Chapter 6
Lifecycle Sustainable Information Management for Waste Electrical and Electronic Equipment

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Abstract Sustainability has become a critical driving force shaping the future of Waste Electrical and Electronic Equipment (WEEE) management. In this research, lifecycle information and flow management has been investigated to enable transition from the current "management authority-centric reporting model for WEEE" to a new "globally distributed and sustainable management model for WEEE". In order to achieve the target, case studies on LCD TV WEEE have been conducted to understand supply chain information flows and recovery and remanufacturing processes. Based on that, information/flow framework design for WEEE management has been explored.

6.1 Introduction

The global resource allocation and increased demand for welfare and new products have increased more production activities in recent years. However, the rapid economic development has been hindered by the increasing concerns of the scarcity of natural resources and environmental issues. Statistics show that from

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1985 the resource consumption on the global level has been higher than the ecological capability of the Earth. It is estimated that the required bio-capacity of two Earths is necessary to satisfy the need of the development in 2050 according to current trends [1]. On the other hand, more and more products after services are filled up in landfills. Among them, Electrical and Electronic Equipment (EEE) and their Waste Electrical and Electronic Equipment (WEEE) are becoming important and challenging waste streams in terms of quantity and toxicity.

With the populations of 1.33 billion in China and 0.5 billion in the EU, both regions are experiencing significant growth of WEEE per year. There is approximately 7 million ton of WEEE generated in the EU per year [2]. In China, 1.1 million ton of WEEE is generated per year, and China is the second in the world in the landfill and incineration of WEEE [3]. Due to rapid technical innovations and shorter usage lifecycle of electronic products, WEEE is growing much faster than any other municipal waste streams. In order for the Earth to be cleaner, sustainability has become a critical driving force shaping the future of WEEE lifecycle management patterns. An important research issue is to develop sustainable processes and information management technologies to better manage WEEE after service to generate less or even zero environmental impact and CO2 footprint.

It is envisaged that in future all WEEE need to be traceable, manageable, recyclable, recoverable and remanufacturable [4]. The WEEE Directive was enacted as the European law in 2003, and the EU Member States were required to transpose the provisions into national laws by August 2004. As one of the biggest EEE and component production nations in the world, China has realized the serious environmental issues from WEEE and addressed them as a rising priority. Many EEE/WEEE companies including manufacturers, suppliers, distributors, retailers, recyclers and remanufacturers geographically distributed in the EU and China have formed closer supply chain partnerships and networks. The operation patterns and practices of the Chinese WEEE management are influencing the entire chain in a deeper and wider scope. For instance, it is infeasible to implement sustainable WEEE management effectively in the EU if Chinese OEMs (Original Equipment Manufacturer) and suppliers [especially SMEs (Small and Mid-size Enterprises)] are incapable to incorporate the overarching eco-requirements imposed by the European legislation in their information management of WEEE.

A GREENet (Globally Recoverable Electrical and Electronic Equipment) research project has been recently funded by the European Commission Framework Program 7 (EU FP7) to support four European universities (Coventry University of UK, Royal Institute of Technology of Sweden, Strathclyde University of UK, and Technical University of Cluj-Napoca of Romania) and four Chinese universities/institute (Huazhong University of Science and Technology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Tsinghua University and Fudan University) as a consortium to investigate the global WEEE information management collectively. Research has being carried out to propose a global WEEE information management architecture, a RFID--based WEEE tracing service and a smart remanufacturing decision-making service. In this chapter, the progress of the project on research gap analysis, case studies on LCD TV WEEE and some designed information/flow frameworks are reported.

6.2 Gap Analysis on WEEE Information Management

The EU and China are presently facing a number of technical challenges in implementing and operating the EEE/WEEE management in global chains. According to the WEEE Directives, a producer's (manufacturer, brand owner or importer) responsibility is extended to the post-consumer stage for their EEE (i.e. WEEE), instead of stopping at selling and maintenance (i.e. Extended Producer Responsibility—EPR [5]). EPR is aimed at encouraging producers especially manufacturers to provide cradle-to-grave support to reduce environmental hazardousness, such that they work closely with remanufacturing industries to recover maximum values and reduce environmental toxicity/hazardousness. However, considering the current technical constraints especially in the global context, the operations of WEEE management (i.e. the producer compliance scheme) do not effectively achieve the aim of the WEEE Directives and EPR. The scenario is illustrated in Fig. 6.1. For instance, the three major sources of WEEE in China are households, offices and OEMs. Yang et al. report that there is no actual official data for WEEE generation and flow in China [6]. People seldom dispose of their used EEE in China even if they are out of date or broken due to a perception that the goods might be useful in the future or they might sell them [7]. The situation is illustrated in Fig. 6.2. The gap is summarized in Fig. 6.3.

