Environmental Chemistry for a Sustainable World

Anish Khan
Inamuddin
Abdullah M. Asiri *Editors*

E-waste Recycling and Management

Present Scenarios and Environmental Issues

Springer

Environmental Chemistry for a Sustainable World

Volume 33

Other Publications by the Editors

Books
Environmental Chemistry
http://www.springer.com/978-3-540-22860-8

Organic Contaminants in Riverine and Groundwater Systems
http://www.springer.com/978-3-540-31169-0

Sustainable Agriculture
Volume 1: http://www.springer.com/978-90-481-2665-1
Volume 2: http://www.springer.com/978-94-007-0393-3

Book series
Environmental Chemistry for a Sustainable World
http://www.springer.com/series/11480

Sustainable Agriculture Reviews
http://www.springer.com/series/8380

Journals
Environmental Chemistry Letters
http://www.springer.com/10311

More information about this series at http://www.springer.com/series/11480

Anish Khan • Inamuddin • Abdullah M. Asiri
Editors

E-waste Recycling and Management

Present Scenarios and Environmental Issues

Springer

Editors
Anish Khan
Chemistry Department
King Abdulaziz University
Jeddah, Saudi Arabia

Inamuddin
Chemistry Department,
Faculty of Science
King Abdulaziz University
Jeddah, Saudi Arabia

Abdullah M. Asiri
Chemistry Department,
Faculty of Science
King Abdulaziz University
Jeddah, Saudi Arabia

ISSN 2213-7114 ISSN 2213-7122 (electronic)
Environmental Chemistry for a Sustainable World
ISBN 978-3-030-14183-7 ISBN 978-3-030-14184-4 (eBook)
https://doi.org/10.1007/978-3-030-14184-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Expanding the rate of market infiltration, financial development and fast mechanical progression prompt the monstrous age of electronic waste in the habitat. The absence of awareness and coarse treatment of e-waste causes a worldwide threat. E-waste is a famous casual name for electronic items generated after their helpful life. Computers, televisions, video cameras, recorders, stereos, copiers and fax machines are some of the regular electronic items being generated as e-waste. A number of items may be reused after giving a face-lift. However, with quick changing advancements and consistent buyer interest for the most recent gadgets, the ascent in e-waste looks set to proceed. Indeed, the purchasers may play an essential role by picking items that are less perilous and are intended for more secure reusing. On the other hand, the e-waste management networks may be set up to guarantee the collection of inappropriately surrendered or censured items and outdated or broken electrical or electronic gadgets. It is obvious that the e-waste items, which are generated and not managed properly, contaminate nature, making it inadmissible for human home. On the other hand, the progression of advancements has decreased the life cycle of electronic items. Thus, the rate to outdated old items increases progressively. Thus, it is very necessary to be aware of the e-waste world and its impact on the global habitat of the species. In view of that, this book is planned to provide a comprehensive literature on the global e-waste recycling and management. This book is divided into 12 chapters as given below:

Chapter 1 explores the status of a cathode-ray tube disposal and environmental issues followed by potential challenges of segregating funnel and panel glass of cathode-ray tube. Separation of funnel and panel glass from the cathode-ray tube based on open-loop and closed-loop process is discussed with pros and cons.

Chapter 2 includes a description of methods of disassembly focused on e-waste recycling in compliance with environmental standards. The required steps of the end-of-life products disassembly vary depending on the category of waste equipment. To show these differences, the chapter includes two case studies showing the configuration of a layout of e-waste processing lines with possible options to reconfigure them. The variants of the system's configuration depend on the volume of the waste stream, labour cost and required purity of output materials. Economic efficiency indicator of e-waste is presented in this chapter on cooling appliances recycling for four European countries.

Chapter 3 discusses some of the most important factors, including legal, statistical, economic and organizational factors that affect the recycling of waste electrical and electronic equipment or more broadly the recycling of general electronic waste in Japan and other countries. The policy importance of incorporating manufacturing supply chains in the design of environmental management of production systems is emphasized. This chapter puts forward some recommendations that need to be taken into account in the public policy debate in order to improve the current low rates.

Chapter 4 discusses the current state of electronic waste management through technology. It begins by giving the definition and classification of electronic waste separation and recycling strategies. It is also mentioning the importance of electronic waste management and statistics of the exponential increase of electronic waste. After that, electronic waste is classified, and the major challenges faced in electric and electronic waste management and control regulations are discussed. Finally, the material composition in waste electrical and electronic equipment and current as well as future electronic waste management technologies are discussed in details.

Chapter 5 discusses the recycling challenges for the adoption of e-waste reverse logistics under the perspective of developing countries. It is also pointing out the categorization of the barriers in financial/economics; environmental; market related; legal; policy related; management; knowledge related and technical and technological related. The compilation of information related to recycling challenges of e-waste in developing countries and the identification of some solutions and actions to overcome these barriers are also discussed which can be useful for practitioners and researchers.

Chapter 6 explores the systematic methods used for the management of electronic waste. It provides information about electronic waste, plastics in electronic waste, electronic waste management issues, worldwide electronic waste generation and issues related to electronic waste and environmental public health. Finally, energy recovery from electronic waste using methods such as chemical recycling, mechanochemical treatment, hydrothermal process, pyrolysis, combustion process, gasification process, integrated process and hydrocracking is discussed.

Chapter 7 contributes to the literature on the management of waste electrical and electronic equipment (WEEE) by comparing the performance of the different European Union countries according to the targets set in the regulation of the Union's environmental policy on WEEE. To this end, the traditional non-parametric data envelopment analysis is used to measure technical efficiency for the first time in the literature. A sample of 30 European countries for the year 2014 is used with the purpose of comparing their performance, ranking the countries and identifying their level of inefficiency.

Chapter 8 addresses the various categories deployed towards effective e-waste management such as collection, disposal of dangerous portions and recovery of precious metals and energy. The benefits, challenges and future of e-waste management are also highlighted.

Chapter 9 discusses the methods used for the recycling of the precious metals obtained from the light-emitting diode industry. These metals are gallium, indium, rare earth elements like yttrium and cerium and precious metals such as gold and silver. Some of the most important methods developed for this purpose include pyrometallurgical (pyrolysis), hydrometallurgical (acid leaching) and biotechnological technologies (microbial leaching).

Chapter 10 discusses the current scenario in the electrical and electronic equipment industry and generation of waste electric and electronic equipment considering the implications of resource management and environment, social and economic impact in this production chain.

Chapter 11 deals with sustainable electronic waste management implications for environmental and human health. It is written to explain the electronic waste and sustainable development goals with electronic waste tracking and driving trends. The electronic waste statistics and measurement along the side positive and negative effects of electronic waste are also discussed. Some of the products that make challenges to a recycler are also discussed. Finally, the implications of electronic waste on human health and the environment discourse with the aim of electronic waste management are discussed.

Chapter 12 provides a brief insight into the global trends of e-waste generation, critical issues and challenges associated with e-waste and its effects on environmental and human health. Finally, the chapter highlights the need for sustainable environmental management of e-waste.

Jeddah, Saudi Arabia Inamuddin
Jeddah, Saudi Arabia Anish Khan
Jeddah, Saudi Arabia Abdullah M. Asiri

Contents

Contributors

Mohamed Aboughaly Faculty of Energy Systems and Nuclear Science, and Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, ON, Canada

Jayaseelan Arun Department of Chemical Engineering, SSN College of Engineering, Kalavakkam, Tamil Nadu, India

D. Balaji Department of Chemical Engineering, SSN College of Engineering, Chennai, Tamil Nadu, India

Feliciane Andrade Brehm Universidade do Vale do Rio dos Sinos – UNISINOS, Porto Alegre, RS, Brazil

Lúcio Camara e Silva Management Engineering Department, CDSID – Center for Decision Systems and Information Development, Federal University of Pernambuco, Recife, Brazil

Gisele Lorena Diniz Chaves Department of Engineering and Technology, Federal University of Espírito Santo, Vitória, Espírito Santo, Brazil

Angéli Viviani Colling Universidade do Vale do Rio dos Sinos – UNISINOS, Porto Alegre, RS, Brazil

Tamires Augustin da Silveira Universidade do Vale do Rio dos Sinos – UNISINOS, Porto Alegre, RS, Brazil

Emanuele Caroline Araújo dos Santos Universidade do Vale do Rio dos Sinos – UNISINOS, Porto Alegre, RS, Brazil

