ENVIRONMENTAL IMPACT AND MANAGEMENT STRATEGIES OF END-OF-LIFE TELEVISION WASTE IN THAILAND

Miss Jakwida Choowongsirikul

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
(Interdisciplinary Program)
Graduate School
Chulalongkorn University
Academic Year 2013

การศึกษาผลกระทบสิ่งแวดล้อมและแผนยุทธศาสตร์การจัดการซากโทรทัศน์เมื่อสิ้นสุดอายุการใช้งานในประเทศไทย

นางสาวจักษ์วิดา ชูวงศ์ศิริกุล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

Thesis Title	ENVIRONMENTAL IMPACT AND MANAGEMENT STRATEGIES OF END-OF-LIFE TELEVISION WASTE IN THAILAND
By	Miss Jakwida Choowongsirikul
Field of Study	Environmental Management
Thesis Advisor	Assistant Professor Chanathip Pharino, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Graduate School

(Associate Professor Amorn Petsom, Ph.D.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Chantra Tongcumpou, Ph.D.)

....Thesis Advisor

(Assistant Professor Chanathip Pharino, Ph.D.)

....Examiner

(Assistant Professor Tawan Limpiyakorn, Ph.D.)

....Examiner

(Assistant Professor Pichaya Rachdawong, Ph.D.)

....External Examiner

(Punjaporn Weschayanwiwat, Ph.D.)

จักษ์วิดา ชูวงศ์ศิริกุล : การศึกษาผลกระทบสิ่งแวดล้อมและแผนยุทธศาสตร์การจัดการซากโทรทัศน์เมื่อสิ้นสุดอายุการใช้งานในประเทศไทย. (ENVIRONMENTAL IMPACT AND MANAGEMENT STRATEGIES OF END-OF-LIFE TELEVISION WASTE IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.ชนาธิป ผาริโน, 213 หน้า.

ประเทศไทยมีการเปลี่ยนแปลงระบบการรับส่งสัญญาณโทรทัศน์ จากระบบอนาล็อกทีวีเป็นดิจิตอลทีวีเริ่มต้นตั้งแต่ปี 2557 ส่งผลให้ปริมาณขยะโทรทัศน์ที่สิ้นสุดอายุการใช้งานมีแนวโน้มเพิ่มขึ้น และส่งผลกระทบต่อสิ่งแวดล้อมได้ในอนาคต เนื่องจากมีสารอันตรายที่อยู่ภายอุปกรณ์ดังกล่าวหากไม่ได้รับการจัดการที่เหมาะสมจะปนเปื้อนต่อสิ่งแวดล้อมและส่งผลกระทบต่อสุขภาพอนามัยได้ งานวิจัยนี้มีเป้าหมายในการศึกษาผลกระทบทางสิ่งแวดล้อมที่เกิดจากการฝังกลบเปรียบเทียบกับการรีไซเคิลของอุปกรณ์โทรทัศน์สามชนิด ได้แก่ CRT LCD และ LED ที่สิ้นสุดอายุการใช้งานโดยการประเมินวัฏจักรชีวิต (life cycle assessment) และวิเคราะห์ผลด้วยโปรแกรม SimaPro 7.3.3 ร่วมกับการประมวลผลด้วยวิธี ReCiPe 2008 งานวิจัยนี้ได้จำลองสถานการณ์ต่างๆ ในอนาคตรวมถึงคาดการณ์ผลกระทบที่เกิดจากการจัดการขยะโทรทัศน์ในช่วงปี พ.ศ. 2557-2566 (10 ปี) โดยคาดการณ์ผลกระทบจากสถานการณ์การจัดการที่แตกต่างกัน ประกอบด้วย (1) ฝังกลบทั้งหมด (2) รีไซเคิล 5% และฝังกลบ 95% (3) รีไซเคิล 20%และฝังกลบ 80% และในการวิจัยได้จัดทำแบบสอบถามความคิดเห็นของประชาชน สำหรับการวางแผนการจัดการที่เหมาะสมกับประเทศไทย

ผลจากการศึกษาโดยรวมพบว่า โทรทัศน์แต่ละชนิด มีองค์ประกอบของสารอันตรายและวัสดุที่สามารถรีไซเคิลในปริมาณที่แตกต่างกัน จึงส่งผลกระทบต่อสิ่งแวดล้อมและการจัดการขยะโทรทัศน์ที่แตกต่างกันออกไป ผลการประเมินผลกระทบต่อ ระบบนิเวศ และ ทรัพยากร พบว่าการฝังกลบ จอโทรทัศน์ชนิดCRT ส่งผลกระทบมากที่สุด ผลกระทบลำดับรองลงมาคือจอโทรทัศน์ชนิด LCD และ LED ตามลำดับ และผลการประเมินผลกระทบต่อ สุขภาพ พบว่าการฝังกลบ จอโทรทัศน์ชนิด LCD ส่งผลกระทบมากที่สุด ผลกระทบลำดับรองลงมาคือจอโทรทัศน์ชนิด CRT และ LED ตามลำดับ ส่วนเทคโนโลยีการรีไซเคิลพบว่าสามารถทำให้ผลกระทบทางสิ่งแวดล้อมลดลงเนื่องจาก การรีไซเคิลได้ชดเชยผลกระทบที่เกิดจากกระบวนการผลิตในขั้นต้น การรีไซเคิลโทรทัศน์ชนิด CRT ส่งผลดีกับสิ่งแวดล้อมมากที่สุดเทียบกับ จอโทรทัศน์ชนิด LCD และ LED ผลการวิเคราะห์สถานการณ์จำลองของการจัดการขยะโทรทัศน์ พบว่าในทุกอุปกรณ์หากมีการนำมารีไซเคิลเป็นสัดส่วนที่เพิ่มขึ้น จะสามารถส่งผลดีด้านบวกต่อสิ่งแวดล้อมที่มากขึ้นตามลำดับ เทียบกับสถานการณฝังกลบพบว่าส่งผลกระทบด้านลบต่อสิ่งแวดล้อม ดังนั้นงานวิจัยได้มีข้อเสนอแนะในการจัดการอุปกรณ์โทรทัศน์ที่สิ้นสุดอายุการใช้อย่างเหมาะสม 3 ยุทธศาสตร์ ประกอบด้วย (1) การลดปริมาณผลกระทบของขยะโทรทัศน์ทั้งสามชนิดที่มีต่อสิ่งแวดล้อม โดยนำผลกระทบที่คำนวณได้จริงจากการศึกษามาประกอบการพิจารณา(2) การเพิ่มความตระหนักต่อ สถานการณ์และการมีส่วนร่วมรับผิดชอบในการจัดการขยะโทรทัศน์อย่างถูกต้อง (3) การเพิ่มประสิทธิภาพในการจัดเก็บ การจัดตั้งระบบการรีไซเคิลโทรทัศน์ที่เหมาะสม (4) การเพิ่มแรงจูงใจในการเก็บรวบรวมขยะซากโทรทัศน์ให้ได้มากที่สุด โดยต้องอาศัยความร่วมมือจากผู้เกี่ยวข้องทุกภาคส่วนเพื่อช่วยเพิ่มปริมาณการนำขยะโทรทัศน์เข้าสู่กระบวนการรีไซเคิล และจัดการสำเร็จอย่างถูกต้องเหมาะสม

สาขาวิชา การจัดการสิ่งแวดล้อม	ลายมือชื่อนิสิต ....
ปีการศึกษา 2556	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

5587515120 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: TELEVISION WASTES / LIFE IMPACT ASSESSMENT / END OF LIFE MANGEMENT / LANDFILLING / CRT/LCD/LED TELELVISION / RECYCLING / E-WASTE

JAKWIDA CHOOWONGSIRIKUL: ENVIRONMENTAL IMPACT AND MANAGEMENT STRATEGIES OF END-OF-LIFE TELEVISION WASTE IN THAILAND. ADVISOR: ASST. PROF. CHANATHIP PHARINO, Ph.D., 213 pp.

In Thailand, television transmission technology was switched from analog to digital system since 2014. These resulted in increasing number of unused televisions and becoming massive television waste problems and intensify environmental impact in the near future. The concerning issues began from hazardous materials contained in large amount of television wastes. If lack of proper management, these are possibilities to contaminate in environment and impact the human health. Therefore, this study aims to evaluate environmental impacts between landfilling and recycling approach from CRT, LCD and LED television at end of life stage by applying life cycle analysis (LCA). The analysis used the SimaPro7.3.3 program under the ReCiPe 2008 assessment method. Furthermore, this research simulate situations in the future and evaluated the potential future impact during 2014-2023 (10 years) from different scenarios management scheme including: (1) 100% landfilling , (2) 5% recycling and 95% landfilling, (3) 20% recycling and 80% landfilling. This study also conducted public surveys to investigate appropriate management planning in Thailand

The results found that each type of television has different amounts of toxic substances and recyclable materials. So, effect to environmental and television waste management depends on each type of model. For the endpoint impact assessment, CRT landfilling could contribute the highest negative burdens to the ecosystem and resource depletion impact following by LCD and LED television screen, respectively. For LCD landfilling could contribute the highest negative burdens to the human health impact following by CRT and LED respectively. Recycling approach can reduce the environmental burden due to the avoided of primary material production stages. Particularly, recycling CRT contributes the most environmental advantage from this scheme more than recycling LCD and LED television screen. The scenario analysis results found that the higher percentage of recycling of TV wastes will correspond with the better environment quality compared to landfilling which yields negative environmental impact. This study developed 3 recommended strategies of television management improvement in Thailand including: (1) Recommendation from life cycle impact assessment to reduce overall impact from television equipment (2) Raise public awareness and increase participation in television waste management, (3) Increase effective management and collection of used electronics and establish the recycling TV system in Thailand, (4) Increase incentives for promoting electronic waste collection for recycling system. All strategies need corporation among all stakeholders to implement waste management plan successfully.

Field of Study: Environmental Management Student's Signature ....

Academic Year: 2013 Advisor's Signature ....

ACKNOWLEDGEMENTS

I would like to express my very great appreciation to my thesis advisor, Assistant Professor Chanathip Pharino for valuable suggestions during the development of this thesis. Besides, I would like to express my deep gratitude to all members of thesis committee Assistant Professor Dr. Chantra Tongcumpou (Chairman), Assistant Professor Tawan Limpiyakorn, Ph.D (Examiner), Assistant Professor Pichaya Rachdawong, Ph.D (Examiner) and Dr. Punjaporn Weschayanwiwat (External Examiner) for their professional suggestions.

In addition, I would like to thank the Center of Excellence of International Postgraduate Program in Environmental Hazardous Substance Management(HSM) Graduate School, Chulalongkorn University, for the scholarships and financial support. Not at all, I wish to thank all 518 respondents from online (122 persons) and paper surveying (396 persons) for their contribution to this project.

My grateful thanks are also extended to Mr. Tatthap Veeratat for helpful in my study and information supports. Moreover, my special thanks to Mr. Natdanai Titayanapong for encouragement and support everything. Finally, I wish to thank my parents for their support and helpful throughout my study.

CONTENTS

Page

Page

Page

Page

List of Figure

Page

Page

Page

List of Table

Page

Page

Page

CHAPTER I

INTRODUCTION

1.1 Background

In Thailand, the numbers of household that have televisions increase by 97% at inside municipality and 96% at outside municipality (Statisticaloffice, 2010) and rapid changes in television technology today. It can shorten average lifespan of a television for instance lifespan. Thailand is the member of International Telecommunication Union (ITU). The ITU suggest that the member countries should change the system from analog TV to digital TV within 2016. Consequently, it is expected that the obsolete television will create massive e-waste problems and intensify environmental impacts in the near future (Nectec, 2009) as estimated the number of total obsolete television might be existed 20 million units after change from analog system to digitals system in 2020 (PCD, 2008) In facts, the environmental and health impact from disposed television depends on the management practices. Thailand still is also a lack good waste management. The concerning issues began from hazardous materials contained in large amount of television wastes. There are possibilities to contaminate in environment and impact the human health.

.

Landfilling is the one approach to manipulate the waste residues under the suitable processes. Secure landfill is a location designed for the systematic long-term storage of waste under conditions that will prevent the contamination of air and water. A landfill may be designed for the storage of inert waste, sanitary waste or hazardous industrial waste. For instance, the television component contained various of chemical element including 5.26-6.61% Lead Oxide, 57% glasses, 0.02-0.03% Cadmium metal, 0.13-0.17% Antimony Trioxide, 1.68-2.09% Tetrabrombisphenol A from printed circuit board, 2.09-2.22% Tetrabrombisphenol A from plastics, 1.59-5.94% electric wire, 6.06-10% metal, 2.33-3% Copper and 5% others (Technologycenter, 2004) Therefore, these pollutants might be released to the environment during end of life treatment at landfill stage. However, recycling of discarded television is can help to minimize potential toxic leachate from improper landfill and recovering the valuable iron and copper metals, glasses and other materials from disposal components. There are also high potential benefits from recycle television wastes if some metals and materials can be recovered and reused.

Unfortunately, Thailand still lack of technology and system for appropriately managing e-waste. About 90% of e-waste is disposed together with municipal solid waste. This causes health effect to waste handling workers including effect to environmental because of mismanagement such as landfill area that not design for storage e-waste and some e-waste will be smuggled in the public area. Moreover, the conflicts of interest between informal sector and formal sector about collection area because there is no clear strategy from government or relate organization and illegal import and export of WEEE are also leads to adversely effect to the environment and public health.

In attempt to find the best practice to investigate the possible environmental situation from this type of wastes, life cycle assessment concept is a standard method which proper to use an important in characterizing and evaluating of the environmental performance. Not at all, it also defines as the effective management supporting tool. (Rolf Widmera, 2005) The evidence from previous researches already provided the discussion about disposal of television equipment in many ways (Menad, 1999; Qingbin Songa, 2012; Qingbo Xu, 2012) There revealed that the disposal of television waste can distribute the wide impact category but not shown the proportions of components in television that effect to enviromental impact and in this study will gather all result with current situation in Thailand.

Television waste could be a problem in Thailand if the less of understanding and studying in-depth regarding the environmental impact are still persisted. Therefore, this research aims to evaluate impacts of television at the end of life stage by comparing two approaches though life cycle analysis (LCA). The result from this process will as recommendation to provide more efficiency in management of accumulated television waste in Thailand in the future.

1.2 Research Objectives

1. To evaluate environmental impacts of selected television models using LCA approach focused on the End-of-Life management stages

2. To forecast future impacts from End-of-Life management of obsolete television in Thailand under different management scenarios

3. To develop pragmatic management strategies to increase efficiency of collecting and recycling of discarded television in Thailand

1.3 Research Questions

1. What is the most critical environmental impact from discarding end-of-life television?

2. What are levels of potential impacts that possibly occur in the future from discarding television if changing system from analog TV to digital TV?