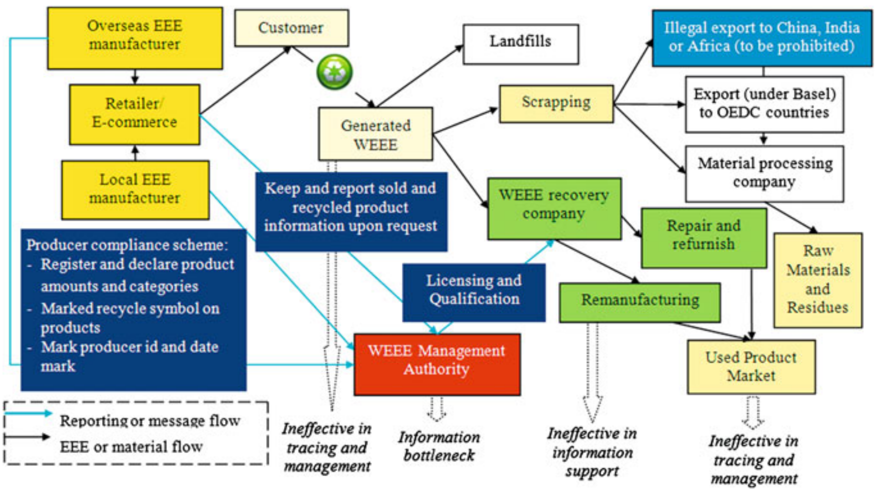

Fig. 6.1 The EEE reporting and WEEE recycling/recovering mechanism

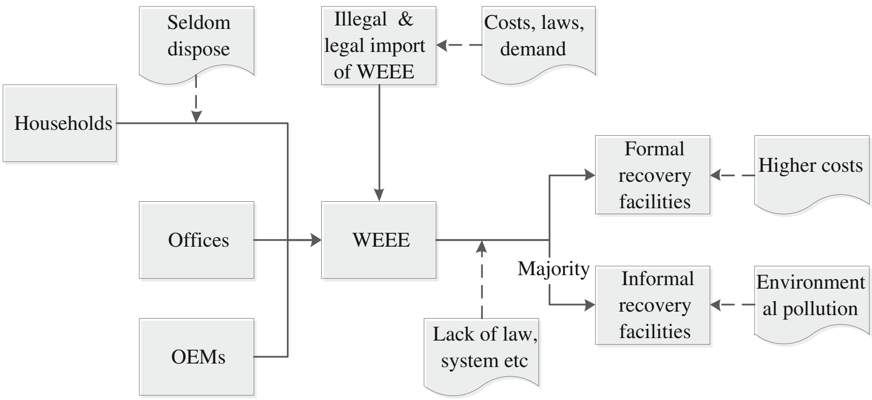

Fig. 6.2 The flow of the WEEE management in China

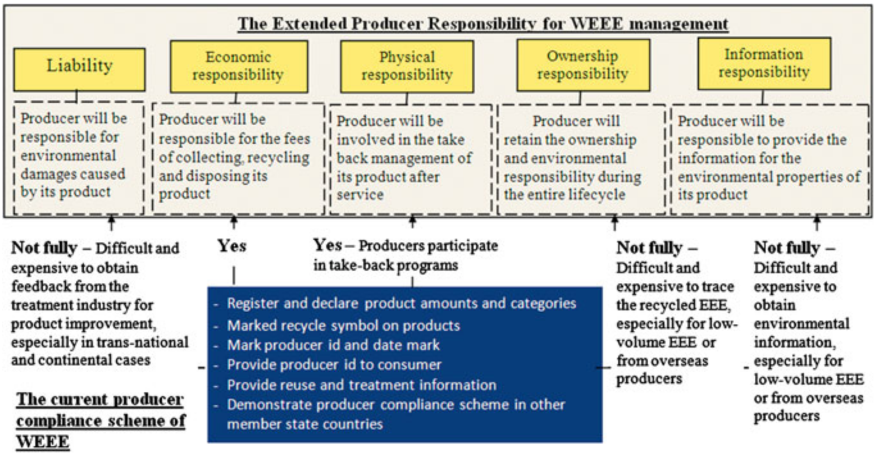

Fig. 6.3 Gaps between the EPR and producer compliance scheme

One of major reasons is the lack of information management services for WEEE in global EEE/WEEE chains. This is expanded below.