Hossam A. Gabbar Faculty of Energy Systems and Nuclear Science, and Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, ON, Canada

Kannappan Panchamoorthy Gopinath Department of Chemical Engineering, SSN College of Engineering, Kalavakkam, Tamil Nadu, India

K. Grace Pavithra Department of Chemical Engineering, SSN College of Engineering, Chennai, Tamil Nadu, India

Patricia Guarnieri Faculty of Economics, Administration, Accounting and Public Policies Management, University of Brasilia, Brasilia, Brazil

Hitoshi Hayami Faculty of Business and Commerce, Keio University, Tokyo, Japan

Victor C. Igbokwe Department of Microbiology, Faculty of Biological Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

Bioconversion and Renewable Energy Research Unit, University of Nigeria, Nsukka, Enugu State, Nigeria

Carlos Alberto Mendes Moraes Universidade do Vale do Rio dos Sinos – UNISINOS, Porto Alegre, RS, Brazil

Masao Nakamura Sauder School of Business, University of British Columbia, Vancouver, BC, Canada

Graduate School of Business and Commerce, Keio University, Tokyo, Japan

Isabel Narbón-Perpiñá Department of Business, Universitat Autònoma de Barcelona, Barcelona, Spain

Piotr Nowakowski Faculty of Transport, Silesian University of Technology, Katowice, Poland

Tochukwu N. Nwagu Department of Microbiology, Faculty of Biological Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

Charles O. Nwuche Department of Microbiology, Faculty of Biological Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

Joyce N. Odimba Department of Microbiology, Faculty of Biological Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

Bioconversion and Renewable Energy Research Unit, University of Nigeria, Nsukka, Enugu State, Nigeria

Chukwudi O. Onwosi Department of Microbiology, Faculty of Biological Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

Bioconversion and Renewable Energy Research Unit, University of Nigeria, Nsukka, Enugu State, Nigeria

Diego Prior Department of Business, Universitat Autònoma de Barcelona, Barcelona, Spain

Shahriar Shams Civil Engineering Programme Area, Universiti Teknologi Brunei, Bandar Seri Begawan, Brunei-Muara, Brunei Darussalam

Bhavisha Sharma Department of Environment and Sustainable Development, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India

Pooja Singh Department of Science, Institute of Computer Science and Technology, SHEPA, Varanasi, India

Rajeev Pratap Singh Department of Environment and Sustainable Development, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India

Panneer Selvam Sundar Rajan Department of Chemical Engineering, SSN College of Engineering, Chennai, Tamil Nadu, India

Barkha Vaish Department of Environment and Sustainable Development, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India

Lúcia Helena Xavier Centre for Mineral Technology (CETEM), Rio de Janeiro, Brazil

Chapter 3
An Economic Assessment of Present and Future Electronic-Waste Streams: Japan's Experience

Hitoshi Hayami and Masao Nakamura

Contents

Abstract In this chapter, we discuss some of the most important factors, including legal, statistical, economic, and organizational factors, that affect the recycling of waste electrical and electronic equipment or more broadly the recycling of general Electronic-waste in Japan and other countries. In doing so, we emphasize the policy importance of incorporating manufacturing supply chains in the design of environmental management of production systems.

The research reported here is in part supported by the Keio Gijuku Academic Development Funds and the Social Sciences and Humanities Research Council of Canada.

H. Hayami
Faculty of Business and Commerce, Keio University, Tokyo, Japan

M. Nakamura (✉)
Sauder School of Business, University of British Columbia, Vancouver, BC, Canada

Graduate School of Business and Commerce, Keio University, Tokyo, Japan
e-mail: masao.nakamura@sauder.ubc.ca

A. Khan et al. (eds.), *E-waste Recycling and Management*,
Environmental Chemistry for a Sustainable World 33,
https://doi.org/10.1007/978-3-030-14184-4_3

We also point out that the rates of collecting and recycling waste electrical and electronic equipment are relatively low in Japan as well as in the European Union countries. This chapter puts forward some recommendations that need to be taken into account in the public policy debate in order that the current low rates are to be improved.

3.1 Introduction

Much attention has been paid to the generation of Electronic-waste (typically termed as "E-waste") in many countries in recent years. Electronic-waste, for example, represents waste electrical and electronic equipment (typically termed as "WEEE"), among other product categories, and is measured in various ways.

The amounts of electronic-waste generated globally have been increasing over time. For example, Fig. 3.1 shows that per capita generation of electronic-waste in Asian countries has been increasing in recent years. In fact, in a growing economy, the total generation of electronic-waste is likely to continue increasing (Kusch and Hills 2017).

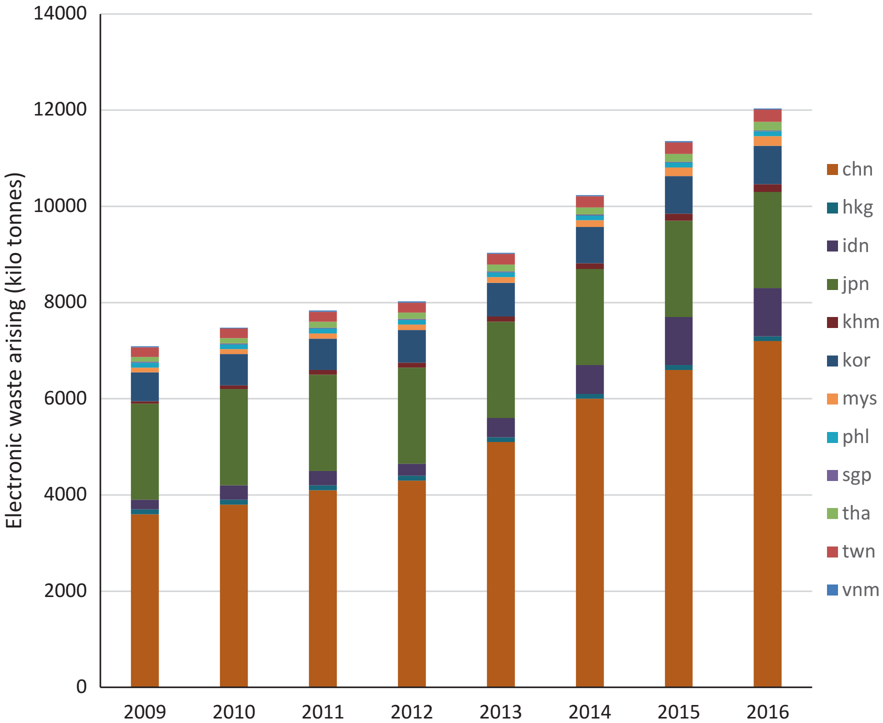

Fig. 3.1 The growth of Electronic-waste in East and Southeast Asia. (Source: United Nations University: Baldé et al. (2015))

The United Nations reports that a record level of waste electrical and electronic equipment, amounting to 41.8 million tons worldwide, was thrown away in 2014, with less than one-sixth of it being properly recycled (Baldé et al. 2015, page 24). It was the largest amount ever of Electronic-waste that was discarded, and there is little sign of a slowdown. Even countries that have recycling and recovery programs including Japan discard large amounts of waste electrical and electronic equipment.

The largest amount of Electronic-waste was generated in the United States and China, which together accounted for 32% of the total. The third most wasteful country by volume was Japan, which discarded a grand total of 2.2 million tons in 2013 (Japan Times, 2015, May 9).

Even though Japan's per capita waste, 17.3 kg per inhabitant, was lower than some less densely populated countries, other countries, such as those in Africa, had much lower amounts of Electronic-waste. Africa's average was 1.7 kg per person, one-tenth the amount of the waste generated by the average Japanese.

This kind of refuse is dangerous and often highly toxic. The refrigerators, washing machines, and microwave ovens routinely discarded contain large amounts of lead glass, batteries, mercury, cadmium, chromium, and other ozone-depleting chlorofluorocarbons (often termed as "CFCs"). The 7% of Electronic-waste last year made up of mobile phones, calculators, personal computers, printers, and small information technology equipment also contained poisonous components.

Electronic-waste last year also contained valuable resources worth $52 billion, only a quarter of which was recovered. Worldwide, an estimated 16.5 million tons of iron, 1.9 million tons of copper, 300 tons of gold (equal to 11% of the world's total gold production in 2013), as well as silver, aluminum, and palladium plastic were simply thrown out. With better recovery systems, those resources wouldn't end up in dumps, increasingly located in poorer countries, but would be recycled.