3. What should be the pragmatic management strategies that could help increasing efficiency of collecting and recycling of discarded television in Thailand?

1.4 Expected Outcomes

1. Specifying the levels of life cycle environmental impacts per unit of End-Of-Life of the selected television models

2. Understanding the future impacts of television disposed under different management scenarios and approaches to better improved the situation of television waste management

1.5 Scope of the Study

The scope of this study is only aim to evaluate environmental burdens from discarded three types of television screen: 21-inche. CRT screen, 32-inche. LCD screen and 32-inche. LED screen in management approach including landfill, and recycling at end of life stage. The criteria for selected these models came from surveying in main electronic markets and focusing on sizes and types of television that were mostly disposed. The study evaluated environmental impacts between landfilling and recycling approach at end of life stage by applying life cycle analysis (LCA). The analysis used the SimaPro7.3.3 program under the ReCiPe 2008 assessment method and showed the impact results in endpoint impact and aggregated into single-score impact. Prior to suggestion of the proper waste management programs, scenario analysis was conducted at least for 10 year future projection together with the public survey.

CHAPTER II

LITERATURE REVIEWS

2.1 Situation television wastes in Thailand

The televisions early entered to household and business market in 1935 (Williams, 1994) Television business is different in each period of times and become the media that has high influences to audients with properties that have picture, sound, speed which realistically increase popularity of television. Currently, television markets have many models, high evolution. The main reason “Why people spend more time with television?” because it can decrease number of seeing movies at outside house and television can help people read fewer books and newspapers. (Swanson, 2013)

Television wastes are defined as the electronic waste. Electronic waste is “Electrical or electronic equipment which is waste including all components, sub-assemblies and consumables which are part of the equipment at the time of discarding.” (EUorganization, 2002). While the rapid output and increasing use of television have produced significant economic benefits and convenience to the national and community levels. It has also cause increasing impact on the local and global environment. Throughout its life cycle, the television generates many environmental impacts. The manufacturing phases require large amounts of natural resources and use amounts of electricity. In addition, the disposal of electronics (End of life) can impose severe impacts on human health and the eco-system. Especially, when they are not well managed as many television components contain hazardous materials (F.O. Ongondo, 2011)

The hazardous materials releasing from the elongation of discarded television device are major concerns when waste stream disposed into the open-dump disposal, landfilled, incinerator hazardous waste (TheBaselActionNetwork, 2002) As a result, these will have the possibility to contaminate the environment and adversely affect human health. So the organization from economic cooperation and development (OECD) countries was established Waste Electrical and Electronic Equipment (WEEE) regulation for generated and ways in which it can be prevented. WEEE can be regarded as a resource of valuable metals such as copper, aluminum and gold; when such resources are not recovered, raw materials have to be extracted and processed to make new equipment, resulting in significant loss of resources and environmental damage necessitated by mining, manufacturing, transport and energy use (F.O. Ongondo, 2011) Restriction of the use of certain Hazardous Substances (RoHS) directive is for responding to e-waste management in proper way and restricts amount of toxic substances in electronic appliances, respectively (Rolf Widmer, 2005)

For Thailand, television equipment began to increase from 2000 and faster grow in this recent year. The beginning of television in Thailand was for education, medical, public health. After that, television change from white-black color to colors and have competition to develop the quality system. Because of economic growth, there is high evolution of television media and higher investment (Srisarakarm, 2003) . Currently, television becomes part of daily life.

The competition between manufacture cause of decreasing price and increasing use including high evolution of technology that has multi-functional can response to all consumers. In contrast, a minimum consumers will aware of this developing about television waste management problem when they after use.

Amount of electrical and electronic equipment in Thailand comes from four sources: produce in country, import equipment, import second hand equipment and import waste equipment. These electrical and electronic equipment after usage may deteriorate but can send to maintenance shop and bring come back to use again. Some electrical and electronic equipment that cannot use, consumer will sell to informal retail store. Informal store collect and separate components of waste equipment. The valuable waste and waste that can recycle will send to recycle plant. Invaluable waste are placed in hazardous waste that must use specific management but sometimes it will be disposed with municipal waste and use not correct technic collecting by local government it cause of health problem and environmental effect. (PCD, 2012)

During 2000-2010, the numbers of household that have televisions are increase up to 97% inside municipality and 96% outside municipality as shown in Figure 1. And Table 1 shown situation and statistics about television usage in Thailand reported by the pollution control department

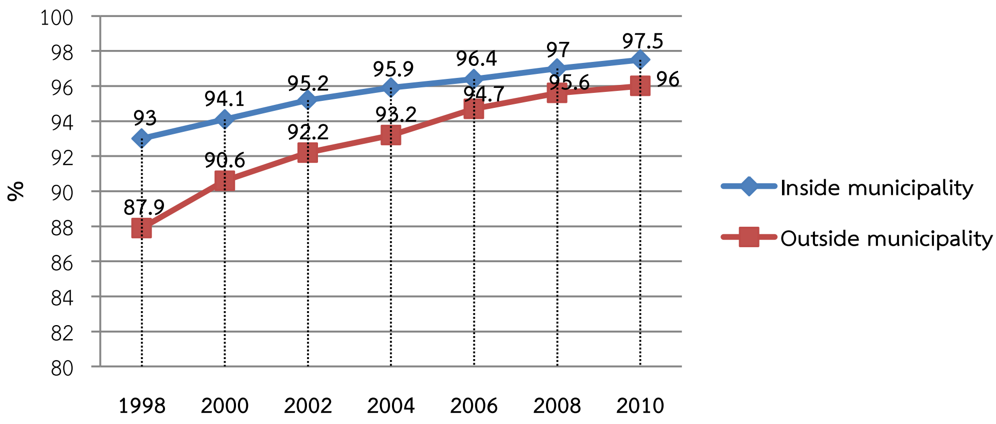


Figure 1 Percentage of household that has television in Thailand during 1998 to 2010 classify from Administrative District

(Adapt from Statistical Forecasting Bureau National Statistical Office, 2010)

Table 1Usage statistics of televisions (Adapt from PCD, 2012)

The usage statistics of televisions (ข้อมูลการถือครองและระยะเวลาการใช้งานเฉลี่ย)			
Product	**% Holder**	**Number/household**	**Average period of usage (year) / unit**
Television (CRT, LCD, Plasma)	95.79		
- CRT	85.52	2.55	6.9
- LCD, Plasma	29.7	0.39	3.8

While the amounts of television waste in the future are expected to increase. From the PCD report of measures to recall the e-waste found that the TV waste increases about 12 percent per year as shown in Figure 2.

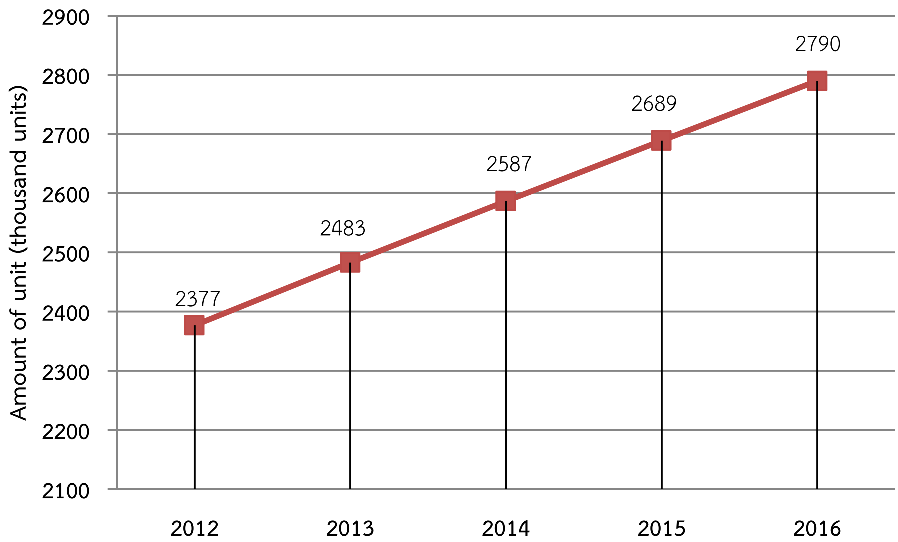


Figure 2 Prediction for the TV waste generation in Thailand in 2012-2016

(Adapt from PCD, 2012)

Due to the growth of electronic products consumption, this actually drives e-waste generation. Moreover, this trend still keep on going in Thailand especially in electrical and electronic waste equipment because growing of high technology evolution and marketing competition.

2.2 Main component and types of hazardous substance

In terms of materials and components makeup as well as the original equipment’s manufacturing processes. Characterization of this waste stream is very importance for environmentally friendly. Selective disassembly, targeting on singling out hazardous and/or valuable components, is an indispensable process in the practice of recycling of WEEE. Disassembly process planning and innovation of disassembly facilities are most active research areas. Mechanical/physical processing, based on the characterization of WEEE, provides an alternative means of recovering valuable materials. Mechanical processes, such as screening, shape separation, magnetic separation, Eddy current separation, electrostatic separation, and jigging have been widely utilized in recycling industry. However, recycling of WEEE is only beginning. It is very costly to perform manual dismantling of those products, due to the fact that television contains very low-grade precious metals. It is expected that a mechanical recycling process will be developed for the upgrading of low metal content scraps. (Jirang Cui, 2003) Due to their hazardous material contents, WEEE may cause environmental problems during the waste management phase if it is not properly pre-treated. Many countries have drafted legislation to improve the reuse, recycling and other forms of recovery of such wastes so as to reduce disposal.(EuropeanCommission, 2000; Siliconvalley, 2003)

Television waste is non-homogeneous and complex in terms of materials and components. In order to develop a cost-effective and environmentally friendly recycling system, it is important to identify and quantify valuable materials and hazardous substances, and further, to understand the physical characteristics of this waste stream.

2.2.1 CRT television screen

CRTs include three parts. As shown in Figure 3, these parts are the neck, the funel and the face plate. In black and white CRT face plates, a fluorescent material can be found as a layer containing a pigment that will glow when the electron beam hits it. However, a color CRT has a more complex design, containing three different fluorescent materials inside the face plate, for the blue, red and green colors. Three different glasses can be found in these CRT parts. Leaded glass is present in the neck (mainly SiO_2 and PbO); the face plate contains various other materials.

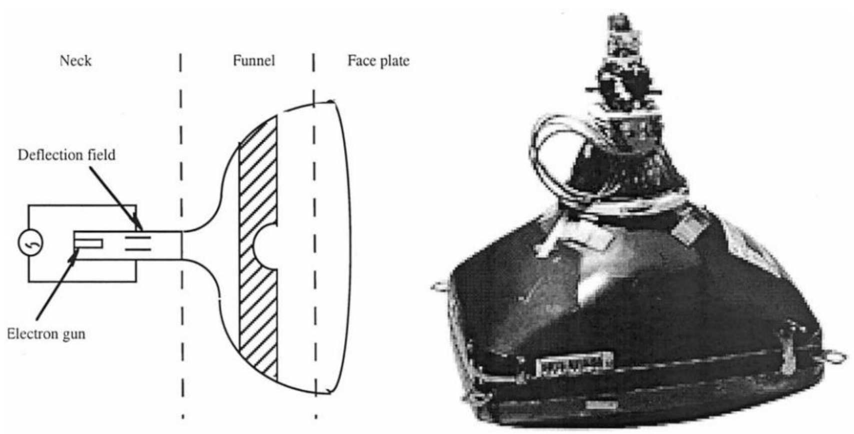


Figure 3 A schematic view of a black-and-white cathode ray tube (CRT) (Bran, 2013)

The CRT unit contains about 63.2% of screen glass, 24% of cone glass, 12% of ferrous metals, 0.4% of getter plus electron gun, 0.4% of ceramic seal and 0.04% of fluorescent powder. In each CRT television contains about 0.4 kg and 1 kg of lead and lead oxide respectively. It is used as radiation shielding (Garrity ER, 1994) and to stabilize the glass. Barium can be found also in the glass of CRT monitors.

Many other metals are present in the pigments used in the layer of fluorescent materials. The inner part of the face plate contains zinc sulphides, yttrium and europium or even cadmium sulphides (Hedemalm, 1994) As shown in Figure 4, the neck and the face plate contain SiO_2, Na_2O, K_2O and PbO as major compounds, and SrO, BaO, Al_2O_2 and CaO as minor ones. Other compounds such as CeO_2, Fe_2O_3, As_2O_3 and TiO_2 are present in trace amounts (Hedemalm P, 1995). As shown in Figure 5, the CRTs from used television sets incorporate screen, cone and electron gun parts. Lead is present on the inner side of the cone glass, where it is used as a protection barrier against X-rays. The fluorescent layer contains cadmium sulphide. Barium oxide is used in the screen glass. The screen and cone parts contain many compounds, such as PbO, BaO, SrO and others (Goforth DE, 1994).