- According to the WEEE producer compliance scheme, producers are required to report to the WEEE management authorities for product quantity, recycling and remanufacturing information periodically. Owing to the active E-Commerce and more personalized EEE design, online transactions and mass-customized productions are more frequent. This brings challenges to record the dynamic, low-volume, and varied WEEE information. In the current operation of WEEE management, authorities will be the "information bottleneck" so that information exchange across the entire EEE/WEEE chains is inefficient or even impossible not only internationally, nationally but also regionally. Closer supply

chain-spanning information linking between manufacturers, suppliers, distributors, retailers, recyclers and remanufacturers should take place. In the current situation, there is almost no any distributed information services deployed in the Internet to enable the convenient and secured retrieving of EEE/WEEE information. To tackle the issue, it is imperative to understand WEEE information flows so as to support the dynamic and robust information management in global EEE/WEEE chains.
- Producers need to report total weights for each category of products, to maintain records and make them available for the whole lifecycle until the recycling and remanufacturing stage and to mark new products with a producer identifier and a crossed out wheelie bin symbol. It requires that the last owners must be able to dispose of products free of charge and producers will pay all or a significant part of the free take-back from this date, setting increasing reuse, recycling and recovery targets. However, many enterprises are faced with difficulties in the traceability of their EEE and components to recycle and remanufacture. In order to identify the producer, EEE needs to be embedded with the producer's name and the date of introduction to the market. Information needs to be provided to enable recycling/remanufacturing facilities to identify EEE, the type and location of hazardous substances and eco-recovery plans efficiently. Due to process related constraints, it is laborious and inaccurate to position readers/writers (such as barcodes) directly to components for identification and life status information retrieval. To develop a WEEE information tracing service with reliable and efficient information identification functions is crucial to keep the continuous traceability and provide appropriate recycling and remanufacturing information of WEEE during lifecycle.
- Recovery/remanufacturing of WEEE, which has been viewed as a "hidden green giant" during WEEE management, is attracting increasing attentions of researchers and practitioners in recent years. Good recovery/remanufacturing flow management will be one of the stronger driving forces for industries to adopt in their practises to balance economic and environmental targets, and close gaps between shorter innovation cycles and longer lives of WEEE. On the other hand, recovery/remanufacturing legislative initiatives are underway in the EU and USA to ensure OEMs and suppliers to provide free access to remanufacturing information facilities in global chains. However, the end-of-life information flows of WEEE between manufacturers and recycling/remanufacturing enterprises have not been effectively established. To establish a better understanding on recovery/remanufacturing flows is therefore paramount for enterprises to apply sensible recovery/remanufacturing strategies to recover diverse WEEE.

In the GREENet project, a technical solution is proposed to change from the current "management authority-centric reporting model" to a new "globally sustainable management model for WEEE" with the following innovative features: a "generic" global WEEE distributed information service architecture, an "efficient" WEEE tracing service and a "smart" recovery/remanufacturing service

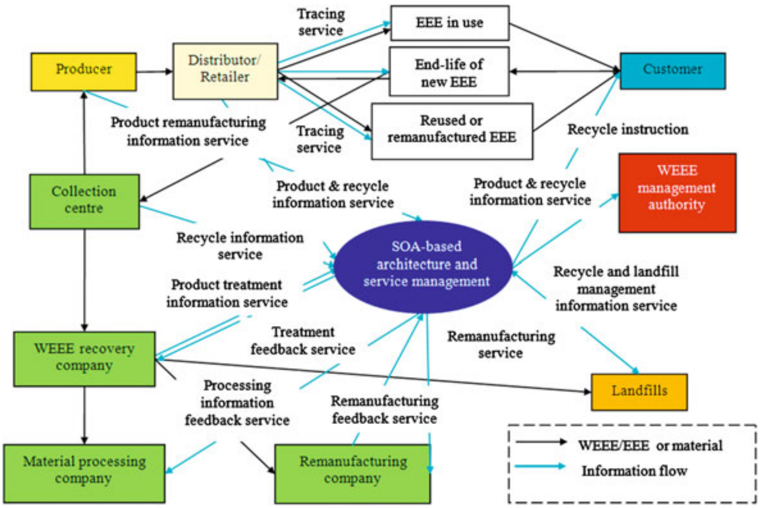

Fig. 6.4 Service oriented information framework

for variant WEEE. The new technology, which is shown in Fig. 6.4, has been based on the new generation.

Service-Oriented Architecture (SOA) to streamline bi-directional, dynamic, efficient and secured information flows across the entire global EEE/WEEE chains. This project will focus on the following information services:

- A SOA-based architecture that is able to facilitate the establishment of a generic and robust distributed information service framework to manage global EEE/ WEEE information networks;
- A wireless tracing service supported by the latest RFID technology and integrated with the SOA-based architecture to enable EEE/WEEE enterprises to implement pro-active WEEE identification management so as to fulfill their eco-responsibilities;
- A smart remanufacturing service, which is based on the retrievable remanufacturing information in the SOA-based architecture, to use artificial intelligent optimization algorithms (i.e. modern bio-inspired optimization algorithms) for effective remanufacturing and recovery planning of WEEE.