Japan was one of the first countries to impose recycling of Electronic-waste, and the Japanese system is thought to be better than in many countries. However, Japan still only treats around 24–30% of its Electronic-waste, the report estimated. The Japanese government reported that 556,000 tons of Electronic-waste was collected and treated in Japan in 2013, but that still only accounts for one-quarter of the total.

The convenience people have sought in the kitchen, laundry, and bathroom, and for daily communication, has become the world's noxious waste. With rising sales and shorter life cycles for products, the Electronic-waste problem is not likely to improve anytime soon.

Individuals should make sure that their disposal of even small gadgets is handled correctly. Governments around the world, including Japan, need to impose stricter rules, establish better disposal and recycling systems, and increase oversight.

One of the main reasons that per capita Electronic-waste generally grows over time is that per capita Electronic-waste increases with per capita gross domestic product (typically termed as "GDP"). Kusch and Hills (2017) present evidence that there is a positive correlation between these two quantities observed cross-sectionally for many nations in the Pan-European region.[1] Furthermore, this correlational relationship seems to hold regardless of the stages of economic development of specific countries in their sample.

Current Issues
As we noted above, the generation of Electronic-waste is likely to continue to grow over time globally. The often included items in waste electrical and electronic equipment are air conditioners, refrigerators, washing machines, television sets, other appliances, and cell phones. Many of these items are bulky and difficult to dispose of. In addition, they might produce toxic substances on the grounds if abandoned. From the life cycle perspectives,[2] production of these products requires large amounts of metal, energy, and other resources and generates significant amounts of greenhouse gases (CO_2, CH_4, N_2O, and CFCs). For these and other reasons for recycling of waste electrical and electronic equipment was identified as an important issue of environmental management.

Recycling of Waste Electrical and Electronic Equipment
While many countries recognize that promoting recycling of waste electrical and electronic equipment is an important policy issue, there are still a number of difficulties to implement policies that promote such recycling. For example, since the items included in waste electrical and electronic equipment are generally consumer goods, such policies must be compatible with consumers' incentives. Similarly, we would like to include producers and/or retailers of these products in the recycling process since retailers, for example, will have first-hand information on the customers who purchase these products. Delegating some responsibility of recycling to producers and retailers is called extended producer responsibility (EPR) and is often included in waste electrical and electronic equipment recycling laws in many countries.

Economics of Recycling Waste Electrical and Electronic Equipment
It is essential to pay attention to the economic principles underlying policy matters on environmental management such as collecting, recycling, and processing of Electronic-waste. Since the products which generate Electronic-waste after they are consumed are produced using metals and also precious metals for some products like cell phones, recovering some of these metals and precious metals from recycled waste electrical and electronic equipment items is likely to give some economic benefits.[3] Also, collecting discarded waste electrical and electronic equipment from consumers' homes and transporting them to the specified deposit is not free. For

[1] Kusch and Hills (2017) show in particular that an increase of 1000 international $ GDP purchasing power parity (PPP) means an additional 0.5 kg waste electrical and electronic equipment is generated.

[2] We regard environmental management analyses and approaches based on life cycle and supply chain perspectives interchangeably (see, e.g., Hayami et al. (2015) and Hayami and Nakamura (2007)).

[3] This is discussed in Sect. 3.3.

Table 3.1 Cost and benefit analysis of waste electrical and electronic equipment recycling: consideration of life cycle (supply chain) stages

Life cycle stages	Cost/benefit implications for recycling process Examples
(1) Design and production stage	Amounts of metals and precious metals used (greenhouse gas emissions/transportation costs of the collection of recycled items)
(2) Sales/marketing stage	Contractual arrangements for expected recycling activities (how the items are to be collected when product life is over)
(3) Collection of used products	Logistics for collection/locations for recycled products (fuel costs of transportation)

Source: By the authors

example, in Japan, these items typically weigh as follows: television set (28 kg/unit), air conditioner (43 kg/unit), refrigerator (58 kg/unit), and washing machine (32 kg/unit). Collecting and transporting of these used appliances is certainly costly, and their costs need to be compared with the economic benefits obtained from recycling.

Stages of Recycling Processes of Waste Electrical and Electronic Equipment
The above discussion suggests that the recycling processes must be studied analytically as follows (Table 3.1), taking into account the effects of recycling-related costs as well as direct and indirect costs and benefits from the recycling.

For example, designing products using smaller amounts of metals and simple designs may allow recycling costs to be reduced, as well as reductions in fuel costs and the associated emissions of greenhouse gases (typically termed as "GHG"). These cost reductions may outweigh the benefits of recovering some marketable metals in the recycling process. Contractual arrangements between producers and customers (consumers) might matter in order to increase the recycling rates of waste electrical and electronic equipment. Similarly, an optimal spatial distribution of the locations for the collecting depot points of recycled products may also facilitate reductions in the cost of transportation.

3.2 Electronic-Waste Management in Japan

Japan was among the first countries which began Electronic-waste recycling. Because of the rapid technological changes that took place in the areas of production and consumption of waste electrical and electronic equipment items recently in Japan, it is of considerable academic and practical interest to study the recycling and other activities related to waste electrical and electronic equipment in Japan. In this section, we describe the basic legal institutions (laws) that oversee Electronic-waste recycling activities in Japan, and then we discuss policy issues related to them.

3.2.1 Legal Institutions Overseeing Electronic-Waste Management in Japan

Two basic laws that oversee environmental management policies in Japan were put forward in 1994 and 1998, respectively. We briefly discuss these laws below.

– 1994: *Law for the Promotion of Effective Utilization of Resources*. This law was subsequently enacted in May 2000 and was put into force in April 2001.

This law aims at establishing a sound material-cycle economic system by:

(i) Enhancing measures for recycling goods and resources by implementing the collection and recycling of used products by business entities
(ii) Reducing waste generation by promoting resource saving and ensuring longer life of products
(iii) Newly implementing measures for reusing parts recovered from collected used products and at the same time as measures to address the reduction of industrial wastes by accelerating the reduction of by-products and recycle

This is an epoch-making law which requires to reduce, reuse, and recycle (typically termed as "3Rs") as part of measures; covers from upstream part, including product design; and measures against industrial wastes through downstream part such as collection and recycling of used products.[4]

– 1998, 2001: *Home Appliance Recycling Act* became a law in June 1998, but it became operational much later in 2001.

The primary objective of this *Home Appliance Recycling Act* is to operationalize its policy contents. It states that "This legislation shall have the objective of contributing to the maintenance of the living environment and the healthy development of the national economy, by taking steps to secure the environmentally sound disposal of waste and effective utilization of resources through the introduction of measures for proper and smooth collection, transportation, and recycling of specific household appliance waste by retail traders or manufacturers of specific household appliances, with the aim of achieving a reduction in the volume of general waste and sufficient utilization of recycled resources."

More specifically, for achieving this objective, this Act is designed to solve the following problems:

(i) Environmentally sound disposal of wastes (hazardous wastes) waste electrical and electronic equipment that is disposed of as bulky waste contains hazardous materials and pollutants. These include chlorofluorocarbons as both greenhouse gas and ozone-depleting substance, oil in motors and compressors, and heavy metals used in making printed circuit boards. Illegal dumping of such products poses even greater environmental risks. Thus, a system to manage waste electrical and electronic equipment in an environmentally sound manner was

[4] See Japanese Ministry of Justice (2017) and Japanese Ministry of Environemnt (2001).

expected to be built. In addition, since environmentally sound management of these wastes was often beyond the capacity of individual local governments, the manufacturers of these appliances were expected to participate in the process of managing these wastes.

(ii) Effective use of recyclable materials waste electrical and electronic equipment contains large amounts of iron, aluminum, copper, and glass. These can be an effective source of materials if they can be recovered efficiently.

The target areas of this act are the following four categories of home appliances:

1. Air conditioners
2. Television sets (cathode-ray tubes) and liquid crystal display types, excluding those designed to be incorporated into a building and that do not use primary batteries or storage batteries for their power source, as well as the plasma types
3. Electric refrigerators and freezers
4. Electric washing machines and clothes dryers

Also, flat-screen television sets (liquid crystal display and plasma types) and clothes dryers were added to the designated categories in April 2009.