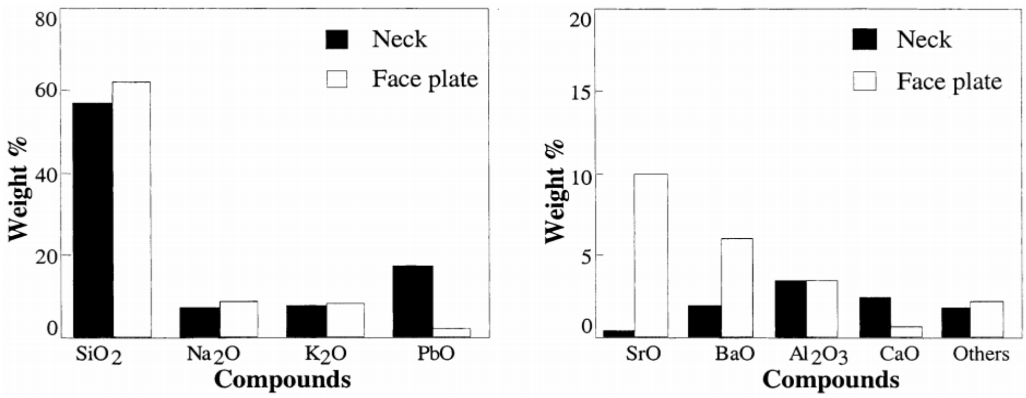


Figure 4 Major compounds contained in a CRT

(Goforth DE, 1994)

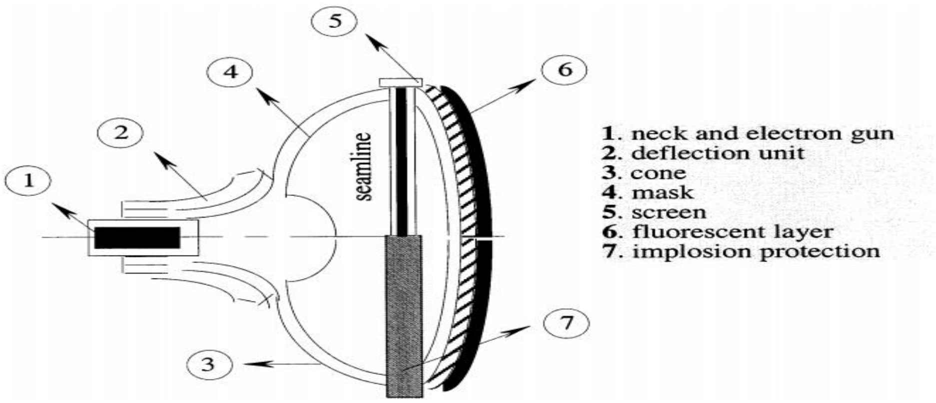


Figure 5 Structure of a color CRT

(Goforth DE, 1994)

2.2.2 LCD television screen

Liquid crystal displays (LCD) are widely used in television. LCD televisions are thinner and lighter than cathode ray tube (CRTs) of similar display size, and are available in much larger sizes. When manufacturing costs fell, this combination of features made LCDs practical for television receivers. In just a few years they replaced CRT televisions because of their crisp display, power-saving ability and overall performance

The display consists of two polarizing transparent panels and a liareuid crystal solution sandwiched in between as shown in Figure 6. The screen front layer of glass is etched on the inside surface I n a grid pattern to form a template for the layer of liquid crystals, Liquid crystals are rod-shaped molecules that bend light in response to an electric current. The crystals align so that light cannot pass through them. Each crystal acts like a shutter, either allowing light to pass through or blocking the light. The pattern of transparent and dark crystals forms the image. It is the same displays technology behind your digital watch but way more sophisticated. The multi-layered structure of an active-matrix LCD panel. Because they use red, green and blue color filters in place of phosphor dots, LCD panels are completely immune to image burn-in. LCD TVs use the most advanced type of LCD, known as an "active-matrix" LCD. This design is based on thin film transistors (TFT) basically, tiny switching transistors and capacitors that are arranged in a matrix on a glass substrate. Their job is to rapidly switch the LCD's pixels on and off. In a color TV's LCD, each color pixel is created by three sub-pixels with red, green and blue color filters.(LCDguild, 2014)

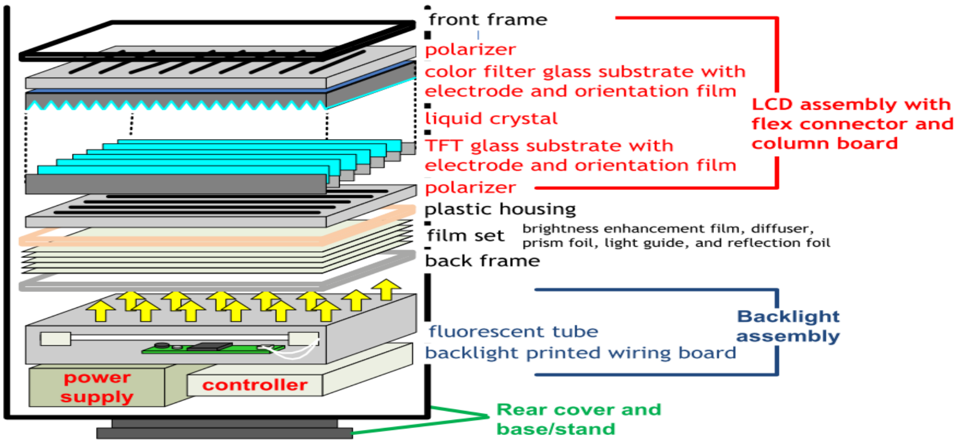


Figure 6 Structure of a color LCD

(LCDguild, 2014)

Focusing on the material component, it can be seen that LCD display consists of many type of materials. Table 2 showed major component in LCD display and types of hazardous substance. These came from the structural part and overall frame.

Table 2 Main component and types of hazardous substance in LCD television (PCD, 2008)

Main component	Types of hazardous substance
1. Monitor: plastic and flame retardant	1. Mercury
2. TCP drivers	2. Liquid crystal
3. Transmission equipment	3. Flame retardant
4. Source of light	4. Barium oxide5. Lead oxide
5. Diffuser: glass	6. Cadmium
6. Rear bezel: metal	
7. LCD panel: plastic and liquid crystal	
8. Inverter	

2.2.3 LED television screen

Many manufacturers use LED lighting for a variety of applications, but the most common LED device is still the television screen. LEDs were not widely used in television screens before 2007, when they fully replaced older light sources, such as fluorescent cathodes. There are several different types of LED technology available for displays. LED stands for light-emitting diode. A diode is a common electrical device found in many circuits, but when a diode is made using specific compounds; its atoms become energized by electrical current and release their energy as visible light. This light changes color depending on the elements of the diode that produces it. Many LEDs can be grouped together in a variety of patterns to form different types of light. LED are a newer version of the older LCD display. Instead of simply using LED borders, LED TVs use an entire panel of LEDs behind the LCD panel. This provides

more light more effectively and allows the TV to control brightness levels more accurately than older versions. These TVs are more expensive than other versions, but their display quality is higher and their predominant use of LEDs helps
them save energy for owners. (Lacoma, 2014)

The LED display similar with LCD as shown in Figure 7 is can be combined by several series of display elements (unit display board or unit display cabinet) constitute screen body, plus a set of appropriate controller (control board or control system). But different only one part is LED use light emitting diode lamp instead of cold-cathode fluorescent lamps (CCFLs) and neon lamps. So many kinds of specifications display board (or unit case) with different control technology of the controller can many LED display, in order to meet different environment, different display requirements need.

Figure 7 Structure of a color LED

(SEONG-RIN LIM, 2011)

Almost hazardous substance very similar LCD screen but LEDs are not hazardous except for low-intensity red LEDs, which leached Pb at levels exceeding regulatory limits (186 mg/L; regulatory limit: 5). However, according to California regulations, excessive levels of copper (up to 3892 mg/kg; limit: 2500), Pb (up to 8103mg/kg; limit: 1000), nickel (up to 4797mg/kg; limit: 2000), or silver (up to 721 mg/kg; limit: 500) (SEONG-RIN LIM, 2011)

2.2.4 Precious metal and valuable material in television

In print wiring board (PCB) scrap is characterized by significant heterogeneity and relatively high complexity, albeit with the levels of complexity being greater for populated scrap boards. The levels of inorganics in particular are diverse with relatively low levels of precious metals being present in conjunction with copper, solders, and various alloy compositions, non-ferrous and ferrous metals. Consequently, there are too many different in the intrinsic physical and chemical properties of the materials and components present in scrap PCBs, and indeed electronic scrap as a whole, to permit recycling approaches that separate them into their individual fractions. Characteristics such as material density, electrical conductivity, polyformity, liberation size, chemical reactivity, electropositivity and response to magnetic field ultimately determine the mechanical and hydrometallurgical separation routes used. Current and potential recycling techniques and infrastructures have usually been developed to exploit differences in these material properties. The range of densities for materials found in PCB scrap is shown in Table 3 (Kellner, 2003)

Table 3 Approximate content and value of metals found in medium grade PCB scrap (Kellner, 2003)

Component	Per cent by wt	Value per kg (£)	Intrinsic value (£/kg)	Intrinsic value (per cent)
Gold	0.025	6,500	1.63	59.4
Palladium	0.010	8,000	0.8	29.2
Silver	0.1	70	0.07	
Copper	16	0.8	0.13	
Tin	3	3	0.01	
Lead	2	0.3	–	
Nickel	1	5	0.05	
Aluminium	5	0.9	0.05	
Iron	5	0.1	–	
Zinc	1	0.8	–	
Total			£2.74	

2.3 End-of-life of television impact

In recent years, there has been a growing recognition of mankind's impact on the environment and the need to adopt a more sustainable approach to our consumption patterns has recently begun to assume an enhanced significance. This has been particularly true in the electronics industry where increasingly short product lifecycles and rapidly advancing technology have led to huge volumes of relatively new electronic goods being discarded. The majority of these goods find their way to landfill and this waste of potentially recyclable materials, coupled with their increasing consumption of scarce landfill capacity, has caused a major shift in thinking towards the possibility of recycling and reuse. This large volume of Waste from

Electrical and Electronic Equipment is known as WEEE and, although some of it is sent for recycling (Goosey, 2004)

Electronic equipment at their end-of-life are managed by one of two end-of-life management practices: they are either collected for recycling (they may then be subsequently reused, refurbished, or recycled for materials recovery), or disposed in landfills or waste-to-energy incinerators as shown in Figure 8.

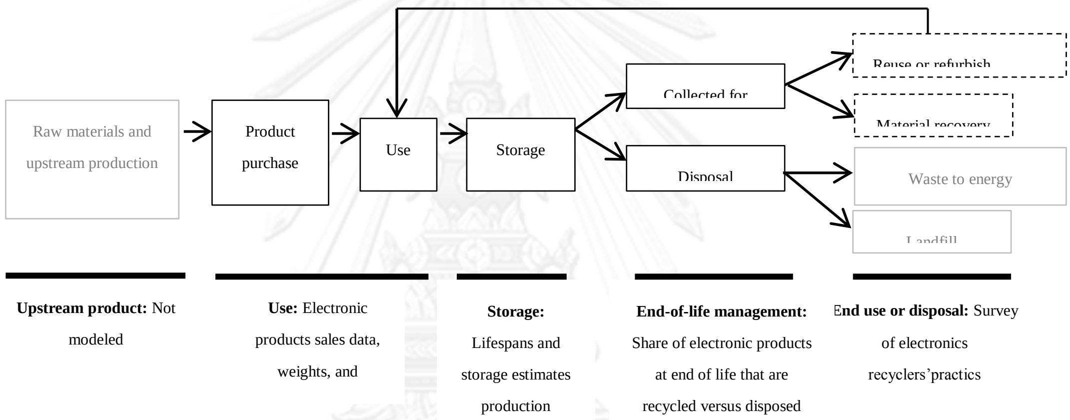


Figure 8 Life-Cycle Flow chart for electronic equipment

(EPA, 2009)

Solid boxes refer to life cycle stages that were modeled in this report; dashed boxes refer to stages where information was collected by recycler surveys. Gray boxes refer to stages that were not included. (EPA, 2009)

An earlier EPA study of electronics life cycles distinguished between two or more phases in the “use” stage of the life cycle, generally “first use” and “second use”. First use indicates use by the original purchaser of the equipment. When the first user after uses the electronic equipment they may sell or give the equipment to another person, which is termed second use. The current analysis makes no distinction between first users and subsequent users in the “use” stage. The EPA consider storage a separate stage because life time of electronic equipment is in use does not necessarily correlate with how long users store it when they have stopped using it. Therefore, since assumptions about storage behavior affect when electronics equipment is ready for end-of-life management, we have found it useful to think about “use” and “storage” separately, using the sum of both to define the total lifespan of equipment. When the owner of electronic equipment decides to send it to a third party for handling and management, the equipment enters the end-of-life management stage. Either the electronic equipment will be disposed or it will be collected for recycling. Equipment collected for recycling may be reused, refurbished, or dismantled or shredded for material recovery within the United States, or in other countries. (EPA, 2009)

2.3.1 Disposing the television into the landfilling

Disposing the television into the landfill remains the most economic form of disposal in the vast majority of cases. Therefore, landfills will continue to be the most attractive disposal route for television waste. Indeed, depending on location, up to 95% of television generated worldwide is currently disposed of in landfills. Alternatives to landfilling are considered as volume reduction processes because they produce waste fractions (e.g. ashes and slag from combustion processes that represent the second leading method of waste disposal) which ultimately must be landfilled. Resorting to landfills is not limited to the disposal of electrical waste, but it includes most other industrial wastes. For instance, nearly 80% of hazardous wastes generated in the U.S. is dumped in landfills (Mutasem El-Fadel, 1995).

Historically, landfills were initiated largely as a result of a need to protect the environment and society from adverse impacts of alternative methods of refuse disposal such as open-air burning, open-pit dumping, and ocean dumping (Senior, 1990) Although landfills eliminated some impacts of old practices, new ones arose, primarily due to gas and leachate formation. Besides potential health hazards, these concerns include fires and explosions, vegetation damage, unpleasant odors, landfill settlement, ground water pollution, air pollution and global warming.

Development of completed landfill sites is invariably hindered by significant settlements caused primarily by refuse decomposition which increases the void ratio and weakens the structural strength of the refuse within a landfill leading to a substantial loss of volume and settlement. Other causes of landfill settlement include refuse dissolution into leachate; incomplete waste compaction; movement of smaller particles into larger voids created by biological and physico-chemical changes, and subsurface fires (raveling); consolidation or mechanical compression due to the refuse thickness and own weight, or the load of construction material and structures erected on the landfill (G. F. Sowers, 1968)

The rate and magnitude of landfill settlement depends primarily on the refuse composition, operational practices and factors biodegradation of landfill waste, particularly moisture (James, 1997) Estimates of the total settlement in a landfill range from 25 to 50% of the original thickness (Stearns, 1987) Operational and load-related settlements typically constitute 5 to 30% of total settlement and occur during landfill operations or shortly after closure (G. F. Sowers, 1973) Long-term settlements due primarily to refuse decomposition can theoretically reach 40% of the original thickness (Cheyney, 1983) and occur gradually for several years after closure at a continually decreasing rate depending on stabilization processes within the landfill. On average, settlement of about 15% of total landfill thickness is expected due to waste decomposition(Rao, 1997)

Landfills often exhibit great variations in waste composition resulting in a non-uniform element pattern. This creates differential settlements whish can have a devastating effect on the integrity of any structure erected on the landfill. Structural failures of buildings, surface cracks in the final cover, damage to the surface water drainage system, piping of leachate and gas collection system, and underground utilities are commonly attributed to differential settlements. As well as variations in waste composition, change in the manner in which the waste is placed or compacted, localized reveling, vertical loads, and subsurface fires can also contribute to differential to differential settlements. Operational and maintenance practices can minimize problems associated with both total and differential settlements. (G. F. Sowers, 1968)

2.3.2 Disposing the television into the recycling

Recycling of WEEE is an important subject not only from the point of waste treatment but also from the recovery aspect of valuable materials. The US Environmental Protection Agency (EPA) has identified seven major benefits when scrap iron and steel are used instead of virgin materials. Using recycled materials in place of virgin materials results in significant energy savings as shown in Table 4 (ISRI, 1991)

Table 4 Recycled materials energy savings over virgin materials (ISRI, 1991)

Materials	Energy savings (%)
Aluminum	95
Copper	85
Iron and steel	74
Lead	65
Zinc	60
Paper	64
Plastics	>80

When e-waste is disposed of or recycled without any controls, there are predictable negative impacts on the environment and human health. E-waste contains more than 1000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants that create dioxins emissions when burned. About 70 % of the heavy metals (mercury and cadmium) in US landfills come from electronic waste. E-waste contains considerable quantities of valuable materials such as precious metals. The value of ordinary metals contained in e-waste is also very high: 1 ton of e-waste contains up to 0.2 tons of copper, which can be sold for about 500 Euros at the current world price (Soderstrom, 2004) Recycling e-waste has the potential therefore to be an attractive business and companies such as Boliden (Sweden), WEEE AS (Norway) and Citiraya (UK) are investing in the area.