For instance, with the support from the above frameworks, the process, information representation and service functions for the lifecycle management of a mobile phone WEEE to be supported by the proposed architecture and services are illustrated in Fig. 6.5. In order to build up the above architecture and smart services, case studies are important to obtain the better understanding of WEEE information and recovery/remanufacturing flows. The following describes a case study on LCD TV WEEE management and its recovery/remanufacturing information/flow frameworks.

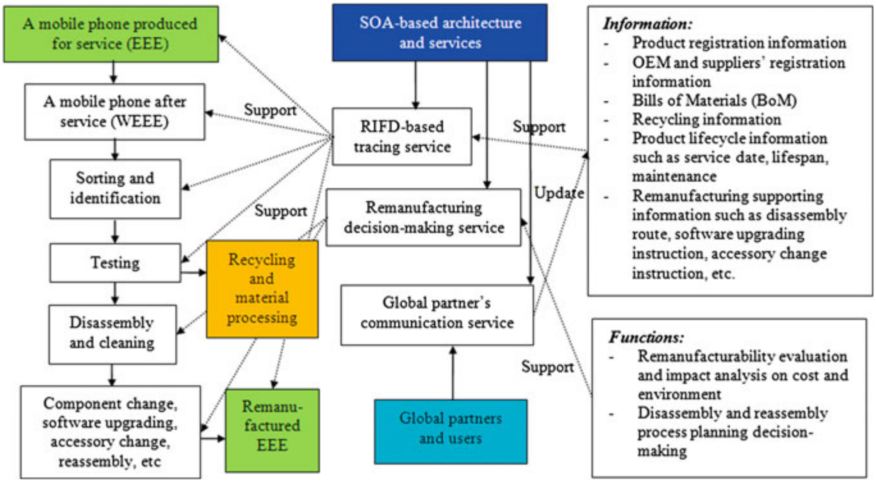

Fig. 6.5 A case to illustrate the process, information and functions of the system

6.3 Case Study and Information Framework Design

Changhong Plc is one of the major consumer electronics producers in China. TV produced in Changhong is classified into five groups: CRT TV, LCD TV, PDP TV, OLED TV and RP TV, and the LCD TV shares the biggest market of TV (the TV shares in the worldwide market is shown in Table 6.1). A LCD TV is typically assembled through three main parts: front cover assembly part, back cover assembly part and base assembly part. Among them, front cover assembly part is composed of surface frame, remote control receiver board, control button board, main board, power supply board, low-noise block converter (LNB) board, and DVD Rom (optional). The typical exploded view of a LCD TV is given in Fig. 6.6, which shows 32 main parts of the LCD TV. The part list is shown in Table 6.2.

6.3.1 LCD TV Supply Chain and Lifecycle Management

In the supply chain and lifecycle management of LCD TV and WEEE, there are several important players such as suppliers, OEMs, distributors, retailers,

Table 6.1 Worldwide market share of TV (from displaysearch.com)