Among other typical waste electrical and electronic equipment items, personal computers are managed under the previously discussed act called *Act on the Promotion of Effective Utilization of Resources (1994)*. Also, small electronic appliances such as mobile phones have been managed under a new law called *Small Electrical and Electronic Equipment Recycling Act* since 2013.

3.2.2 Overview of Electronic-Waste Recycling

Environmental management policies need to focus on, among other topics, (i) recycling of Electronic-waste, particularly its costs aspects, and its implications for (ii) reductions (if any) in the generation of greenhouse gases and (iii) reductions in the use of resources such as metal and precious metals. Earlier we discussed cost issues associated with the transportation of recycled Electronic-waste. How do such recycling costs compare with the tangible benefits of recycling (e.g., the commercial value of metals recycled, etc.)? Such cost and benefit trade-offs and analyses may ultimately determine the publicly justifiable degree of recycling activities.

From Table 3.2, we see that Japan's per capita Electronic-waste generated is considerably higher than that of Germany. Japan collects and recycles about a fourth of its per capita Electronic-waste generated.

In later sections, we will further look at the European Union's performance in Electronic-waste recycling in comparison with Japan's. Figure 3.2 shows the general upward trend in Japan's waste electrical and electronic equipment over time. It also shows a volatile pattern in the collection and recycling of total waste electrical and electronic equipment units. This suggests the importance of public policies that facilitate more robust performance in recycling activities.

Table 3.2 Generation and collection/recycling of Electronic-waste: Germany and Japan, 2013

	Germany	Japan
Electronic-waste generated (per capita), in kg	21.6	17.3
Total Electronic-waste generated, in kilotons	1769	2200
Total Electronic-waste collected and recycled, in kilotons	–	556
Population	81,589	127,061
National regulation of Electronic-waste recycling	Yes	Yes

Source: Compiled by the authors based on publicly available information. JEMAI (2017), and EU Eurostat (2017)

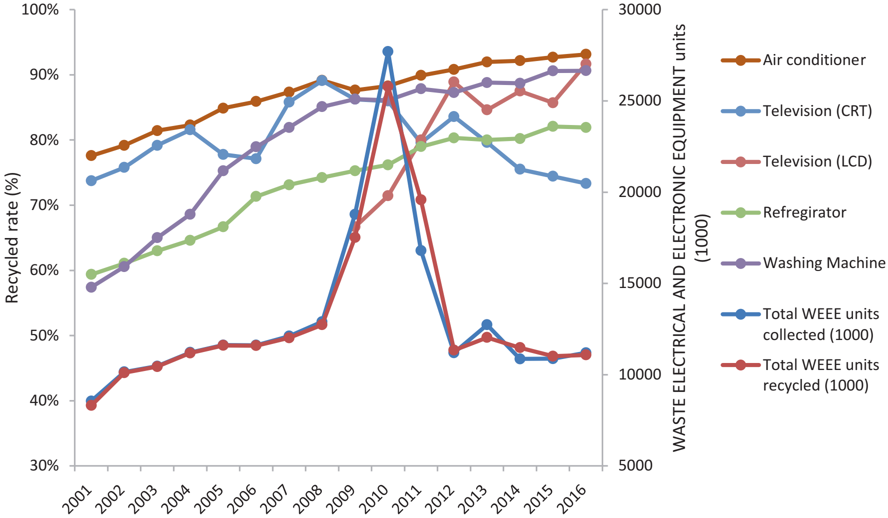

Fig. 3.2 Rates (%) of recycling and collection of Electronic-waste in Japan, 2001–2016. (Source: Compiled by the authors based on data from the Japanese Ministry of Environment Data Source http://www.env.go.jp/policy/keizai_portal/A_basic/a06.html and other sites)

3.2.3 *Costs of Electronic-Waste Recycling*

Given the large numbers and weights of units of these products in waste electrical and electronic equipment that need to be collected physically for recycling,[5] it is not difficult to see that the transportation costs play an important role among the deter-

[5] See Sect. 3.3 for further information regarding the physical border of waste electrical and electronic equipment items to be recycled.

minants of the recycling rates. (See Sect. 3.3 for the numbers of Electronic-waste items that need to be collected for recycling.)

The observed recycling costs of home appliances in Japan vary significantly depending on the types of appliance products to recycle, the companies which provide services to remove appliances out of homes and to transport them to the recycling depots, among other things, and also the availability of local recycling services provided by the local government offices. Table 3.3 presents a few examples of such

Table 3.3 Home appliances recycling costs: some examples, Japan, 2016

Product	Recycling fee (in yen)	Transportation cost (in yen)	Cost of removal from home (in yen)
Products covered by the 2001 Home Appliance Recycling Act			
Air conditioner	972[a]	500–3000	3000–20,000
TV sets (with screens below 15″)	1836	500–3000	3000–20,000
TV sets (with screens larger than 16″)	2916	500–3000	3000–20,000
Refrigerators (capacity below 170 liters)	3672	500–3000	3000–20,000
Refrigerators (capacity above 171 liters)	4644	500–3000	3000–20,000
Washing machine	2484	500–3000	3000–20,000
Personal computer	3000–4000[b]		
Other appliances	**Recycling fee (in yen, Tokyo 23 wards government offices)**	**Recycling fee (in yen, private recycling businesses)**	**Transportation and removal costs (in yen, private recycling businesses)**
Oil heater	700	1500 or more	Yes
Audio equipment	300	1000 or more	Yes
Gas burner	300	1000 or more	Yes
Lighting equipment	300	700 or more	Yes
Dishwasher/dryer	1000	1500 or more	Yes
Electric fan	300	500 or more	Yes
Microwave oven	300	800 or more	Yes
Video recorder	300	1000 or more	Yes
Printer	300–1000	1000 or more	Yes
Home sewing machine	700	2800 or more	Yes

Notes:
[a]Monetary figures presented in this table are in Japanese yen in 2016. The exchange rate between the Japanese yen and the US dollar for December 2016: $1.00 = 116 Japanese yen
[b]Personal computers with publicly registered marks for recyclable products may be turned into their producers for recycling for free. Other public organizations may collect used personal computers for recycling free of charge. But the private sector businesses usually charge recycling fees
Source: Compiled by the authors based on public-use government information from Enechange (2016)

Table 3.4 Numbers of Electronic-waste items collected at designated sites across Japan, 2016

Product (Electronic-waste item)	Number of collected appliances		
	#Collected appliances (in 1000s of units)	Fraction of total (%)	Year-on-year change
Air conditioners	2567	22.9	+9.0%
CRT TVs	1184	10.6	−23.7%
LCD and plasma TVs	1279	11.4	+23.8%
Refrigerators and freezers	2829	25.3	+1.1%
Clothes washers and dryers	3339	29.8	+6.4%

Note: The observation period is between April 2016 and March 2017 (Japan's 2016 fiscal year)
Source: Compiled by the authors based on information available from METI (2017)

recycling costs observed in Japan for certain home and other appliances. Most of these appliances were sold by large national appliance producers.

As we see from Table 3.4, the recycling rates (or collection rates here) of the main Electronic-waste products for 2016 for Japan were all less than 30% and are the only small fractions of the total products sold to the consumers. While we can think of many possible reasons for this, the costs of recycling given in Table 3.3, which are relatively high compared to the prevailing prices of equivalent new products in the markets, might be in part responsible.

3.3 Life Cycle Policy Analysis Using Input-Output (I-O) Tables: Recycling of Mobile Phones and Personal Computers and Their Supply Chains in Japan

So far we have not discussed recycling of mobile phones and personal computers. These products were not included in the original Japanese laws on Electronic-waste recycling as we discussed in the previous sections. In this section, we calculate the indirect savings in the use of materials and other resources resulting from the recycling and processing of these electronic products. To do this we use the input-output tables for the Japanese economy (e.g., Hayami et al. (2015), Hayami and Nakamura (2007)).

Trends in the recycling of mobile phones and personal computers are presented in Figs. 3.3, 3.4, and 3.5.

Rates of the recycling of mobile phones for the phone bodies, batteries, and chargers remain relatively stable over the recent years at levels below 10 million units (Fig. 3.3). This is despite the significant decline in the shipments of new phone units. On the other hand, the recycling patterns for both desktop and notebook personal computers show that the general decline and fluctuations in the shipments of these personal computers are also reflected in the rates of recycling for these products (Figs. 3.4 and 3.5).