The informal recycling activities have been proliferated more in developing countries because they have less restriction about these activities. Many developing countries are the destination for dropping the waste which there is estimate that around 50 to 80 percent of the wastes collected and transport from developed countries. As Thailand situation, it was revealed that E-waste imported from Singapore, Japan and USA was being dumped in areas around Klong Toey Port (Lundgren, 2012).

2.4 Current policy and regulation of E-waste management

2.4.1 International regulation scheme

The rate of waste electrical and electronic equipment (WEEE) is growing at an alarming rate, especially in organization for economic cooperation and development (OECD) countries where markets are saturated with huge quantities of new electronic goods so WEEE is mainly generated in countries of the OECD, which have highly saturated markets for electronic and electrical equipment. Global management of WEEE practices from in different regions of the world by highlighting the following issues: trends in the use of EEE, quantities of WEEE produced, potential health and environmental impacts, collection and treatment practices and policies and legislation specific to WEEE.

Many countries around the world have established many of policy frameworks to control of E-waste and directly impact to the television equipment which have to be collected and recycled within legislative borders. Moreover, there also restricts some toxic substances used in manufacturing and improve the recycling models of materials among the national level.

The Waste Electronic and Electronical Equipment (WEEE) Directive is the well-known regulation to mandates electronics take back or recycling systems in 27 countries of European Union. Typically, Europe is far leading the way in framing and implementing policies to manage its WEEE stream.

Restriction on Hazardous Substances directive (RoHS) is the prevention approach to control materials in electronics for all products sold in the European Community (EC, 2006). There has been in force since 2003 in purpose to restrict the use of hazardous substances in electrical and electronic equipment. Moreover, there also provide measurement to the protection of human health, the proper recovery and disposal of e-waste.

In opposite to some non-OECD countries, electronic wastes are not a priority waste in management policy in countries such as South Asian countries, Latin America or Pacific. There is no direct law for e-waste but there are several regulations details the implementation of trade law regulations which control the import of used appliance (Arora, 2008).The difficulties of E-waste management are mainly because of the lack of awareness in end-users mind, improper collection methods, collection as the bulky wastes, no waste disposal facilities, still keeping as stockpiles at household or open dump landfill and lack of organized market and insufficient data/statistics for policy setting (Arora, 2008).

2.4.2 Thailand regulation scheme

Today, Thailand still has no specific legal framework for control the WEEE disposal. The overall wastes are controlled under two bodies of legislation. Prior to providing a waste disposal service to their citizens in their local government, the Public Health Act, B.E. 2535 (A.D. 1992) allows local governments to issue local regulations and levy service collection and disposal of municipal solid waste.

Thailand policy still require nothing from the producer such as payment of the waste disposal and also neither have specific take-back programs nor effective procedure for recovery, reuse and recycle. However, Thailand already drafted the WEEE Policy Proposal which synchronizes various ministries for effective management. Unfortunately, a draft documents still considered for implementation.

Existing Policy & Management Scheme for this Type of Wastes: Thailand still has no specific legal framework for control the WEEE disposal but has two stages of strategies for management in country as shown in Figure 9.

i. First stage in 2007-2011:

The objectives are for effective of WEEE management in our country and have participated from all sectors including decrease hazardous waste and increase competition market within 2017.

ii. Second stage in 2012-2016:

The objective are waste has been correct and complete management, effective of collection system promote and support of design or manufacture for decrease hazardous waste in product, establish complete recycle plant, environmental awareness and worth use resource, control import low quality product and develop database of waste product

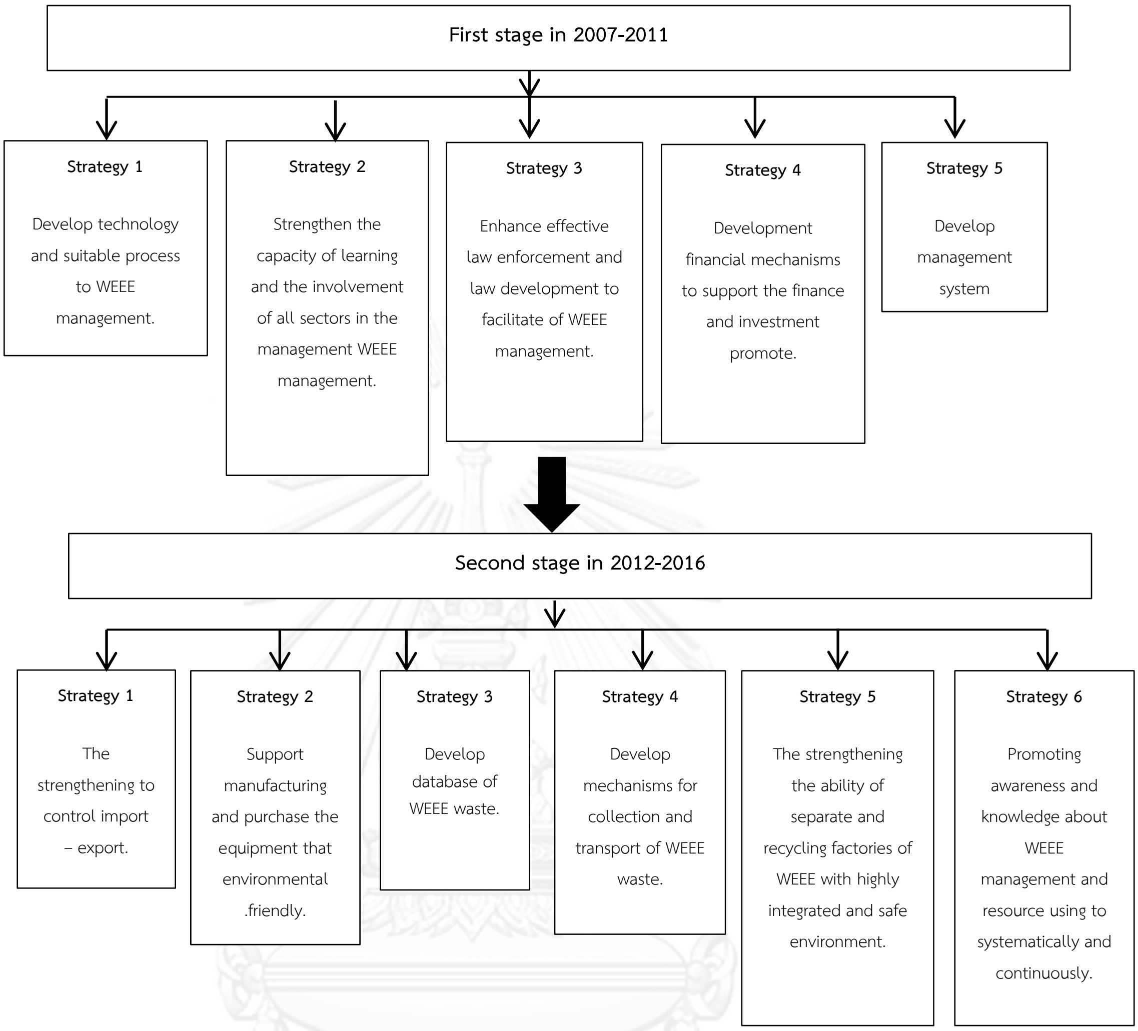


Figure 9 Existing policy & management scheme for this type of wastes in Thailand (PCD, 2012)

2.5 End of life impact assessment method

Environmental life-cycle assessment (LCA) is a technique to perform environmental information of product system throughout the life cycle by analyzing in many processes such as raw material preparing, materials processing, manufacturing, distribution, using, repairing and maintenance, and disposal or recycling.

LCA became popular in the early nineties. Initially many thought that LCA would be a very good tool to support environmental claims that could directly be used in marketing. Over the years, it has become clear that this is not the best application for LCA, although it is clearly important to communicate LCA results in a careful and well-balanced way. In recent years life cycle thinking has become a key focus in environmental policy making. A clear example is the concept of IPP (Integrated Product Policy) as communicated by the EU, but also in Asia (China: Circular Economy) and the America's many countries develop strategies that promote life cycle thinking as a key concept. Another development is the sustainability reporting movement. LCA provides the more quantitative and scientific basis for all these new concepts. In many cases LCA feeds the internal and external discussions and communications. Being active in LCA means to be able to communicate the environmental impacts of products and business processes. The LCA methodology widely used LCA software.(Productecology, 2006)

2.5.1 Application of LCA

This ability to track and document shifts in environmental impacts can help decision makers and managers fully characterize the environmental trade-offs associated with equipment or process alternatives. By performing an LCA, analysts can:

- Develop a systematic evaluation of the environmental consequences associated with given equipment.
- Analyze the environmental trade-offs associated with one or more specific equipment/processes to help gain stakeholder (state, community, etc.) acceptance for a planned action.
- Quantify environmental releases to air, water, and land in relation to each life cycle stage and/or major contributing process.
- Assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media.
- Assess the human and ecological effects of material consumption and environmental releases to the local community, region, and world.
- Compare the health and ecological impacts between two or more rival equipment/processes or identify the impacts of a specific equipment or process.
- Identify impacts to one or more specific environmental areas of concern

2.5.2 Examples of LCA Application

The previous LCA study from China about television use rapid increase in both equipment and use. There is an increasing awareness of the environmental impacts related to the accelerating mass equipment, electrical use, and waste management of these sets. Moreover, life cycle assessments (LCA) are used to investigate the environmental performance of Chinese TV sets and assessment of the TV set device (focusing on the Cathode Ray Tube (CRT) monitor). The LCA was constructed using SimaPro software version 7.2 and expressed with the Eco-indicator' 99 life cycle impact assessment method. The LCA showns that the use stage of such devices has the highest environmental impact, followed by the manufacturing stage. In the manufacturing stage, the CRT and the Printed Circuit Board (PCB) are those components contributing the most environmental impacts. The final processing step the "end-of-life stage" can lead to a clear environmental benefit when the TV sets are processed through the formal dismantling enterprises in China (Qingbin Songa, 2012)

Evaluating both new and existing processes for primary metal production to assess their environmental impacts is often difficult due to the many inputs and outputs involved. Life Cycle Assessment (LCA) is a methodology that can be used for such purposes to identify those parts of the metal production life cycle that have significant environmental impacts. LCA has been used by CSIRO Minerals to assess the "cradle to grave" environmental impacts of a number of metal production processes practiced either currently or potentially in Australia. The metals considered included copper, nickel, aluminum, lead, zinc, steel, stainless, and titanium. The environmental profile included greenhouse and acid rain gas emissions, solid waste emissions and gross energy consumption. The results for various metals are compared. New process technologies for primary metal production can be expected to reduce the environmental impacts of metal production and estimates of likely reductions for technologies involving stainless, titanium and aluminum are also presented.(T.E. Norgate, 2007)

The recycling of plastic wastes from discarded TV sets: comparing energy recovery with mechanical recycling in the context of life cycle assessment by (Dodbiba, 2008) found that the energy recovery is an option that uses more resources and emits a larger quantity of greenhouse gases. Mechanical of recycling is more effective because it uses fewer resources, as well as has a lower environmental impact on global warming.

From LCA analysis for TV set found that during operating stage use the most energy when compare with other stages. As anticipated, the analysis shows the importance of energy efficiency in improving the environmental performance of this equipment. However, the analysis also brings out the importance of material and resource use, recycling and impacts such as toxicity. The LCA of the television reveals that 630 kg of materials are used to produce a 42.7 kg television set. Thus about 93% of the resources are used in the manufacture of a television. The calorific value of the materials correspond to only 11% of the total energy used in extraction and material equipment and material recovery at the end of equipment life is a better option than incineration or dumping (Gheewala, 2003)

Hischier and Baudin (2010) describes a detailed LCA study of a plasma television device (PDP), including a first comparison of it with the two competing technologies, the cathode ray tube (CRT) and the liquid crystal display (LCD) technologies. PDP devices shown the least impact on the environment when compare with CRT and LCD.(Baudin, 2010)

CHAPTER III
METHODOLOGIES

This chapter explains about steps in conducting this research. The methodologies are divided into three main sections including (I) step of reviewing and collect data for developing and analyzing the thesis study, (II) step in evaluating environmental impact using life cycle assessment approach, and (III) step of recommendation for television waste management in Thailand. Details of each step are as following;

3.1 Review and collect relevant data

The research experiment was designed based on useful information that was gathered from various sources and the literature review. The relevant types and sources of data are as described below;

3.1.1 Substances in television equipment

Many previous studies were investigated and discussed about various substances involving in disposed televisions. The research reviewed existing environmental problem from managing television wastes and valuable materials in various television models.

3.1.2 Current situation of television and future forecast

The data for estimated of total amount of televisions waste in Thailand nowadays and in the next 10 years during 2014-2023 come from governmental institution will be reviewed. The information will be used for evaluating overall environmental burdens including toxic and valuable materials existing in television will also be evaluated based on available information.

3.1.3 Life cycle assessment method and analysis software

Many researches using life cycle assessment method for evaluating environmental impacts to review and compare to select the assessment method which appropriate in this study. The review focused more about interface software procedures relating in this research field. SimaPro program working procedure and other relating researches were reviewed. These materials are useful for develop the life cycle assessment analysis in overall of E-waste treatment.

3.1.4 Situation of changing analog TV to digital TV in Thailand

The research reviewed current situation of changing analog TV to digital TV in Thailand regarding timeline of changing, responsibility of consumer and estimated amount of television will be disposed after switch of system that relevant data. All data were gathered with future plan policy in Thailand.

3.1.5 Current E-waste management approaches and policies in Thailand

The previous studies about E-waste management in Thailand and other countries were reviewed such as waste disposal approaches, proper and improper recycling system, law and regulation in order to understand the current E-waste managing approaches and understand situation before developing the recommendation that possible to apply in Thailand.

3.2 Environmental impact assessment

Environmental impact assessment is evaluated according to the international standards of the ISO 14040 series (ISO 14044, 2006) and using the LCA software and database from the software to estimate the impact from end of life management steps.

3.2.1 SIMAPRO Program

This study use Microsoft excels 2010 and system for integrated environmental assessment of products program (SimaPro) version 7.3.3. In addition, ecoinvent database V.2.1 was used as source of data to develop and analyze the environmental impacts from end of life television waste management.

3.2.2 Purpose of the LCA study

This main objective of this section is to evaluate the environmental impacts from landfilling and recycling approach of end of life television equipment and to understand the future of impacts through the different scenario analysis.