Date	LCD TV	PDP TV	OLED TV	CRT TV	RP TV
Q2/2011	80.1 %	7.6 %	0.0 %	12.3 %	0.0 %

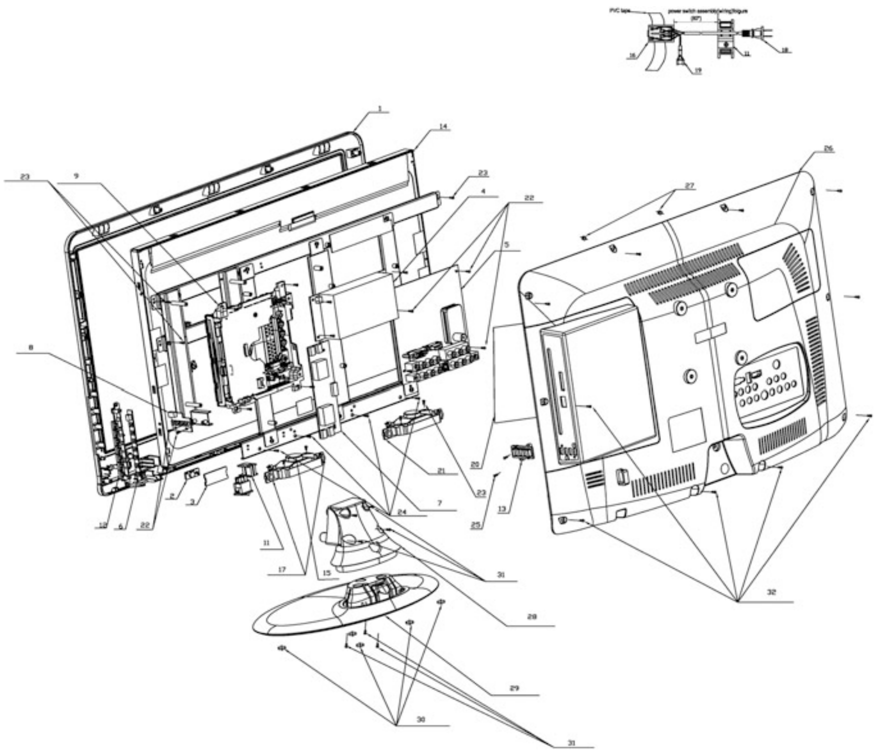

Fig. 6.6 The exploded view of a LCD TV

consumers, repair stations, collectors, second-hand sellers, recovery facility, etc. A flow of LCD TV/WEEE and the players are shown in Fig. 6.7. Suppliers provide materials and parts for OEMs. Recovery factories become suppliers when they produce recycled materials and reused parts for OEMs. Repair stations get new parts from suppliers and OEMs and reused parts from recovery factories. TV OEMs fabricate their self-made parts and assemble them with outsourced parts from suppliers. Self-made parts generally include surface frame, kinds of PCBs, back cover, brace, seat etc. Outsourced parts generally include LCD screen, DVD Rom, dynamoelectric loudspeaker, etc. Customers are categorized as business consumers and residential consumers from which the recovery system collects WEEE. The two primary modes of collection from business consumers are end of lease and asset recovery. Meanwhile, the two modes of collection from residential consumers are municipal pick-ups and retail take-back (such as buy-back, trade-back and free program). Customer returns is not only the return reasons for reverse logistics. The other reasons include manufacturing returns, distribution returns etc. Therefore, collectors take WEEE from OEMs, distributors, retailers, business consumers, residential consumers and second-hand sellers. Importing of obsolete

Table 6.2 List of main parts according to exploded view of LCD TV

No.	Name	Code	Amount
1	Surface frame	1-1-1	1
2	Lens	1-1-2	1
3	Remote control receiver board	1-2	1
4	Power supply board	1-5	1
5	Main board	1-4	1
6	Control button board	1-3	1
7	Inverter	1-1-3	1
8	Control button board for DVD/DVD	1-1-4	1
9	DVD rom	1-7	1
10	Metallic mounting plate	1-1-5	1
11	Wire clip	1-1-6	1
12	Button	1-1-7	1
13	Button for DVD/DVD	2-1	1
14	LCD screen	1-1-8	1
15	Dynamoelectric loudspeaker	1-1-9	2
16	Power switch	1-1-10	1
17	Rubber washer	1-1-11	4
18	Electrical wire	1-1-12	1
19	Connector plug	1-1-13	1
20	Insulation board	1-1-14	1
21	Pedestal for loudspeaker	1-1-15	2
22	Screw (M3×8)	1-1-16	16
23	Tapping screw (3×8BTHCH)	1-1-17	7
24	Tapping screw (4×8BTHCH)	1-1-18	4
25	Tapping screw (3×8KTHCH)	1-1-19	2
26	Back cover	2-2	1
27	Rivet nut	2-3	4
28	Brace	3-1	1
29	Seat	3-2	1
30	Rubber washer	3-3	5
31	Tapping screw (4×12BTHCH)	3-4	7
32	Tapping screw (3×10BTHCH)	2-4	10

TVs is not considered since it is not allowed by law. After being checked and sorted, parts of collected obsolete TVs are directly re-used and the others are sent to recovery facilities for process recovery.

6.3.2 Recovery and Remanufacturing Flows of LCD TV

The general recovery and remanufacturing processes as an inverted pyramid are shown in Fig. 6.8. Recovery and remanufacturing include the direct recovery and indirect recovery and remanufacturing. In addition, Recovery can include several

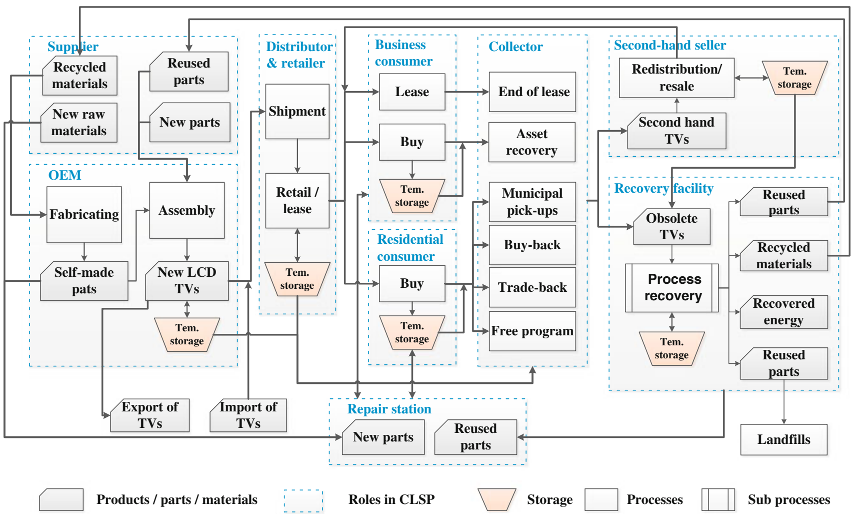

Fig. 6.7 Supply chain and lifecycle flows of LCD TV and WEEE

cases such as product recovery and remanufacturing, component recovery and remanufacturing, material recovery, energy recovery, etc. The impact on the environment of recovery and remanufacturing from top to bottom of the inverted pyramid is from min to max, while the value recovered is from max to min.