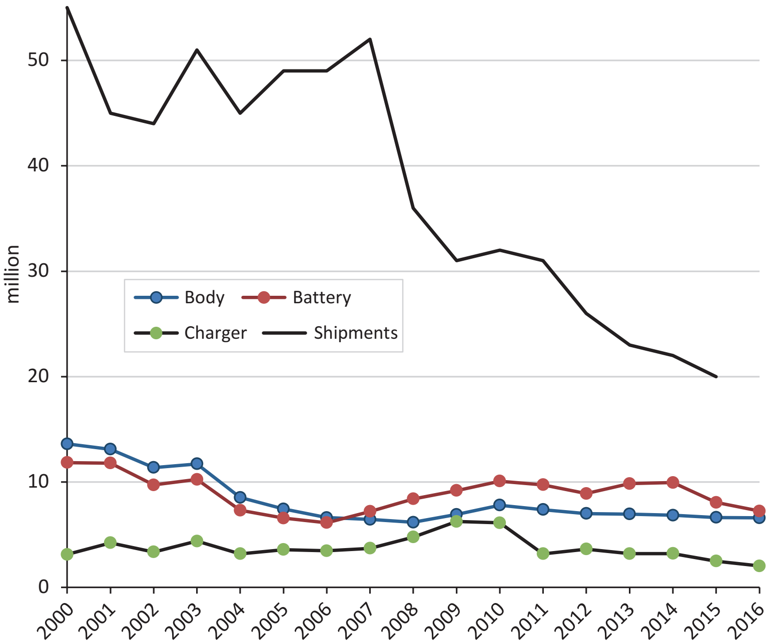

Fig. 3.3 Trend of recycled mobile phones by parts: body, battery, and charger compared to the shipments (in million). (Source: compiled by the authors using information for public use from Mobile Recycle Network (2018) and JEITA (2017).

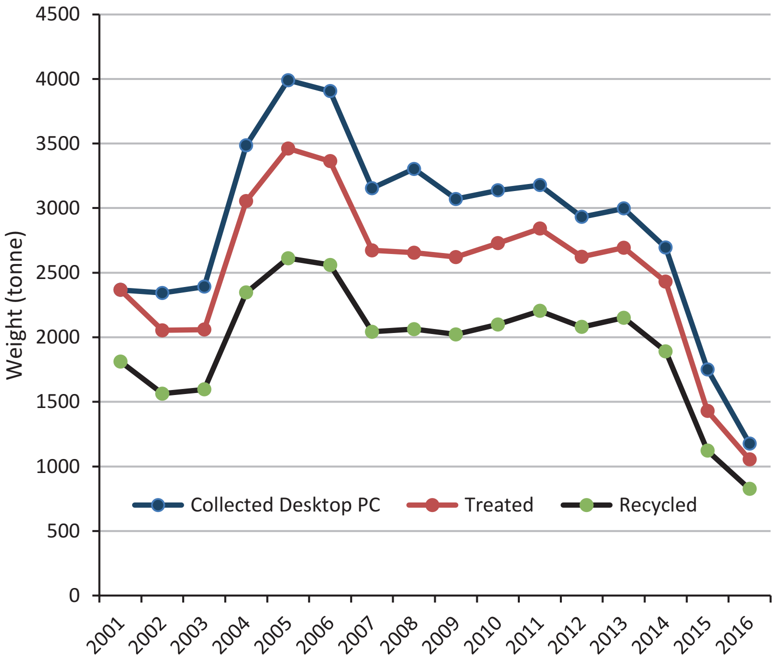

Fig. 3.4 Trend of the number of recycled desktop personal computers

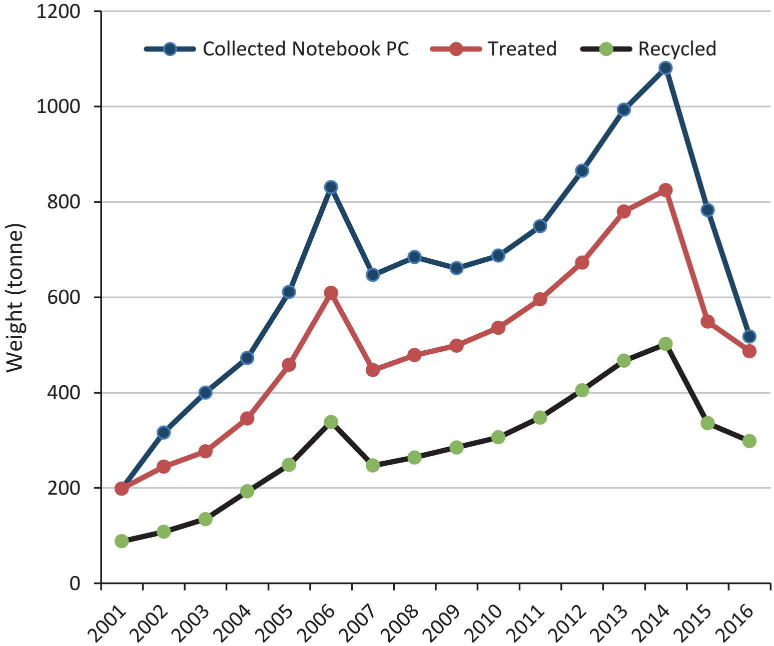

Fig. 3.5 Trend of the number of recycled notebook personal computers. (Source: compiled by the authors using information for public use from PC3R Promotion Association (2017)

The numbers of shipments for personal computers are not shown in Figs. 3.4 and 3.5. But the desktop personal computers' shipments declined from 5,192,000 in 2006 fiscal year (April 2006–March 2007) to 1,753,000 in 2015 fiscal year (April 2015–March 2016). Similarly, the notebook personal computers' shipments declined from 6,858,000 in 2006 fiscal year (April 2006–March 2007) to 53,582,015 fiscal year (April 2015–March 2016) (Japan Electronics and Information Technology Industries Association 2017).

Collected personal computers are treated and recycled at very high rates (over 70%). But notebook personal computers collected from the households are recycled at the lower rates around 57.1% (in 2015 fiscal year (April 2015–March 2016) according to the Personal Computer Reduce, Reuse and Recycle (often termed as "PC3R") Promotion Association (2017). The Personal Computer Reduce, Reuse and Recycle Promotion Association states that after the collected 12.87million units of personal computers go through the final treatments, 2.8 million units will be reused domestically, 3.64 million units will be recycled as resources domestically, 0.35 million units will be put in the landfills, 2.15 million units will be exported overseas for reuse purpose, and 3.08 million units will be set aside for resource purposes in the 2014 fiscal year (April 2014–March 2015).

Table 3.5 Electronic waste and recycled appliances

Panel A: Yields (metals, plastics, etc.) derived from collected small appliances	
Item	**Weight (tons)**
Total small electric appliances collected	57,260
Metals recycled after processing	36,567[a]
Recycled plastics	2550
Incinerated plastics	13,612
Reused appliances	149
Residuals	4298

Panel B: The estimated amounts of electronic-waste generated by small appliances		
Item	**Number of recycled units**	**Weight (tons)**
Electric shaver, jar, electric pots, and others	61,368,572	185,179
Mobile phones, phones, and others	47,842,169	16,053
Speaker (automobile), digital camera, DVD	90,400,559	132,750
PC, printer, monitor and others	22,868,114	140,290
Bulbs, electric lighting equipment	795,062,951	110,055
Camera	91,057	37
Clock	82,431,127	12,384
Desktop game machine, portable game machine	13,223,334	12,916
Electric calculator, digital dictionary	10,273,500	1129
Electronic thermometer, sphygmomanometer etc.	22,229,256	20,576
Electronic keyboard, electric guitar, etc.	1,089,299	4459
The handheld game machine, and mobile toys	1,128,449	186
Electric drill and others	6,633,000	14,100
AC adapter, controller and others	2,109,710	427
Total	**1,156,751,096**	**650,539**

Source: compiled by the authors using information for public use from the Japanese Ministry of Environment (2012)

[a]Breakdown of various metals collected out of the total recycled metals in tons:

iron	26,326;	stainless steel and brass	148;
aluminum	2023;	gold, silver and palladium	2798;
copper	1469;	other metals	6573.