3.2.3 Functional units

Functional unit is 1 unit of end of life television entering different treatment process. This study chose 3 television models including the details from each step can be explained as following 21-inches.CRT, 32-inches.LCD and 32-inches.LED television screen.

(a) (b) (c)

Figure 10 Television in this study: (a) 21-inches.CRT, (b) 32-inches.LCD and (c) 32-inches.LED

There were evaluation environmental impacts of selected television models at the end of life stages. The research focused on some parts of television that have toxic components. This LCA study, using obsoleted Cathode ray tube (CRT), liquid-crystal display (LCD) and light-emitting diode (LED); size 21, 32 and 32 inch respectively. By use popular brand as the model for making life cycle inventory because there were large proportions of these models television popularity used in Thailand.

3.2.4 Scope and System boundaries

This study focused on the end of life phase for investigating the environmental impact from relevant unit processes within the life cycle. The system boundary is at the end of life of waste treatment and disposal landfill and recycles. Typically, the main system of this study mainly contains two large approaches:

i. End of life management approach: Best practice for landfilling

Landfill is the final disposal site for waste, designed to minimize the impact of solid waste on environment and human health (Johannessen 1999) It consists of liner systems to prevent leachate and harmful substances to the near area. (Hoornweg, 2012) In this case, during operation time, landfill leachate will be collected and treated in municipal wastewater treatment plant. The sludge from this step also incinerate in further municipal incineration plant and remain residue is assumed to be dumped at residual material landfills. The environmental burdens depend on assumption so-called waste specific burdens. It means that the information about landfill models of all waste type disposed into will be calculated by elemental composition of the waste (Doka, 2009)

Thailand has several landfill operation approaches but mostly there still is inadequate prevention of leachate leaking and improper operation. Therefore, the selected landfill data in this research can be defined as management practice of landfilling which might reflect to the future proper landfilling in Thailand.

ii. End of life management approach: Best practice for recycling

There is no formal recycling scheme in Thailand. The levels of solid waste are increasing annually. Recycling also reduces the need for landfills and incineration. Preventing pollution caused by the manufacturing of products from virgin materials is another benefit. Recycling also saves energy and decreases emissions of greenhouse gases.

Normally, the recycling process involves 3 main steps, which form a circle or loop. They are collection, processing, and purchasing new products made from recycle material (EPA, 2008) But the process boundary in this recycling scheme focus on processing waste until produce the new secondary product as avoided primary material not include step 1 and step 3. Because of this study assumed that waste material enters the system boundaries without collection system, the life cycle burdens would be directly delivered from the compositions of waste management. Actually, according to recycling of WEEE can be broadly into three major stages (E., 2003)

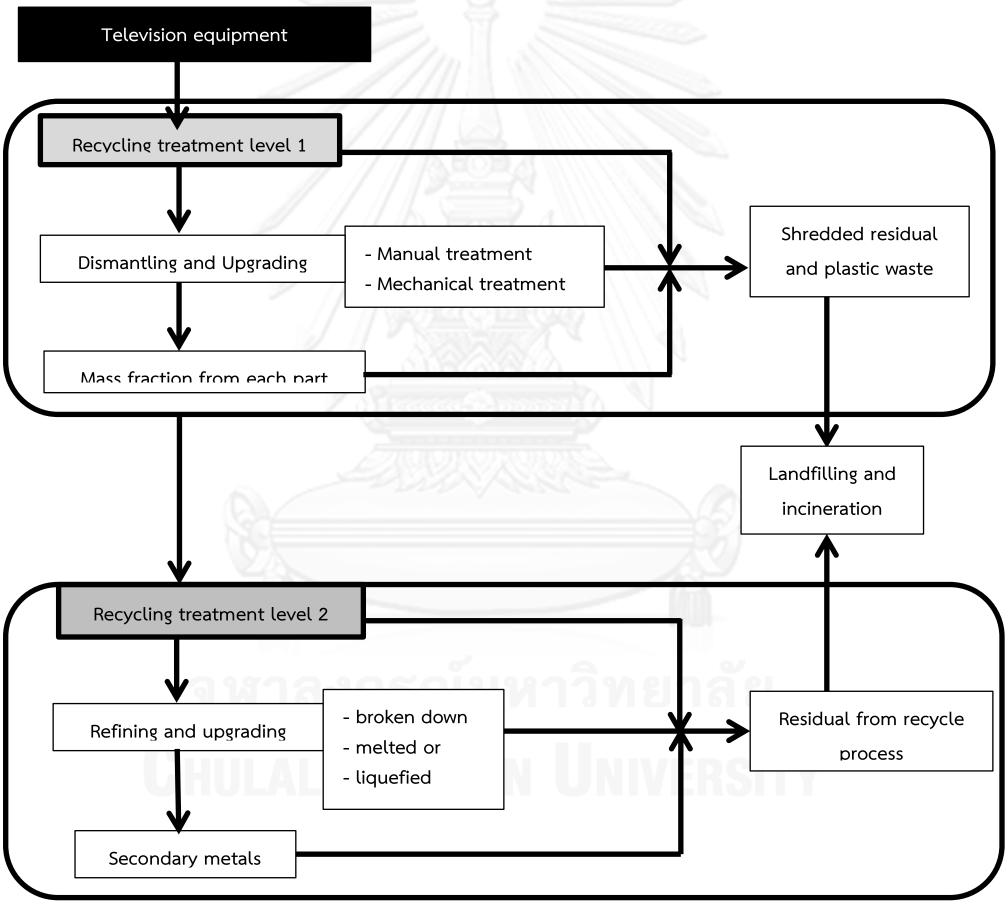


Figure 11 Recycling scheme in this study developed from Ecoinvent database

(1) Dismantling stage: selective disassembly, targeting on singling out hazardous or valuable components, is an indispensable process

(2) Upgrading stage: represent using mechanical/physical processing and/or metallurgical processing to upgrade desirable materials content, i.e. preparing materials for refining process

(3) Refining stage: in the last stage, recovered materials return to their life cycle

For this study, these three stages are summarized in to two treatment levels: treatment level1 dealing with the dismantling of the devices and treatment level 2 dealing with the upgrading and/or refining of the from level1 resulting fraction.

Within the overall treatment chain, two levels are distinguished. The device specific treatment level 1 and the fraction-specific treatment level 2. Furthermore it can be seen that all the processes here are established as shown in Figure11. Treatment level 1(dismantling of device) describe of the general procedure for the datasets of the first part of recycling treatment. Treatment level 2(treatment of fraction) describe of the various treatment procedure for the different fractions that are established in the dismantling step. Details for each treatment level are as following;

➢ Recycling treatment level one

The first level for the treatment is the dismantling of entire devices into a number of different fractions either for further treatment for disposal. Within this first treatment step, two different ways can be distinguished are a manual treatment and a mechanical treatment as show in Figure 12. The manual treatment can be characterized by a thorough depollution of the device such as removal of hazardous components but the complete process is more labor intensive and takes much more time. The mechanical treatment (i.e. shredding process) on the other hand can be characterized by technical (i.e. magnetic separation, Eddy-current separation) with comparably few personal. Concerning the result fractions, the quality depends much from the preceding depollution step (a manual step) that takes off those fractions that are not suitable for the subsequent shredding step and the various separation steps that follow on the shredding step.

Therefore, calculation the results of treatment level 1 and sent to treatment level 2 used transfer coefficient follow method treatments. As already mention above, the manual treatment can be characterized by a through depollution of the device.

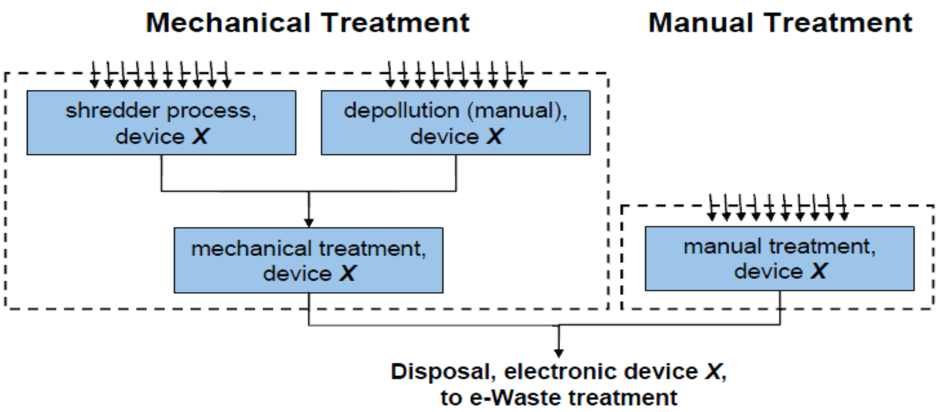


Figure 12 Two different ways of dismantling of recycling (Hischier R., 2007)

For manual treatment, the transfer coefficients according to Table 5 are used in order to determine the further treatment of the various parts of the device. The manual treatment can be characterized by a thorough depollution of the device follow by a detailed separation into fractions of the different materials that can be found in a device. (Gabriel.R., 2000)

Table 5 Transfer coefficient in the manual dismantling of WEEE (Hischier R., 2007)

Components / Parts	Amount	further treatment	Remarks
[i] Housing / Support			
- metal parts, outside	100%	Scrap, for metal production	steel / alu / copper / others
- metal parts, inside	100%	Scrap, for metal production	steel / alu / copper / others
- plastic parts, outside	100%	plastics, to incineration	
- plastic parts, inside	100%	plastics, to incineration	
[ii] Slide-in Modules	100%	*in "Shredder material"*	e.g. HDD, DVD/CD-ROM, ...
[iii] Printed Wiring Boards			
- high quality, mounted	100%	PWB, for further treatment	
- low quality, mounted [1)]	50%	PWB, for further treatment	
	50%	*in "Shredder material"*	
[iv] Cables			
- cable (without plugs)	100%	Cable, for further treatment	
- plugs	100%	PWB, for further treatment	
[v] Hazardous Components			
- Batteries	100%	Batteries, for further treatment	
- Capacitors [2)]	100%	Capacitors, to special disposal	big capacitors
	-	*(part of "Printed Wiring Boards")*	small capacitors
[vi] Special components / modules			
- toner	100%	Incineration (in MSWI)	approximated as Polystyrene
- LCD module, dismantled	100%	LCD module, to incineration	
- LCD, backlight (CCFL)	100%	backlight lamp, to further treatment	
- CRT tube, without gun	100%	CRT glass treatment	
- CRT, electron gun	100%	*in "Shredder material"*	
- CRT, deflection yoke	100%	*in "Shredder material"*	

[1] Low-value PWB are only partly taken off separately. Amount of 50% is an assumption of the author of this dataset here.
[2] In accordance with the current treatment rules in Switzerland (Swico Environmental Commission (2006))

In the mechanical treatment a high throughput with comparably few personal can be achieve. Within the process, different phase can be distinguished as shown in Figure 13 Thereby, two different steps have to be distinguished having each one its proper transfer coefficients the (manual) depollution before and the separation activities after the shredder. The main data source for the transfer coefficients of the various components in this depollution step is the personal experience of the author in framework. Table 6 shows the resulting transfer coefficients for various components in which such devices are dismantled in the first step of a mechanical treatment, the manual depollution step. All those parts with the indication to shredder process will then be mechanically treated in the shredder in a subsequent process step. When all fractions suitable for shredding process are usually mixed up and put together into the mechanical treatment process by different technology. The procedure for the separation of different valuable fractions out of the so crushed material again by showing a process that ends up in four different fraction are three metal and residual fraction as shown in Figure 14.

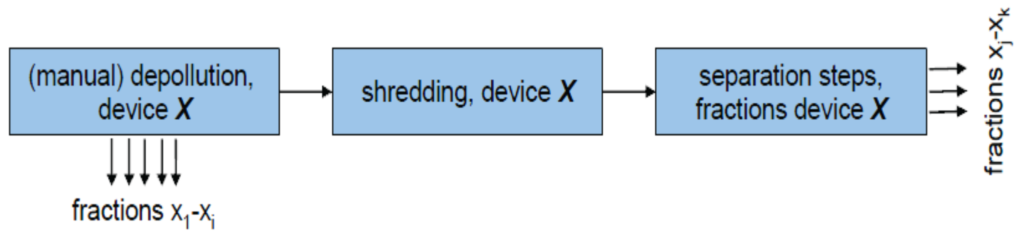


Figure 13 The different phases within the mechanical treatment of recycling device (Hischier R., 2007)

Table 6 Transfer coefficient in the mechanical dismantling of WEEE (Hischier R., 2007)

Components / Parts	Amount	further treatment	Remarks
[i] Housing / Support			
- metal parts, outside [1]	50%	Scrap, for metal production	steel / alu / copper / others
	50%	-> *to shredder process*	
- metal parts, inside	100%	-> *to shredder process*	
- plastic parts, outside [1]	50%	plastics, to incineration	
	50%	-> *to shredder process*	
- plastic parts, inside	100%	-> *to shredder process*	
[ii] Slide-in Modules	100%	-> *to shredder process*	e.g. HDD, DVD/CD-ROM, ...
[iii] Printed Wiring Boards			
- high quality, mounted [2]	50%	PWB, for further treatment	
	50%	-> *to shredder process*	
- low quality, mounted	100%	-> *to shredder process*	
[iv] Cables			
- cable (power, w/o plugs)	100%	Cable, for further treatment	
- plugs (power cable)	100%	PWB, for further treatment	
- cable (others, with plugs)	100%	-> *to shredder process*	
[v] Hazardous Components			
- Batteries	100%	Batteries, for further treatment	
- Capacitors [3]	100%	Capacitors, to special disposal	big capacitors
	100%	-> *to shredder process*	small capacitors
[vi] Special components / modules			
- toner	100%	Incineration (in MSWI)	approximated as Polystyrene
- LCD module, dismantled	100%	LCD module, to incineration	
- LCD, backlight (CCFL)	100%	backlight lamp, to further treatment	
- CRT tube, without gun	100%	CRT glass treatment	
- CRT, electron gun	100%	-> *to shredder process*	
- CRT, deflection yoke	100%	-> *to shredder process*	

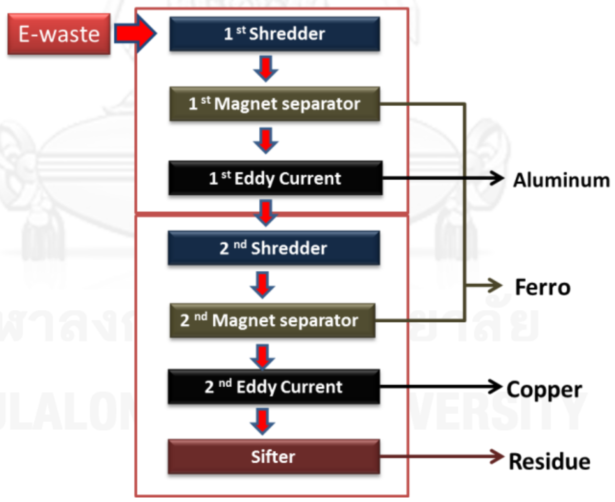


Figure 14 Shredding and separation of e-waste

(Huisman, 2003)

In this study used transfer coefficients for the main material flows are used as shown in Figure 15. The example of resulting transfer coefficients for the ingredients of the WEEE entering into the shredding process and their distribution to four output fractions and are shown in Figure16.

