a unified collection channel to handle WEEE, needs strong government policy support and supervision. The promotion of Mode II will gradually formalize existing unqualified collection entities and it also requires the government support. Demand of government support for Mode III is relatively weak but its initial development needs government financial support due to large upfront investment, that is, network construction and self-built logistics. Mode IV, on account of its strong vitality in taking advantage of social resources, the role of government is mainly on the promotion in preliminary stage.

5.3. Model Selection for Different Regions

According to our survey in Bijie city in Guizhou Province, 49.2% families used to purchase commodities on the Internet and only 19.1% families perform transactions online more than once each month. Most end-of-life electric and electronic equipment is collected by peddlers or stacked at home. For the undeveloped area like Bijie where the awareness on environmental protection of people is relatively weak, unified collection channels mode is more suitable. Besides, for not enough popularization of the Internet application and lack of formal recycling corporations and personnel, person-to-person transaction not involving information technology in this mode are more easily accepted. That responsible for implementing Mode I is state-owned integrated collection company, meeting the need for government-led WEEE collection in the area. For collecting WEEE conveniently, regional WEEE collection stations are advised to be set up in more villages.

Small and medium-sized cities are advised to apply manufacturer alliance mode. The Internet has been generalized but the online transaction is still unfamiliar to a considerable number of people, particularly the elderly and some middle-aged residents, so the two network platform modes are not very suitable for these regions. The manufacturer alliance in manufacturer alliance mode is practical because numbers of manufacturers have been moved into small and medium-sized cities in China, facilitating their manufacturer alliance establishment. The competitiveness among manufacturer alliances and cooperation of members in a manufacturer alliance enable all of them to enhance recovery rate and get more benefits, furtherly, the local economy and environment are to be improved.

Innovative enterprise self-built network platform mode is suitable for large cities or regions (mainly eastern coast cities) where mobile Internet is generalized like Qingdao in Shandong Province near Bohai Bay, Hangzhou and Ningbo in Zhejiang located shore of the East China Sea. In these cities, the economic levels rank is on the top of the nation, the environmental awareness of the residents is relatively high and many companies have succeeded in or tried processing business on the Internet. Mode III applied in the areas has a good control of informal WEEE collection entities, reduces environment pollution and improves residents' overall welfare.

As the most efficient WEEE collection system, third-party integration network platform mode motivates the public to join in the WEEE collection and requires the participants to have a good

command of the operating of Internet platform. The areas of metropolises are large but the traffic is well-developed, being in favor of meeting consumers' demand on time by taking full use of idle vehicles. So it is advisable to implement this mode in metropolis such as Beijing, Shanghai and Guangzhou first and popularize it in large and medium-sized cities subsequently, especially those adjacent to metropolis. With further network universality and familiarity of network platform manipulation, we believe that this novel mode will eventually spread over every city even the remote areas.

6. Conclusions

This paper provides an overview of the status of the WEEE collection system in China and analyzes the responsibilities of every recycling entities involved in the system. In allusion to WEEE collection situation where informal channels encompassing street peddlers, appliance repairing stores, waste collection stations and dismantling workshops are dominant while formal channels such as "old for new" activity only occupy a minority in WEEE collection market, we demonstrate four innovative WEEE collection mode by elaborating on operating processes and comparing their characteristics. Because of regional developing disparities in China, we also have made recommendations on regions' choice of the innovative WEEE collection modes. We aim to explore appropriate innovative WEEE collection modes and give suggestions for countries or economies whose WEEE collection situation or system are similar with China

The actual situation of e-waste management in China calls for innovative WEEE collection system. When installing a new system, we consider that: (1) Informal WEEE collection is currently dominant in recycling system, so the main challenge is how to transform or integrate existing informal collectors into the formal sector; (2) The small-sized, scattered, informal collectors, transporting and recycling enterprises should be incorporated; (3) With the advancement of information technology and popularization of the Internet, it is a general trend that WEEE collection will be operated on network platform. In general, the four WEEE collection systems are all to build cooperative and complementary relationships between formal and informal sectors. Mode III and Mode IV combine the brick-and-mortar and the Internet to carry out collection practice to increase the number of WEEE collections and guarantee the formal treatment of the WEEE. In the form of "Internet + WEEE collection," Mode IV is conducive to transform the traditional industry into a novel recycling trading platform and develop a creative e-commerce pattern by integrating online and offline resources with a new operation platform. Besides, the support and publicity of the government, the advancement of information technology and the social responsibility for corporations on WEEE recycling are emphasized in the process of promoting the modes.

The limitations of this paper follow: By using a mixed research method of public survey, field visit and literature review, this study is exploratory and descriptive in nature; comparison of the modes are based on their characteristics ignoring their economic benefits for participants. Future studies are encouraged to extract significant element from our general exploration for potential research and policy issues on WEEE recycling. It is our hope that future work can focus on quantitative analysis to evaluate which mode is more profitable from the perspectives of consumers, the network platform, the treatment corporations and the government. The material flow analysis (MFA) method can be used to operational activities dealing with circulation of waste material. With the arrival of blockchain technology, we can also examine how the blockchain is likely to affect material flow, transportation and payment for WEEE collection modes.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2071-1050/10/5/1446/s1>, Table S1: Questions of interview for different WEEE recycling entities.

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