Although we don't have a detailed breakdown of the recycled metals for mobile phones, we have statistics for small electric appliances including mobile phones. We summarize these as follows for 2015 fiscal year (April 2015–March 2016) (Table 3.5).

Table 3.6 shows that the recycling and processing of Electronic-waste from small appliances, personal computers, and mobile phones give potentially significant amounts of valuable metals. This observation recently prompted the Tokyo Organising Committee of the 2020 Olympic and Paralympic Games to decide that Olympic medals for winners of the Tokyo games are to be made of metals distilled from mobile phones and called for the local governments and the local post offices in Japan to collect them for recycling.

Table 3.6 Metals included in the used small electric and electronic appliances

Metals (tons)	Total: small appliances	Mobile phones	PCs
Iron (Fe)	230,105	418	16,845
Aluminum (Al)	24,708	50	3914
Copper (Cu)	22,789	1001	2730
Lead (Pb)	740	19	220
Zinc (Zn)	649	44	70
Silver (Ag)	68.9	10.5	21.1
Gold (Au)	10.6	1.9	4.5
Antimony (Sb)	117.5	2.3	43.5
Tantalum (Ta)	33.8	3.2	14.9
Tungsten (W)	33.0	27.1	1.1
Neodymium (Nd)	26.4	18.9	–
Cobalt (Co)	7.5	2.2	–
Bismuth (Bi)	6.0	0.7	0.8
Palladium (Pd)	4.0	0.5	2.1

Source: Compiled by the authors using information for public use from the Japanese Ministry of Environment (2012)

3.3.1 Supply Chain Implications of Recycling End Products: Reductions of the Resources Used in Upstream Suppliers

We know that all electric and electronic appliances we consider here are manufactured products whose production processes consist of many stages of inputs from the upstream suppliers. Many of these upstream inputs are basic and precious metals which remain in the final products as the output from the relevant supply chains. For this reason, it is important to look at the behavior of not only the final product Electronic-waste but also many inputs of electronic nature (electronic commodities) that were used in the upstream production processes of the supply chains. For these reasons, we consider Electronic-wastes as consisting of toxic and nontoxic wastes generated throughout the upstream stages by suppliers of the supply chain.

For example, the first and third panels of Table 3.7, respectively, show the amounts of industrial wastes that are generated by one million yen worth of production of personal computers and one million yen worth of production of mobile phones. These wastes generated consist of 37 types of industrial wastes in all self- and other industry sectors that form the upstream stages of the supply chains. Table 3.3 shows the waste outputs for the top five industry sectors, as well as the total amounts of industrial wastes generated for each electronic product. The amounts that were landfilled of the final wastes generated after the recycling and process treatments are presented in Table 3.8. For example, the first panel of Table 3.8 shows that after recycling and processing of Electronic-wastes, one million yen worth of personal computer production generated 7.8 kg of residual to be landfilled.

Table 3.7 Industrial wastes, directly and indirectly, generated from the unit production of e-commodities

	I-O industry sector specific for the product	
	1 million yen worth of PC production	Induced wastes (kg)
Industrial wastes generated in	Electricity	23.1
	Other electronic components	22.9
	Pig iron	20.7
	Paper	10.1
	Printing, plate making, and bookbinding	8.3
	Total	156.2
	1 million yen worth of electronic computing equipment (accessory equipment) production	Induced wastes (kg)
Industrial wastes generated in	Electronic computing equipment (accessory equipment)	65.9
	Electricity	28.5
	Pig iron	26.4
	Other electronic components	21.6
	Crude steel (converters)	10.6
	Total	247.6
	1 million yen worth of cellular phones production	Induced wastes (kg)
Industrial wastes generated in	Pig iron	28.2
	Electricity	26.8
	Other electronic components	22.5
	Copper	17.0
	Plastic products	14.5
	Total	218.7
	1 million yen worth of electric measuring instruments production	Induced wastes (kg)
Industrial wastes generated in	Pig iron	35.9
	Other electronic components	25.4
	Electric measuring instruments	24.2
	Electricity	23.1
	Crude steel (converters)	14.8
	Total	201.5
	1 million yen worth of liquid crystal element production	Induced wastes (kg)
Industrial wastes generated in	Liquid crystal element	48.4
	Electricity	42.0
	Pig iron	16.2
	Other electronic components	10.2
	Printing, plate making, and bookbinding	8.8
	Total	216.2

Source: By authors' calculations. The methodology and the data used are presented in Hayami et al. (2015). Further details are also given in Asakura et al. (2001), Hayami and Nakamura (2007), Hayami et al. (2008), and Japanese Ministry of Internal Affairs and Communications (2017)

Table 3.8 Amounts landfilled: induced (directly and indirectly) wastes after treatments of recycled Electronic-wastes

	1 million yen worth of PC production	Induced wastes after treatment: landfilled (kg)
Industrial wastes generated in	Printing, plate making, and bookbinding	1.3
	Paper	0.9
	Other nonferrous metals	0.8
	Electricity	0.8
	Copper	0.5
	Total	7.8
	1 million yen worth of electronic computing equipment (accessory equipment) production	Induced wastes after treatment: landfilled (kg)
Industrial wastes generated in	Printing, plate making, and bookbinding	1.1
	Electronic computing equipment (accessory equipment)	1.0
	Electricity	0.9
	Other nonferrous metals	0.8
	Paper	0.7
	Total	9.3
	1 million yen worth of cellular phone production	Induced wastes after treatment: landfilled (kg)
Industrial wastes generated in	Copper	2.2
	Printing, plate making, and bookbinding	1.3
	Paper	1.0
	Lead and zinc (inc. regenerated lead)	0.9
	Plastic products	0.9
	Total	11.4
	1 million yen worth of electric measuring instrument production	Induced wastes after treatment: landfilled (kg)
Industrial wastes generated in	Other nonferrous metals	1.0
	Printing, plate making, and bookbinding	1.0
	Electricity	0.8
	Paper	0.7
	Copper	0.7
	Total	8.6
	1 million yen worth of liquid crystal element production	Induced wastes after treatment: landfilled (kg)
Industrial wastes generated in	Other nonferrous metals	1.4
	Electricity	1.4
	Printing, plate making, and bookbinding	1.4
	Liquid crystal element	0.8
	Paper	0.7
	Total	10.0

Source: By authors' calculations. The methodology and the data used are presented in Hayami et al. (2015). Further details are also given in Asakura et al. (2001), Hayami and Nakamura (2007), Hayami et al. (2008), and Japanese Ministry of Internal Affairs and Communications (2017)

3.3.2 Reductions in Emissions of Greenhouse Gases from Recycling Electronic-Waste

Greenhouse gases are typically measured in terms of carbon dioxide (often noted as "CO_2") equivalent in tons. Greenhouse gases are by-products of most production processes along the stages of supply chains where production inputs such as electricity and metals are used by the suppliers. So we can analyze possible reductions in the generation of greenhouse gases resulting from the recycling of Electronic-waste. Analysis of the implications of Electronic-waste recycling for reductions in greenhouse gas emissions along the supply chains can be done by employing the input-output method, using the input-output tables and some relevant data of the kinds we used in the previous Sect. 3.3.1. To save space we only present certain summary results illustrating how the recycling of Electronic-waste could potentially reduce emissions of greenhouse gases and hence contribute to the possible solution to the global warming problem.

We are particularly interested in measuring the impact of the following government policy-driven form of recycling of Electronic-waste on the reductions in the generation of greenhouse gas emissions (measured in carbon dioxide equivalent measured in tons) generated from the production processes. The particular government policy of our interest to analyze here is called the Eco Policy, which gives some (not insignificant) rewards to the users of older-generation home appliances if they recycle them and buy newer more energy-efficient appliances with equivalent functions. (See, e.g., Japanese Ministry of Environment (2011), Japan Environmental Management Association for Industry (2013, 2017), and Hotta et al. (2014), for details of this policy.)