[%]	Ferro	Aluminium	Copper	Residue
Aluminium	0.50%	82.58%	4.92%	12.00%
Copper	0.94%	5.00%	78.21%	15.85%
Ferro	95.00%	1.00%	1.00%	3.00%
Glass	0.56%	0.56%	10.00%	88.89%
Plastics	1.21%	0.50%	10.00%	88.29%
Ag	0.99%	0.99%	84.92%	13.10%
Au	0.99%	0.99%	80.00%	18.02%
Pb	1.18%	1.18%	80.00%	17.65%
Others	0.69%	0.67%	35.29%	63.35%

Figure 15 Transfer coefficient of the most important to the four shredder fractions (Huisman, 2003)

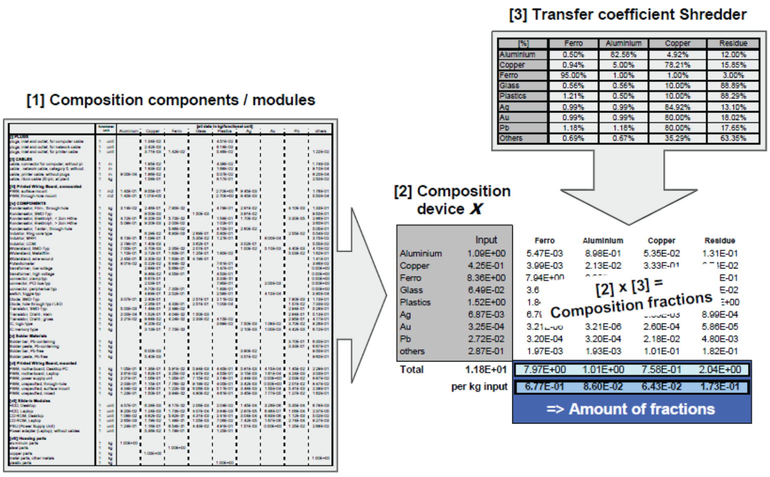


Figure 16 Procedure for the calculation of the output amounts and output composition of the three metal containing fractions in the mechanical treatment. (Huisman, 2003)

All results in this treatment level 1 will sent to treatment level 2 for upgrading and/or refining by several technics as explain in the next part.

- **Recycling Treatment level 2**

In the recycling scheme, the mass fractions from previous treatment level one are imported to this level. In this step, all recyclables need to broken down, melted or liquefied into its basic elements, before it can be either made directly into new materials or mixed with virgin resources and made into new materials for using again.

Due to the unavailable of the recycling of E-waste in Thailand, the study retrieve dataset of secondary metal production from Life cycle inventories of metal embedded in Ecoinvent database report No.10 (Classen, 2009; Garrity ER, 1994)

Additionally, the study boundary does not include the impact of the collection system of wastes to treatment system.

3.2.5 Life cycle inventories analysis

The disassemble inventory analysis is required characteristics of waste types before entered the data into management scheme either landfilling or recycling process. Assembly step will indicate the type of landfill or recycling processes by Ecoinvent database of waste-specific burden. So, the waste mass will be input data to the operation process in each type of landfilling or recycling pathways. After that, SimaPro program will develop database automatically.

Environmental results of waste management depend on the type of waste and add weight input to the specific treatment in a landfilling and recycling scheme. The study chose the self-assembly device to create waste input to landfilling and recycling process. Moreover, lists of materials are cross checked from several databases.

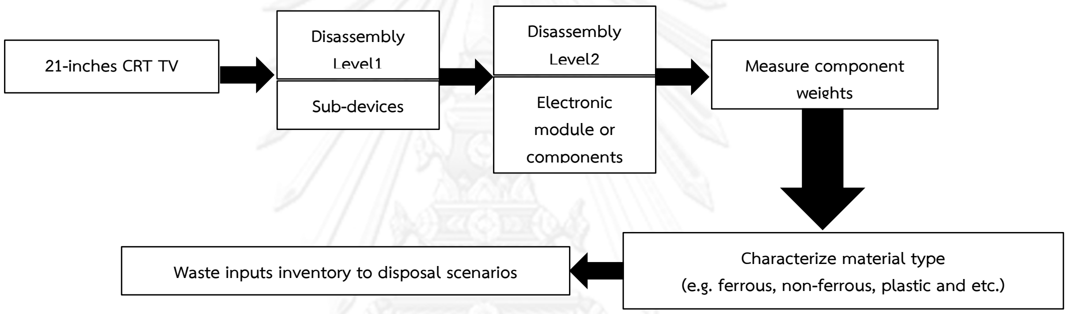


Figure 17 Disassembly analysis of television equipment

As shown in Figure 17, disassembly process of television equipment is done by self-disassembly until reach the limitation at component unit as showed on disassembly level 2 (i.e. PWBA, liquid crystal unit, and large capacitor) .Then, the weight of each component were measured and multiply with qualitative trace element dataset in electronic equipment obtained in Ecoinvent report NO.18 (Hischier R., 2007) Overall, the result of these steps would be showed as the list of waste before entering to management processes.

i. Life cycle inventory of landfill

After disassemble components reach to substance then group all substance follow the characteristic of waste types (i.e. glass, plastic, ferrous). When input the data into program, it necessary to used information of landfill approach from Ecoinvent database obtained in SimaPro 7.3.3 software. Overall, Table 7 presents the selected landfill type assumption for this study.

Table 7 Landfill assumption according to waste-specific burden (Doka, 2009)

LCI dataset embedded Ecoinvent database (Doka G., 2007)	Waste Input to reference process
1. Inert material landfill	- Glass - Ferrous metal - Non-ferrous metal - Oxide ceramic compounds - Ceramic - Epoxy - Polycarbonate (PC) - Polysulfone - Polyurethane
2. Sanitary landfill	- Organic compounds - Polyethylene (PE) - Acrylonitrile-butadiene-styrene (ABS) - Polystyrene (PS) - Polyethylene terephthalate(PET) - Polymethyl methacrylate (PMMA) - Polypropylene(PP) - Polyvinyl chloride(PVC) - Nylon - Unidentified plastics - Rubber - Paper
3. Underground deposit	- CRT coat substances (i.e. lead , phosphor) - CCFL coated substance (i.e. mercury) - LED coated substance (i.e. mercury) - Other Inorganic compounds

ii. Life cycle inventory of recycling

To investigate impacts from the recycling system, data of recycling system came from the Ecoinvent version 2.1. This can divide into two main stages.

➢ **Recycling approach LCI : Treatment level I**

Treatment level one is defined following the Ecoinvent database of E-waste management including manual depollution, separation, shredding and fraction separation. Typically, the treatment level one LCI result depends on the waste inputs following disassembly analysis. The pathway of each specific waste input are indicates in Table 8. All of waste is assumed that all 100 percent admit to treatment level one. For the output material, the transfer-coefficiency between treatment level I and II are reported in Ecoinvent database except for plastic waste and residue releasing from process will be disposed.

Table 8 Treatment level one processes (Hischier R., 2007)

Treatment level one	Inputs	Processes	LCI dataset embedded in Ecoinvent database
i. Depollution process	CRT, LCD and LED television screen	Manual separation between the hazardous and useful substance	- Manual treatment plant, WEEE scrap/GLO/I U
ii. Shredding and Separation steps	CRT, LCD and LED television screen	Pretreatment of recyclable substance before access to further refining process	- Mechanical treatment plant, WEEE scrap/GLO/I U - Facilities for mechanical treatment of WEEE scrap/GLO/I U - Shredding, electrical and electronic scrap/GLO U
	Residue fractions from shredding process	Treatment by proper incineration process (i.e. including flue gas Cleaning , bottom slag disposal and fly ash landfilling)	- Disposal, residues, mechanical treatment, CRT screen, in MSWI/CH U - Disposal, residues, mechanical treatment, LCD screen, in MSWI/CH U - Disposal, residues, mechanical treatment, television, in MSWI/CH U
iii. Plastics fraction	Television equipment |plastics scrap	Treatment by proper incineration process similar treatment of residue from shuddering fraction	- Disposal, plastic, consumer electronics, 15.3% water, to municipal incineration/CH U

➢ Recycling approach LCI : Treatment level II

The recycling processes in this stage came from output of previous treatment level by used LCI dataset in each metal recovery process is presented inTable9. The output of this step is calculated by multiplying with scrap utilizing factor. Results will be shown as the secondary product. Particularly, these recycled materials also assumed that can avoid producing new raw of material and be utilized again as same primary products.

Table 9 The treatment level two considered recovery system in this study (Classen, 2009)

Treatment level two	Scrap inputs	Processes	LCI dataset embedded Ecoinvent database
1. Metal steel recycling	Metal Housing Shredded iron fraction	Refining the metal scrap through- electric arc furnace, steel making process and casting.	- Steel, electric, un- and low-alloyed, at plant/RER U
2. Copper recycling	Uncovered copper cable Shuddered copper fraction	Refining the copper scrap through pyro metallurgy (blast furnaces, converters and anode furnaces) and electrolytic refinery	- Copper, secondary, at refinery/RER U
3. Aluminum recycling	Aluminum shredder fraction	Refining the aluminum through Melting, alloying and casting in refinery and casting plants	- Aluminum, secondary, from old scrap, at plant/RER U

Treatment level two	Scrap inputs	Processes	LCI dataset embedded Ecoinvent database
4. Precious metal recycling	Printed wired board assembly (i.e. mainboard, RAM, control board)	Refining the precious metal recovery through refining processes manly including anode refinery facilities, anode refinery facilities, and precious metal refinery facilities	- Lead, secondary, from electronic and electric scrap recycling, at plant/SE U - Copper, secondary, from electronic and electric scrap recycling, at refinery/SE U - Nickel, secondary, from electronic and electric scrap recycling, at refinery/SE U - Silver, secondary, at precious metal refinery/SE U - Palladium, secondary, at precious metal refinery/SE U - Gold, secondary, at precious metal refinery/SE U
5.CRT tube treatment process	CRT tube	Crushing CRT glass, removing coating and separating out the metals inside.	- Disposal, treatment of CRT glass/GLO U
6.LCD screen backlight lamp treatment	CCFL lamp in LCD screen	Cutting CCFL tube, crushing step, cleaning step and drying mercury separation steps	- Disposal, fluorescent lamps/GLO U
7.LED screen backlight lamp treatment	LED lamp in LED screen	Cutting LED tube, crushing step, cleaning step and drying mercury separation steps	- Disposal, LEDlamps/GLO U

When comparing between television waste management options, the inventory datasets of recycling activities and the avoided primary material process as avoided are examined the net impact of recycling. Thus, this study requires the LCI of primary metal from Ecoinvent database for evaluating avoided impact Table 10 presents the secondary production and their avoided processes.

Table 10 The avoided production processes due to recycling process subsidy (Hischier R., 2007)

The recycled material output	The avoided primary process referring to Ecoinvent database
- 2^{nd} Steel	Steel, low-alloyed, at plant/RER U
- 2^{nd} Aluminum	Aluminum, primary, at plant/RER U
- 2^{nd} Lead	Lead, primary, at plant/GLO U
- 2^{nd} Copper	Copper, primary, at refinery/GLO U
- 2^{nd} Nickel	Nickel, 99.5%, at plant/GLO U
- 2^{nd} Silver	Silver, at regional storage/RER U
- 2^{nd} Palladium	Palladium, primary, at refinery/ZA U
- 2^{nd} Gold	Gold, primary, at refinery/GLO U
- 2^{nd} Mercury	Mercury, liquid, at plant/GLO U
- 2^{nd} phosphor	Zinc sulphide, ZnS, at plant/RER U (proxy assumption)
- Glass cullet	Glass cullet, sorted, at sorting plant/RER U

iii. Life cycle inventory in different scenarios

While the amounts of television waste in the future are expected to increase. To forecasting future potential impact of television wastes in Thailand is necessary. The study applied the predicted number of television equipment during year 2014-2023 in Thailand retrieving from Pollution Control Department report

(PCD, 2012) as show in Figure 18. This study projected for the next 10 years. However, data from PCD is available that during 2014-2016. The PCD report of the television waste will increases 12 percent per year. This information is used to for estimated during 2016-2023. Typically, the calculation of television equipment number performed regarding to the many factors including equipment lifespan, historical stales, world population growth during study time and market inflation rate. However, the study assumed that the amounts of discarded equipment are 39,592,143.85 units using in three types of television as representative models. So, assumed all types of television will generate same amount of discarding.

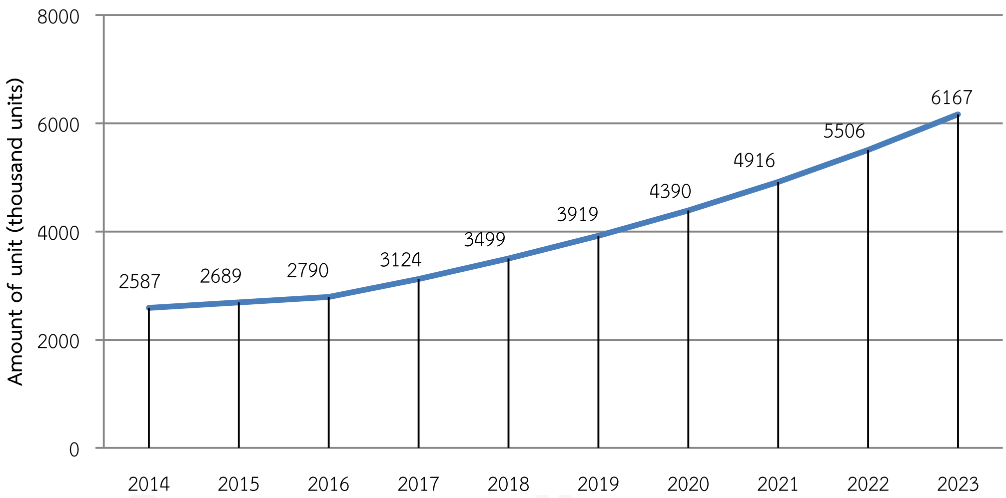


Figure 18 The prediction number of television equipment

Adapt from: (PCD, 2012)

Therefore, the prediction number from end of life television would be analyzed with material composition embedded in disassembly analysis and then used as waste inputs to management scheme in different disposal options. The quantities of wastes in any scenario are assumed with defined already in different recycling collection rate and landfilling dumping rate (Table11). In this study, scenario 1 performs environmental impact when applying the proper landfilling scheme (100% landfilling) in Thailand, this scenario will be used as the baseline scenario for comparing with others two recycling approaches. Scenario 2 is established in order to show the environmental perform after beginning of 5% recycling collection rate (5% recycling and 95% landfilling).This rate number referred to the initiate plans of national strategy of E-waste collection strategy goal. Scenario 3 aims to examine the environmental performance due to the high rate of E-waste recycling (20% recycling and 80% landfilling).This rate number retrieved from household recycling rate which apply for measure the burdens or benefits in case of high effort to implement the E-waste collection scheme.