The recovery and remanufacturing processes of LCD TV WEEE are shown in Fig. 6.9, including cleaning, product disassembly, checking and sorting, parts disassembly, material recycling, and energy recovery.

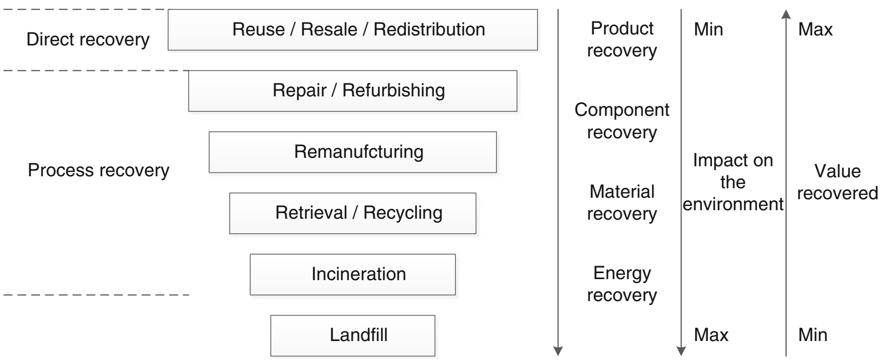

Fig. 6.8 Recovery and remanufacturing processes

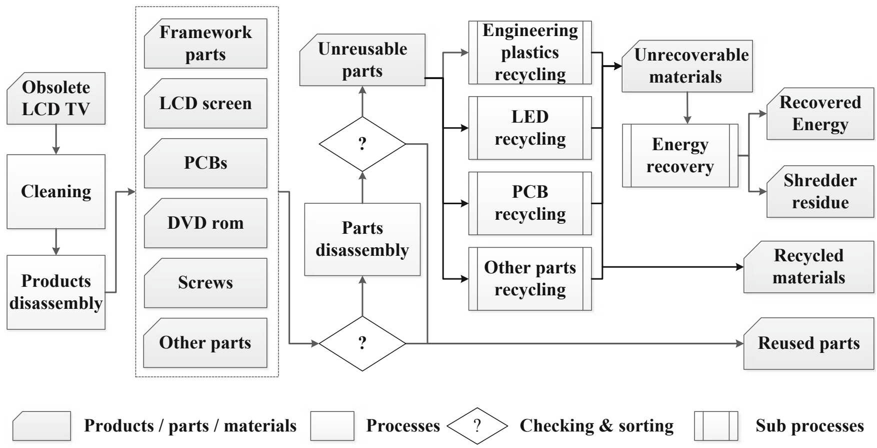

Fig. 6.9 Recovery and remanufacturing of LCD TV WEEE

After cleaned, obsolete TVs are dissembled to six main parts: framework parts, LCD screen, PCBs, DVD Rom, screws and other parts. Take the LCD TV as an example. The framework parts include surface frame, metallic mounting plate, insulation board, pedestal for loudspeaker, back cover, brace, seat and rubber washer. PCBs include remote control receiver board, control button board, main board, power supply board and control button board for DVD.

The disassembled parts then go through the processes of checking and sorting. If the parts are reusable and inspected to be good, it could be reused, such as DVD Rom, power supply board, insulation board, dynamoelectric loudspeaker and screws. Good LCD screens without obvious nicks may be also reusable. The next process is parts disassembly. Then there are more parts reusable, including lens, magnet (from loudspeaker), electronic components (or chips) and more crews. The others are considered as unreusable parts, which are the majority. They fall into four groups: framework parts, LCD screens, PCBs and other parts. Because the product life of TV is much longer than the design life of it, framework parts or PCBs would be out of date and undesirable to customers. The performance of used LCD screens also would not equal to that of new ones. There are many techniques to recycle materials from unreusable parts. Materials recycled from framework parts include recycled ABS and HIPS. The suitable plasticizer could be used to improve the toughness of recycled ABS or HIPS (form back cover). Taking a TV of type of LT24GX699EB from Changhong as an example, the net weight of the products is 5.4 kg, while the weight of materials of ABS and HIPS is respectively 549.5 and 739 g. That’s to say ABS and HIPS hold 23.86 % of the product in weight.