Rewards are given in terms of some level of subsidy for the purchase of newer-generation appliances. Based on the actual implementation of this social experiment, many (but not all) consumers owning older energy-inefficient appliances had chosen to recycle their old appliances and buy newer appliances using the rewards. The Eco Policy was implemented for a limited period of May 2009–March 2011. The appliances covered in this program are air conditioners, refrigerators, and television sets. The analysis reported in the Japanese Ministry of Environment (2011) divides the periods of analysis into three time periods: May 2009–March 2010, April 2010–December 2010, and January 2011–March 2011. Given the initial consumers who own particular appliances, some fractions of them choose to replace their old products with new ones. They benefit from the Eco Policy and their information is shown under the "replacement purchase." Some consumers who did not own particular appliances may choose to buy new units. Their information is shown under "new unit purchase." In the last period, January 2011–March 2011, only "new unit purchase" occurs since replacements are no longer allowed under the Eco Policy. Using carbon dioxide emission rates and the power consumption rates estimated elsewhere for older and newer appliances, the difference in the amount of greenhouse gas emissions that were saved by consumers' purchases of newer appliances is calculated and shown in Table 3.9. The total reductions in carbon dioxide

Table 3.9 Reductions in greenhouse gas emissions (CO_2 equivalent): Japan's Eco Policy experiments (2009–2011)

	Number of units	Replacements purchased (%) (rate of recycling)	Replacements purchased (number)	Year purchased of old unit	Electric power consumed old units/year (KWH/year)	Electric power consumed new units/year (KWH/year)	Reductions (%) in electric power used	Estimated total CO_2 emissions (tons/KWH)	Reductions in CO_2 emissions (tons/year)	Total reduction in CO_2 emissions (tons)
May 2009–March 2010 (replacement purchase)										
Air conditioner	2,668,000	47.6%	1,269,968	95	1396	1138	258 (18%)	0.000561	183,813	May 2009–March 2010: 948045 tons
Refrigerator	2,838,000	70.6	2,003,628	95	822	343	479 (58)	0.000561	538,413	
Television set	14,347,000	65.5	9,397,285	98	151	122	29 (19)	0.000561	152,884	
TOTAL	19,853,000		12,670,881						875,110	
May 2009–March 2010 (new unit purchase)										
Air conditioner	2,668,000	52,4%	1,398,032		1193	1138	55 (5%)	0.000561	43,136	
Refrigerator	2,838,000	29.4	834,372		377	343	34 (9)	0.000561	15,915	
Television set	14,347,000	34.5	4,949,715		127	122	5 (4)	0.000561	13,884	
TOTAL	19,853,000		7,182,119						72,935	
April 2010–December 2010 (replacement purchase)										

Air conditioner	6,507,000	44.8%	2,915,136	96	1373	1046	328 (24%)	0.000561	536,408	April 2010–December 2010: 1587688 tons
Refrigerator	3,529,000	73.1	2,579,699	96	783	318	465 (59)	0.000561	672,953	
Television set	20,185,000	68.3	13,786,355	99	143	96	47 (33)	0.000561	363,505	
TOTAL	30,221,000		19,281,190						1,572,866	
April 2010–December 2010 (new unit purchase)										
Air conditioner	6,507,000	55.2%	3,591,864		1048	1045	3 (05)	0.000561	6045	
Refrigerator	3,529,000	26.9	949,301		321	318	3 (1)	0.000561	1598	
Television set	20,185,000	31.7	6,398,645		98	96	2 (2)	0.000561	7179	
TOTAL	30,221,000		10,939,810						14,822	
January 2011–March 2011 (new unit purchase only)										
Air conditioner	233,000	45.6%	106,248	96	1373	973	400 (29%)	0.000561	23,842	January 2011–March 2011: 1782041 tons
Refrigerator	272,000	72.0	195,840	96	783	270	513 (66)	0.000561	56,361	
Television set	5,054,000	67.1	3,391,234	99	143	83	60 (42)	0.000561	114,149	
TOTAL	5,559,000		1,693,322						194,352	
May 2009–March 2011 total reductions in CO_2 emissions due to the Eco Policy: 4317774 tons										

Source: Compiled by the authors using information for public use from the Japanese Ministry of Environment (2011) and JLCA (2013) equivalent emissions for the three time periods are estimated to be 4,317,774 tons. These reductions are deemed to be the effects of the Eco Policy for the three appliances.

3.3.3 Issues of Who Bears the Burden of the Costs of Electronic-Waste Recycling

We have pointed out above that the recycling rates for waste electrical and electronic equipment are generally low (mostly under 30% of recycling ready Electronic-waste in Japan; see Table 3.2). We have also pointed out that the costs associated with recycling Electronic-waste, including the recycling fees as well as the costs of transportation and waste material removal, which are to a large extent borne by the consumer, are relatively high in general. Japanese policy discussions on Electronic-waste recycling have also raised the issues related to the lack of transparency in the determination of the Electronic-waste recycling cost (Recycling Working Group 2007).

Electronic-Waste and European Union
Unlike the four categories of Electronic-waste considered by Japanese laws (i.e., air conditioners, television sets, electric refrigerators and freezers, and electric washing machines and clothes dryers), European Union's Waste Electrical and Electronic Equipment Directive specifies the following ten Electronic-waste categories: (1) large household appliances; (2) small household appliances; (3) information technology equipment; (4) consumer equipment (television sets, etc.); (5) lighting appliances; (6) power tools; (7) toys, leisure, and sports equipment; (8) medical equipment; (9) monitoring and control instruments; and (10) vending machines and automatic teller machines.

Another area of European Union's Electronic-waste management that differs from Japanese practices is in the areas of allocation of the responsibility for collection and the allocation of costs. For example, producers are responsible for their own new products, but that all producers shall cover costs jointly when products that are already on the market are discarded by consumers. Until 2011 (2013 for large white goods), however, producers will be permitted to add waste processing costs to the prices of new products separately (visible fee).

In general, the European Union regulations differ from Japan's in a number of ways. The European Union laws cover a broad range of products, assign responsibility and costs to producers, establish collection targets and recycling rates, and limit the use of hazardous substances (Yoshida and Yoshida 2010). As OKOPOL (2007) notes, European Union's policy aim is to build a system that, by these means, recovers waste electrical and electronic equipment separately rather than disposing of it as municipal solid waste. We note that the municipality is an important stakeholder in the European Union's waste electrical and electronic equipment recycling system.

In terms of performance, the European Union's overall collection rate, however, is not so high compared to Japan's. Based on Table 3.10, Yoshida and Yoshida (2010) observe that although, in 2005, with a per capita recovery amount of 5.13 kg (Japan's per capita collection amount for the four types is 3.5 kg), the European Union had more than attained its 4-kg target; nevertheless, between individual countries, considerable differences remain: Sweden had collected 12.20 kg and the United Kingdom 9.9 kg, whereas the Czech Republic in Eastern Europe had recovered only 0.33 kg (Table 3.1). A look at the collection rates for each of the ten categories shows that, among the ten product categories, refrigerators and air conditioners account for 27% of the possible total, with 40% for large household appliances, 28% for information technology equipment, 30% for cathode-ray tube CRT TVs, and 65% for monitoring and control instruments (United Nations University and AEA Technology 2007, Table 56). According to the recent Waste Electrical and Electronic Equipment Forum data for 2007, the per capita recovery amount is nearly 7.80 kg, and 11 countries have collectively managed to collect over 4.0 kg.

According to estimation by Makela (2009), of the amounts of waste electrical and electronic equipment the European Union had collected for treatment, only 33% of them were treated and 13% were landfilled properly within EU; while 54%

Table 3.10 Collection performance in the European Union countries and Japan by category, 2005

Category number totals											
Country	1	2	3	4	5	6	7	8	9	10	1–10
Japan	2.58	n.d.	n.d.	0.82	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	NA
Norway	8.15	0.46	2.68	2.01	–	–	0.04	0.06	–	0.01	13.41
Switzerland	4.19	1.40	3.52	2.17	0.12	0.04	0.01	0.00	0.00	0.00	11.44
Austria	2.00	0.3	0.1	0.2	0.1	Inc 2	Inc 2	Inc 2	Inc 2	Inc 2	2.77
Belgium	2.99	1.12	1.16	1.64	0.20	0.14	0.00	0.02	0.00	0.00	7.26
Czech Republic	0.14	0.00	0.12	0.05	0.00	0.00	0.00	0.01	0.00	0.01	0.33
Estonia	0.48	0.00	0.04	0.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.63
Finland	4.75	0.28	1.44	1.30	0.27	0.03	0.00	0.02	0.01	0.00	8.10
Hungary	0.91	0.04	0.09	0.22	0.01	0.00	0.00	0.00	0.00	0.00	1.27
Ireland	6.68	0.28	0.43	0.67	0.09	0.07	n.d.	n.d.	0.00	n.d.	8.22
Netherlands	2.59	0.53	n.d.	1.18	0.03	0.06	0.03	0.00	0.00	0.02	4.44
Slovakia	0.35	0.04	0.05	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.66
Sweden	5.01	1.41	2.54	2.36	0.74	0.11	0.02	0.02	n.d.	n.d.	12.20
UK	7.17	0.54	0.59	1.10	0.04	0.35	0.16	0.00	0.00	0.00	9.95
I=NO=CH average	4.97	0.93	3.10	1.67	0.06	0.02	0.02	0.03	0.00	0.01	10.80
Euro average	3.11	0.42	0.65	0.88	0.14	0.08	0.02	0.01	0.00	0.00	5.31

Figures here show the amounts of wastes collected per inhabitant (kg) by country and category. See the source for details on the used categories (1–10). Categories 1–10 represent the total aggregates
Notes: *n.d.* no data, *Inc 2* included in category 2 figure, *NA* figure not available
Source: United Nations University and AEA Technology (2007), Table 43, page 74: Collection performance (kg per inhabitant) by Category

of them were submitted to substandard treatment both inside and outside the European Union.