Table 11 The scenario analysis in this study

Scenario	Recycling Collection rate	Landfill dumping rate	Scenario descriptions
1	-	100%	Dispose all screens during 2012-2021 waste to proper landfill and no recycling activities have been applied
2	5 %	95%	Apply all waste during 2012-2021 to recycling at 5% collection rate followed The national integrated strategy for the management of waste electrical and electronic equipment extended version, year 2012-2016 (PCD,2013)
3	20%	80%	Apply all waste during 2012-2021 to recycling at 20% collection rate followed the household recycling rate at 2009 A.D (PCD,2009)

After estimated the amount of wastes and recyclable materials in each scenario, it will be analyzed in term of recyclable materials and potential revenue by used data from Wongpanit company (Wongpanit., 2013).

3.2.6 Life cycle impact assessment and interpretation

i. Impact assessment approach: ReCiPe 2008 method

The endpoint environmental impact is used to compare impacts from different management scenarios. Therefore, the analysis method for this study is ReCiPe 2008 Endpoint (H) V1.07, World ReCiPe H/A. This method developed by Goedkoop et al. 2009 which fully aggregate between CML midpoint impacts with Eco-indicator 99 endpoint methodologies. The results were performed following this method. The mechanism of this methodology and LCI data is explained in Figure 19 below, the various environmental midpoint impacts examined within this method are presented in this picture. SimaPro program was used for analysis follow these steps. Firstly, the LCI results were converted to midpoint indicator unit. Then, these results are subsequently converted to the endpoint impact. Moreover, there was also aggregated into a single score by multiplying normalized category indicator results with the corresponding impact category weights and summing up the results.

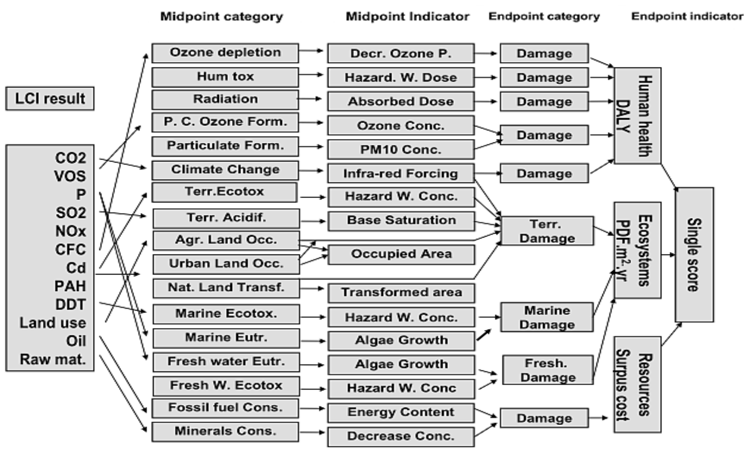


Figure 19 Impact categories and pathways covered by the ReCiPe methodology (Hischier R., 2007)

As the “World ReCiPe H/A” (Hischier R., 2005), the world normalization values with the hierarchist perspective weighting set to this study because this types support to global situation in making policy decision regarding to the providing suitable calculating factors. This calculation factor supporting issues in term of scoping of time (balance between short and long term impacts), situation manageability (based on policy solving) and problem awareness (adequate calculation factor in consensus environmental concerning).

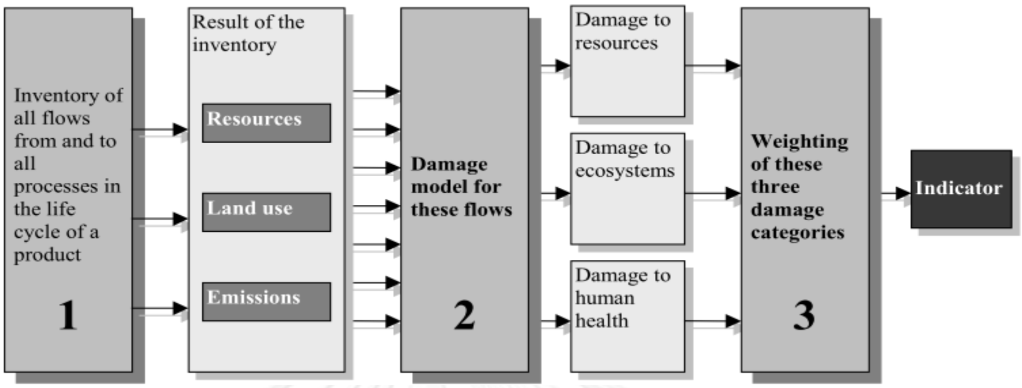


Figure 20 General procedure for the calculation of mass flows system in this study

(Hischier R., 2007)

Figure 20 shows method for calculation results impact in this study. Start from advantages and disadvantages to use midpoints and endpoints. Midpoints are generally moderately provided accuracy of data, but it is difficult for the analyst or a policy maker to understand the overall impact the units such as CO_2 for climate change. Apart from this, the endpoints are much easier and understand the impact. Endpoints are expressed by using a point system including, amounts of dollar, number of species, or number of human life years lost. Due to these indicators, it is easier to understand the severity of impact more than midpoint impact. However, the translating of midpoint impacts to endpoint units also contributes much uncertainty to results as tradeoff. In particular, this uncertainty established from vague understanding and other mechanisms through pollutants and other dependence mechanisms may have on geographical factors. Thus, the tradeoff between result accuracy and result interpretation becomes quite evident. Generally, there are eighteen midpoint impact categories and three endpoint impact categories in the ReCiPe method for calculating in SimaPro program, three steps are needed:

Firstly, this is necessary to calculate the total inventory of all relevant emissions, resource extractions and all processes to form the life cycle following the standard procedure in Life Cycle Assessment (LCA).

Secondly, there also need to analyse the damages of these flows which might cause the Human Health, Ecosystem Quality and Resources. The way to the characterization of impact at the endpoint level starts from the intervention calculation with the emission factor without intermediate midpoints. The formula is showed below.

$$I_e = \sum_i Q_{ei} m_i$$

where m_i is the magnitude of intervention i (e.g., the mass of CO_2 released to air), Q_{ei} is the characterization factor that connects intervention *i* with endpoint impact category *e* and I_e is the indicator result for endpoint impact category .

Thirdly, this last step is to aggregate the results by weighting of these three damage including the human health, ecosystems diversity and resources availability impact categories (in the ratios of 4:4:2 for this study approach) was used to weight the normalized values to evaluate the single-score. This single score values can be regarded as dimensionless as similar to Eco-indicator point (Pt) in Eco-indicator 99 approach.

ii. Sensitivity analysis

This step aims to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input variables.

3.3 Recommendation for television waste management in Thailand

3.3.1 Questionnaire method

To develop recommendations for improving television waste management scheme in Thailand, this study conducted the investigation to identify preferable solutions from public opinions. Based on the questionnaires, there are two parts of information obtained from the survey: The answer from first part can show the current behavior and knowledge of people to television waste management. The second part is results on the potential alternatives for management plan in coping with waste collection to recycling system.

This questionnaire was used through the two pathways; online and paper survey. There are about 518 persons responded to the questionnaire from online surveying 122 persons and paper surveying 396 persons respectively.

3.3.2 Development of recommendation for EoL television in Thailand

This part aims to develop the recommendation in television waste management according to data collected from the previous surveying integrating with the other sources of information approach. The recommendation plans include comprehensive issues relevant to television waste collection system, the stakeholder of waste management, and other incentive in management scheme.

CHAPTER IV
LIFE CYCLE INVENTORY DEVELOPMENT

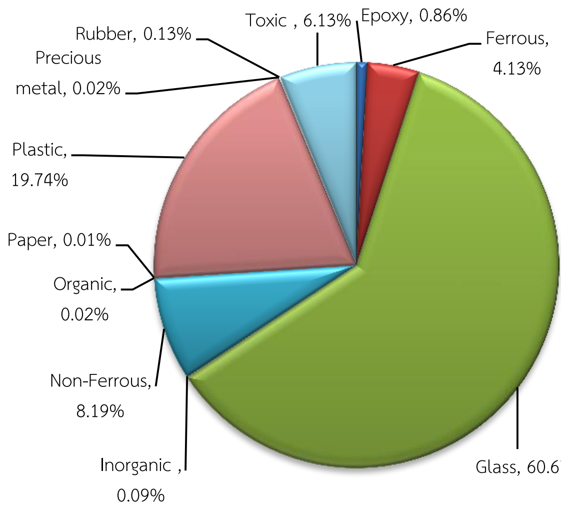
Life cycle inventory, which is the data collection portion of LCA and account everything involved in the “system” of interest. It consists of detailed tracking of all the flows in and out of the television system. Actually, almost results in this work come from the primary and secondary data. This chapter presented inventories of 4 sections including composition of television in different models, the classification of composition fragments in landfilling and recycling treatment method, the amount of recycled material , and the last section, compare two scenario analysis (5% recycling and 20% recycling) for 10 years timeframe to estimate amounts of wastes, amount of recycle material and potential revenue.

4.1 Composition of television in different models

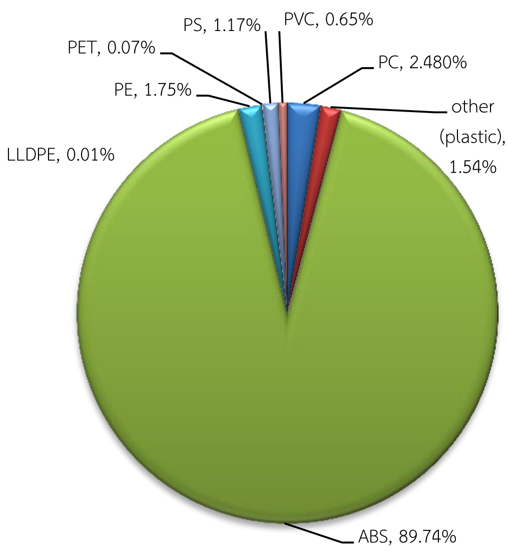
To generate lists of residue inputs to the landfill and recycling inventory, a selected model of television equipment were disassembled into components parts and constructed substance lists as the important data for entering into calculation module of inside of SimaPro 7.3.3 program. Overall equipment profiles are including:

4.1.1 Model 1: CRT television screen material composition

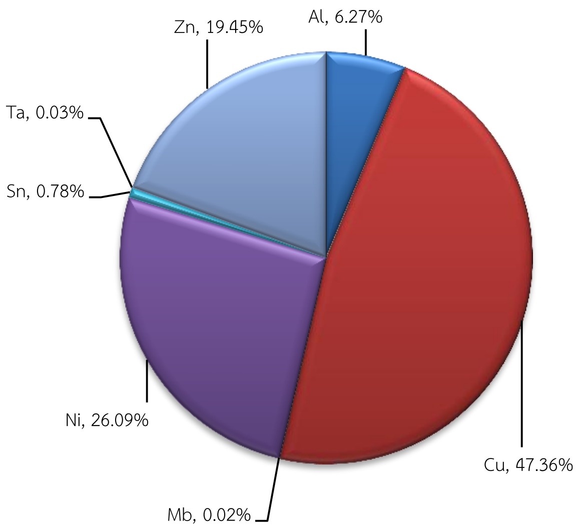
This type of screen was disassembled and thoroughly analyzed for find residues as showed in Figure 21 (a). The weight of CRT television screen was 23.26 kg. The bulk of weights data in different part for CRT television screen were classified as summarized in the appendix. In brief, the CRT glass contributed approximately 60.67% of total weight which existed the CRT tube basic building block such as panel glass, funel glass and frit. Apart from this, plastic composition is about 19.74%, which ABS plastic has highest proportion about 89.74% because it is the main structural in Cabinet (Figure 21-b). Nevertheless, there are other types of plastic from several parts in several functions.



(a)



(b)



(c)

Figure 21 The classified residues consisted in CRT television screen described as: (a) the entire material categories in CRT television screen (b) particular proportion of plastics (c) the particular non-ferrous proportion substances

Figure 21(c) shows the largest proportion of toxic copper contained about 47.36% of total non-ferrous metal part by utilizing in deflextion yoke, anode connection, printed wiring board and demagnetic coil. 26.09 % of nickel substances are from nickel alloy (invar) sub-assembly in panel glass. Panel glass and frit contain approximately 19.45% of zinc. Nevertheless, the useful panel glass and frit contained about 19.45 of zinc.

For toxic substances which were analyzed in this study was any chemical including inorganic substance that may be harmful to the environment and to human health if inhaled, swallowed, or absorbed through the skin. Types of toxic substance follow Thai Pollution Control Department database as showed in appendix A. In CRT television represent toxic substance contains lead oxide, cadmium, antimony oxide, and barium oxide about 1.43E+00 kg (6.13%) of total weight from electron gun, frit, and funel glass.

4.1.2 Model 2: LCD television screen material composition

Apart from the CRT display, LCD television screen weights were approximately 14.33 kg. Focusing on overall material categories (Figure 22-a), the ferrous metal of monitor base steel is accounted for 48.25% of total weight, subsequently followed by existed plastics about 41.34 % of total weight. Particularly, Figure 22 (b) described overview of plastic compartment. This ABS plastic is contributed as the highest fraction of overall plastics (58.68%) which utilized as structural material such as base/ stand, outer frame, power switch and rear cover. Moreover, PE plastics is the second rank of plastic which is the light guide panels used in LCD backlight reflection and power supply. Furthermore, PC plastic contributed as the third order which came from printed wiring board and backlight reflection.