The waste PCBs is a kind of important recoverable resource of nonferrous metals. Recoverable materials from PCBs include plastics, copper (Cu), iron (Fe), lead (Pb), tin (Sn), antimony (Sb), silver (Ag), nickel (Ni), aurums (Au), palladium (Pd) and platinum (Pt). Three kinds of techniques of reclamation and recovery are used to recycle waste PCBs, such as hydrometallurgical treatment, pyrometallurgical treatment and physically mechanical treatment.

There are three valuable and recoverable/remanufacturable parts in a waste LCD screen: panel glass, liquid crystal and indium tin oxide. Panel glass is special silicon glass without boron and alkali, so it is unable to be recycled by fusion as usual glass. After separated and crushed up, the panel glass used as one of the raw materials of red bricks or glazed tiles. Liquid crystal is expensive chemicals, and indium is also expensive. However, the technology of recycling LCD screen is not proven and in practice. There are demands and challenges in developing the techniques of recycling and remanufacturing LCD screens. In Chap. 2, a disassembly planning service has been reported.

6.3.3 Information Management for LCD TV WEEE

Before a WEEE is recovered and remanufactured, information about the product is needed. Information for recovery and remanufacturing is divided into 8 categories: factory information, tracing information, technological information for recovery and remanufacturing, feedback information, recovery/remanufacturing-oriented design support information, legal information, economical information and ecological information. Table 6.3 details the relevant information.

Factory information is thought to be the most important information for recovery and remanufacturing of WEEE. Identification of product helps to identify the WEEE. The physical characteristics of WEEE can be analyzed, such as magnetic, density and electric conductivity properties. Finally, the treatment strategy is decided, e.g. the strategies of disassembly include non-destructive and destructive disassembly. Information about joining is also helpful to disassembly. The conceptual data model of the factory information is shown in Fig. 6.10. The entities of manufacturer and supplier are inherited from entity of role-in-SC. Every role-in-CS has his unique role-ID, and so do entities of material and product. The entity of MBON is denoted in a tree structure, in which a note represents a component or part. Corresponding to every note, the materials bill, process sequences and joining can be found. Accordingly, EEE/WEEE information for tracing is shown in Fig. 6.11.

In the GREENet project, the information framework design from the LCD TV WEEE will be further developed and generalized to other WEEE management. Meanwhile, smart remanufacturing decision-making service has been partially developed (see Chap. 2).

Table 6.3 LCD TV WEEE information

Factory information	Identification of product	Product category
		Product code
		Product description
	BOM	Component number
		Material bill
		Process sequence
	Substances	Used substances
		Hazardous substances
	Joining	Joining mode
		Joining element
		Joining comment
Tracing Information	Utilization history	Consumer
		Serving time
		Maintenance history
		Reuse times
	Deterioration	Deterioration category
		Deterioration description
	Component's condition	Performance parameter
		Condition assessment
Technological information for recovery	Information for reuse	Product reuse
		Component reuse
	Technological information for disassembly	WEEE analysis
		Assembly analysis
		Disassembly strategy
		Disassembly process planning
		Required device
		Required tool
	Technological information for remanufacturing	Component analysis
		Remanufacturing strategy
		Remanufacturing process planning
		Required device
		Required tool
	Technological information for recycling	Material and substance analysis
		Recycling strategy
		Recycling process planning
		Required devices
		Required tool
	Technological information for energy recovery	Material and substance analysis
		Energy recovery strategy
		Energy recovery process planning
		Required device
		Required tool
Feedback Information	Product/component reuse feedback	
	Disassembly feedback	
	Remanufacturing feedback	
	Recycling feedback	
	Energy recovery feedback	
Recovery/remanufacturing-oriented design support information	Product structure design support	
	Process planning support	
	Materials choosing support	
	Joining design support	

(continued)

Table 6.3 (continued)

Legal information	2002/96/EC (WEEE Directive)
	2002/95/EC (RoHS Directive)
	China WEEE
	China RoHS
Economical information	New material price
	New component price
	New product price
	Recycled material price
	Reused component price
	Second-hand product price
	Collecting cost
	Treatment cost
Ecological information	Treatment energy consumption
	Treatment environmental pollution