3.4 Concluding Remarks

In this chapter, we have considered a variety of factors, including legal, statistical, economic, and organizational factors, that affect the recycling of waste electrical and electronic equipment or more broadly the recycling of general Electronic-wastes in Japan and other countries.

Despite significant efforts on the part of governments at all levels as well as other stakeholders, collecting, recycling, and processing of Electronic-waste remain to be a difficult task. Generally, there is a consensus that Electronic-waste continues to increase as per capita gross domestic product increases. Such increases are significant not only in developed nations but also in developing nations as well. This necessarily implies that shipping out Electronic-waste out of developed countries to developing countries is no longer a viable means of Electronic-waste disposal.

These substances that make up the Electronic-waste contain valuable resources, some of which are toxic and cannot be simply put away for landfills. We summarize our findings on the aspects of production and waste management systems, broadly termed environmental management systems, that need to be redesigned in an integrated manner.

1. Design products so as to minimize Electronic-waste while their functions remain intact. Also, design products so that the ultimate recycling of the products could be done with ease.
2. Design recycling-related facilities that can efficiently recycle process valuable metal and other resources.
3. Design a system that allocates the responsibilities among the stakeholders of Electronic-waste recycling policies based on their respective incentives.
4. Estimating accurately the relevant costs and benefits of alternative methods of collecting, recycling, and processing of Electronic-waste is important. Then, how such costs and benefits are to be allocated among the stakeholders consistent with their respective economic incentives is also important.
5. Manufacturing supply chains must be taken into account when Electronic-waste recycling and processing policies are formulated. It is important to clarify which upstream suppliers are responsible for particular components of Electronic-waste.
6. Another important policy issue is to decide what the primary objectives of Electronic-waste recycling are for the nation. Is it to reduce the greenhouse gas emissions that are emitted in the production process by minimizing the use of Electronic-waste causing metals and other materials? Or is it simply to reduce the amounts that go to landfills?

Environmental management of Electronic-waste requires consideration of many of these and other issues by the government policymakers as well as other stakeholders, including consumers, producers, and other private sector and public sector parties.

References

Asakura K, Hayami H, Mizoshita M, Nakano S, Nakamura M, Shinozaki M, Washizu A, Yoshioka K (2001) The input-output table for environmental analysis (Kankyo Bunsekiyo Sangyo Renkanhyo in Japanese). Keio University Press, Tokyo

Baldé CP, Wang F, Kuehr R, Huisman J (2015) The global electronic waste monitor 2014: quantities, flows and resources. United Nations University, Bonn

Enechange (2016) Recycling costs of home appliances (in Japanese). Tokyo. https://enechange.jp/articles/kaden-rycycle-cost-list. Accessed 16 June 2018

EU Eurostat (2017) Waste statistics-electrical and electronic equipment. November 2017. http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics_-_electrical_and_electronic_equipment. Accessed 16 June 2018

Hayami H, Nakamura M (2007) Greenhouse gas emissions in Canada and Japan: sector-specific estimates and managerial and economic implications. J Environ Manag 85(2):371–392

Hayami H, Nakano S, Nakamura M, Suzuki M (2008) The input-output table for environmental analysis and applications (Kankyo Bunsekiyo Sangyo Renkanhyo to sono Oyo, in Japanese). Keio University Press, Tokyo

Hayami H, Nakamura M, Nakamura A (2015) Economic performance and supply chains: the impact of upstream firms' waste output on downstream firms' performance in Japan. Int J Prod Econ 160:47–65

Hotta Y, Santo A, Tasaki T (2014) EPR-based electronic home appliance recycling system under home appliance recycling act of Japan. Tokyo. https://www.oecd.org/environment/waste/EPR_Japan_HomeAppliance.pdf. Accessed 16 June 2018

Japan Electronics and Information Technology Industries Association (JEITA) (2017) Shipment of cellular phones. Tokyo. https://www.jeita.or.jp/japanese/stat/cellular/2017/index.htm. Accessed 16 June 2018

Japan Environmental Management Association for Industry (JEMAI) (2013, 2017) Recycle data book. Tokyo. http://www.cjc.or.jp/data/databook.html. Accessed 16 June 2018

Japan Times (2015, May 9) Electronic waste recycling still falling short. Tokyo

Japanese Ministry of Economy, Trade and Industry (METI) (2017) FY 2016 enforcement status of the home appliances recycling law and recycling statistics for manufacturers and importers. Tokyo

Japanese Ministry of Environment (2001) Laws: waste and recycling. Available from: http://www.env.go.jp/en/laws/recycle/06.pdf. Accessed 17 Mar 2019

Japanese Ministry of Environment (2011). Eco policy and effects, (in Japanese). Available from: http://www.env.go.jp/policy/ep_kaden/pdf/effect.pdf

Japanese Ministry of Environment (2012) Central environment committee 31 January 2012. Available from: http://www.env.go.jp/press/files/jp/19123.pdf. Accessed 17 Mar 2019.

Japanese Ministry of Internal Affairs and Communications (2017) Input-output table for Japan. Tokyo. http://www.soumu.go.jp/english/dgpp_ss/data/io/index.htm. Accessed 15 Feb 2018

Japanese Ministry of Justice (2017) Tokyo. http://www.japaneselawtranslation.go.jp/?re=02. Accessed 15 Feb 2018

Kusch S, Hills CD (2017) The link between electronic waste and gross domestic product: new insights from data from the Pan-European region. Resources 6(2):15

LCA Society of Japan (JLCA) (2013) LCA database. Life Cycle Assessment Society of Japan. http://lca-forum.org/database. Accessed 16 June 2018

Makela T (2009) The waste electrical and electronic equipment directive-business generation. In: Proceedings of IERC 2009, Salzburg, pp 183–190

Mobile Recycle Network (MRN), and also Japan Environmental Management Association for Industry (JEMAI) (2018). http://www.mobile-recycle.net. Accessed 18 June 2018

OKOPOL (Okopol GmbH Institute for Environmental Strategies), IIIEE (The International Institute for Industrial Environmental Economics, Lund University), and RPA (Risk & Policy Analysts) (2007) The producer responsibility principle of the waste electrical and electronic equipment directive, final report. Hamburg

PC3R Promotion Association, Tokyo (2017). http://www.pc3r.jp. Accessed 18 June 2018

Recycling Working Group, Industrial Structure Council Environment Subcommittee, Japanese Ministry of Economy, Trade and Industry (2007) Lowering and making transparent of the recycling prices and recycling costs (in Japanese). Tokyo. http://www.meti.go.jp/committee/gizi_1/14.html#meti0003770. Accessed 18 June 2018

United Nations University and AEA Technology (2007) 2008 Review of Directive 2002/96 on Waste electrical and electronic equipment (WEEE), final report, 05 August 2007, United Nations University, Bonn

Yoshida F, Yoshida H (2010) Japan, the European Union, and waste electronic and electrical equipment recycling: key lessons learned. Environ Eng Sci 27(1):21–28

Index

A. Khan et al. (eds.), *E-waste Recycling and Management*,
Environmental Chemistry for a Sustainable World 33,
https://doi.org/10.1007/978-3-030-14184-4