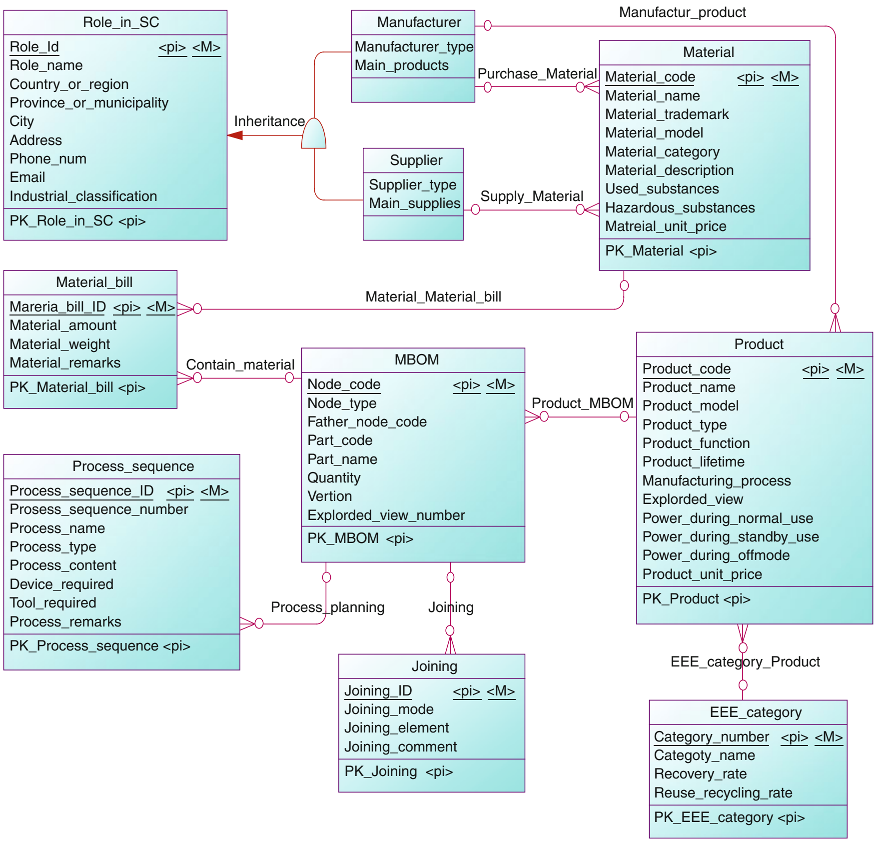

Fig. 6.10 Conceptual information model of factory information

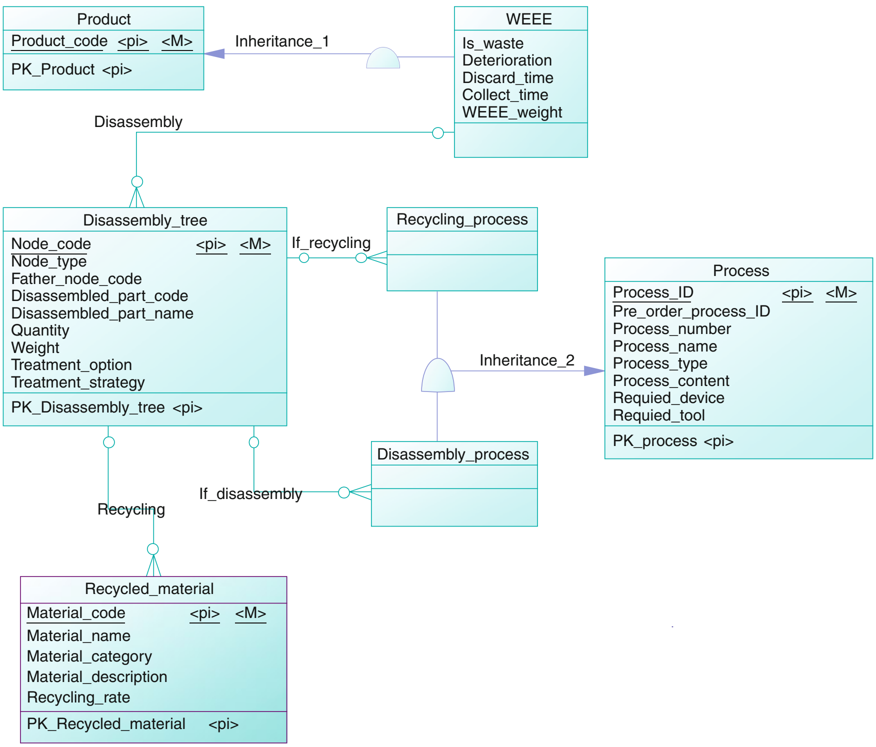

Fig. 6.11 Conceptual information model for recovery and remanufacturing

6.4 Conclusions

In this research, investigation and case studies on LCD TV WEEEE have been made to support sustainable WEEE management. With the innovative features including a generic global EEE/WEEE distributed information service architecture and smart EEE/WEEE services, the research outcomes will be a promising solution to change the current EEE/WEEE management from the traditional "management authority-centric reporting model" to a new "sustainable management model for WEEE". Detailed technical implementation of the research is under development, and more case studies are expected to verify and validate the research.

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