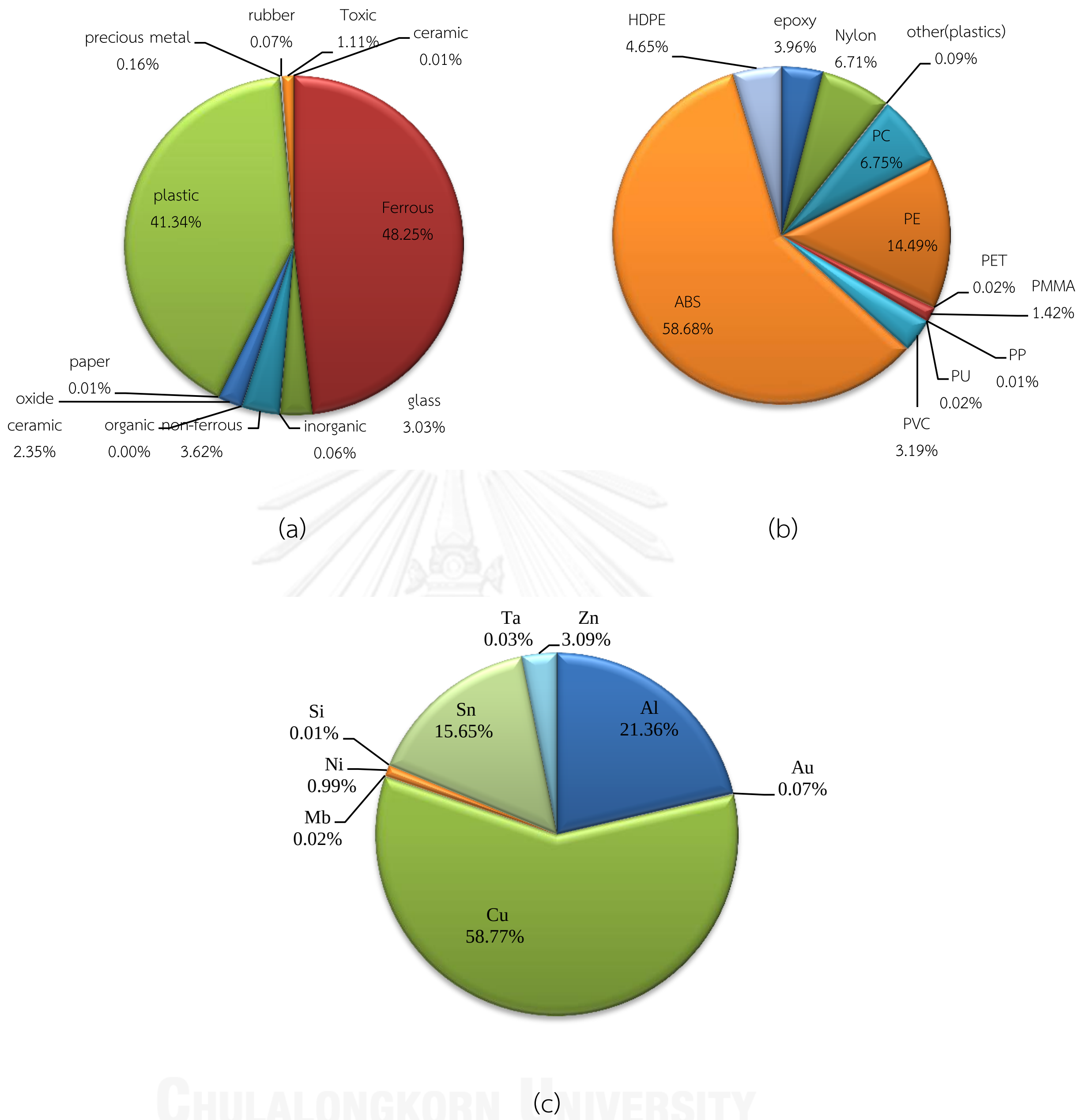


Figure 22 The classified residues consisted in LCD television screen described as: (a) the entire material categories in LCD television screen (b) the particular plastic compartment substances (c) particular proportion of non-ferrous metal compartment

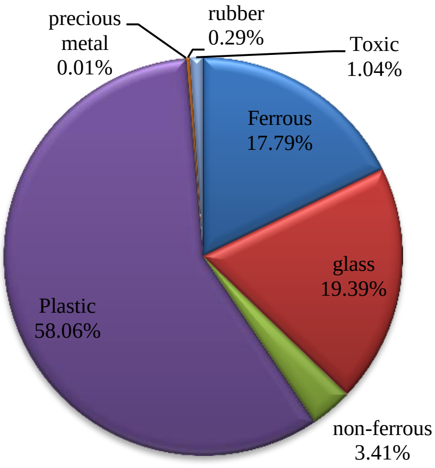
Copper has the highest amount of non-ferrous fraction (58.77% of non-ferrous metal fraction) which commonly found as the LCD cell. Next, the aluminum substances was embedded about 21.36% of entire non-ferro metal fraction, this is the result of the power supply and printed wiring board. This type of material found in back pane cover of LCD television screen.

Toxic substances represent that one LCD contains mercury, barium oxide, lead oxide, liquid crystal and cadmium about 1.60E-01 kg (1.11%) of total weight from PWBs, and cold cathode fluorescent tube.

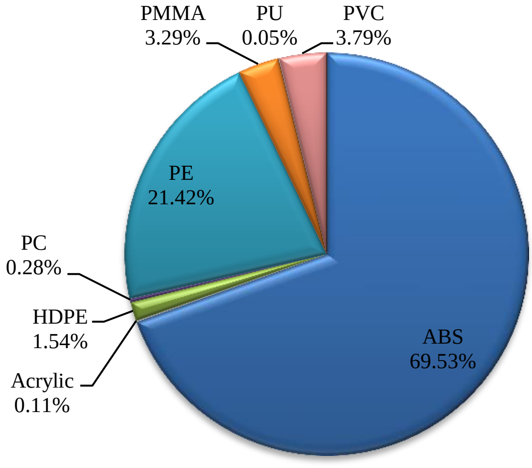
4.1.3 Model 3: LED television screen material compositions

The entire total weight of one LED screen used in the study is 4.42 kilograms. After dissembling and classifying into compartments as shown in Figure 23a, the results found that one regular 32”LED screen about 58.06% is made from plastic, 19.39% from glass, 17.79% from ferrous-metal and 4.76% from others.

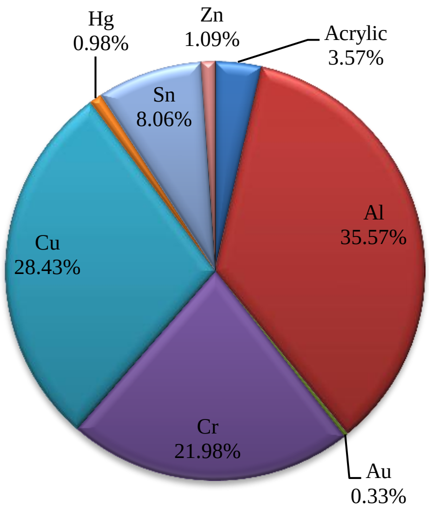
For plastic compartment as shown in Figure 23b, ABS plastic is the main compound in rear cover sub compartment such as subassembly main frame and monitor base. Moreover, PE plastic as the second rank of plastic embedded in flexible diffusor, reflective foil and thick reflective diffusor of in backlight unit. Thirdly, PVC plastic is comprised a high amount in inverter, cable line plug and interface cable.



(a)



(b)



(c)

Figure 23 The classified residues in LED television screen described as: a) the entire material categories in LED television screen b) the particular plastic compartment substances c) particular proportion of non-ferrous metal compartment

Non-ferrous compartment in LED are presented in Figure 23c. An aluminum compound is embedded in almost every sub-part of these devices such as a fan-cooled heat sink and power supply. In next descending, copper fraction in these devices was found significantly in connection flex, electricity cable line and inverter.

Toxic substances in this study represent that one LED contains mercury, barium oxide, lead oxide, and cadmium about 4.59E-02 kg (1.04%) of total weight from backlight unit, and liquid crystal.

4.2 Classification of composition fragments in different treatment method

Due to the SimaPro program procedure, this is necessary to classify the type of waste specific burdens generating by a specific waste composition. With data from substance flow analysis in disposal process, it becomes feasible to model the fate of single chemical elements in disposal processes. With this information it is to calculate waste specific disposal inventory. These inputs will be calculated with background data and released into built process tree that describes all relevant processes and inventory of end of life management. Amount of several types of materials to classify and analyze by the landfilling and recycling approaches are described in section below.

4.2.1 Landfilling approach

The materials sent to landfill are not split but dumped in bulky form. However, modeling using SimaPro program has to model separating fraction of wastes sent to landfill which splits according to waste-specific burdens. The television screen fraction entering to model specific landfill partway in SimaPro programs were classified and summarized in Table 12, 13 and 14.

Table 12 The CRT television screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	Cabinet (kg)	Deflection yoke (kg)	Demagnetic coil (kg)	Electrical wire (kg)	PWBA (kg)	Anode connector (kg)	Main CRT (kg)	Other (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	-	1.21E-01	-	-	-	1.21E-01
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	-	2.71E-01	-	-	2.37E-01	7.24E-03	4.03E-01	4.40E-02	9.62E-01
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	-	2.25E-01	2.53E-01	8.63E-02	4.46E-01	3.91E-02	8.61E-01	-	1.91E+00
4. Oxide ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	-	5.59E-02	-	1.39E+01	-	1.40E+01
5. Epoxy	Disposal, paint, 0% water, to inert material landfill/CH U	-	-	-	-	2.00E-01	-	-	-	2.00E-01
6. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	-	-	-	-	8.05E-02	-	-	-	8.05E-02
7. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	1.67E-01	-	3.33E-02	-	2.00E-01
8. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	3.34E-02	-	-	-	-	-	3.34E-02
9. PET plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	-	-	3.13E-03	-	3.13E-03
10. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	5.73E-02	-	-	-	-	4.62E-03	4.00E-03	6.60E-02
11. Poly-sulphone	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	5.33E-02	-	-	-	5.33E-02
12. PP	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U	-	-	-	-	2.57E-03	-	-	-	2.57E-03

Table 12 (continue) The CRT television screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	Cabinet (kg)	Deflection yoke (kg)	Demagnetic coil (kg)	Electrical wire (kg)	PWBA (kg)	Anode connection (kg)	Main CRT (kg)	Other (kg)	Total (kg)
13. PVC	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	-	-	2.77E-02	-	2.12E-03	-	-	-	2.98E-02
14. ABS plastic	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	4.12E+00	-	-	-	6.61E-02	-	-	-	4.12E+00
15. Other plastic	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	-	6.61E-02
16. Chemical organic compound	Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	-	-	-	-	5.04E-03	-	-	-	5.04E-03
17. Paper	Disposal, paper, 11.2% water, to sanitary landfill/CH U	-	--	-	-	3.36E-03	-	-	-	3.36E-03
18. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	1.10E-02	-	-	1.31E-03	1.72E-02	-	-	2.95E-02
19. CRT coating substances	Disposal, coatings in CRT screens, to municipal waste incineration/CH U	-	-	-	-	-	-	9.21E-03	-	9.21E-03
20. Other Inorganic	Disposal, waste, silicon wafer production, 0% water, to underground deposit/DE U	-	-	-	-	2.19E-02	-	-	-	2.19E-02
21. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	-	-	-	-	2.20E-02	-	1.40E+00	-	1.43E+00

Table 13 The LCD television screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	Backlight Unit (kg)	Base/ Stand (kg)	Inverter (kg)	LCD Cell (kg)	LCD Controllerr (kg)	Outer frame (kg)	Power Supply (kg)	Power Switch (kg)	PWBA (kg)	Rear Cover (kg)	Other (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	1.27E-01	-	-	2.67E-01	-	-	-	-	4.05E-02	-	-	4.35E-01
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	3.84E+00	1.43E+00	-	-	-	-	5.37E-01	-	1.44E-02	1.10E+00	-	6.91E+00
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	1.68E-03	-	3.64E-02	2.59E-01	9.31E-03	-	7.17E-02	-	1.80E-01	-	-	5.58E-01
4. Oxide ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	3.17E-01	-	-	-	-	1.87E-02	-	-	3.36E-01
5. Ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	-	-	-	-	-	7.55E-04	-	-	7.55E-04
6. Epoxy	Disposal, paint, 0% water, to inert material landfill/CH U	-	-	-	2.15E-01	-	-	-	-	1.93E-02	-	-	2.34E-01
7. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	3.62E-01	-	-	-	-	-	-	-	3.68E-02	--	-	3.99E-01
8. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	--	-	3.21E-04	-	-	-	4.49E-06		1.02E-03	1.34E-03
9. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	7.86E-01	-	-	-	-	--	4.25E-02	-	2.69E-02	-	-	8.55E-01
10. PET plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	-	--	-		1.05E-03	-	-	1.05E-03
11. PP	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	-	8.59E-04	-	-	8.59E-04
12. PVC	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	1.63E-03	-	3.57E-02	-	1.60E-02	-	-	-	7.08E-04	-	1.34E-01	1.88E-01

Table 13 (continue) The LCD television screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	Backlight Unit (kg)	Base/ Stand (kg)	Inverter (kg)	LCD Cell (kg)	LCD Controller (kg)	Outer frame (kg)	Power Supply (kg)	Power Switch (kg)	PWBA (kg)	Rear Cover (kg)	Other (kg)	Total (kg)
13. ABS and ABSPC	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	-	6.42E-01	-	-	-	1.20E+00	-	1.20E-02	-	1.61E+00	-	3.47E+00
14. Nylon	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	3.84E-01	-	-	-	-	1.19E-02	-	-	3.96E-01
15. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	8.40E-02	-	-	-	-	-	-	-	2.21E-05	-	-	8.40E-02
16. other(plastics)	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	7.25E-03	-	1.58E-01	-	-	-	-	-	5.43E-03	-	1.09E-01	2.80E-01
17. Chemical organic compound	Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	-	8.48E-05	-	-	8.48E-05
18. Paper	Disposal, paper, 11.2% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	-	1.12E-03	-	-	1.12E-03
19. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	3.64E-03	5.41E-03	-	-	-	4.39E-04	-	1.72E-02	2.66E-02
20. LCD backlight coating	Disposal, spent activated carbon with mercury, 0% water, to underground deposit/DE U	5.43E-03	-	-	-	-	-	-	-	-	-	-	5.43E-03
21. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	-	-	-	-	-	-	-	-	-	-	1.59E-01	-
22. Inorganic	Disposal, waste, silicon wafer production, 0% water, to underground deposit/DE U	-	-	-	-	-	-	-	-	5.14E-03	-	-	5.14E-03

Table 14 The LED television screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library :(based on waste specific burdens)	Backlight Unit (kg)	Base/Stand (kg)	Inverter (kg)	LED Cell (kg)	LED Controller (kg)	Outer frame (kg)	Power Supply (kg)	Rear Cover (kg)	Other (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	1.42E-02	-	-	8.42E-01	-	-	-	-	-	8.56E-01
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	1.31E-02	3.41E-01	-	-	-	-	1.68E-01	2.63E-01	-	7.85E-01
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	7.26E-02	-	2.21E-03	6.00E-03	2.19E-02	-	2.25E-02	-	2.68E-02	1.52E-01
4. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	7.14E-03	-	-	-	-	-	-	-	-	7.14E-03
5. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	7.56E-04	-	-	-	4.67E-04	1.22E-03
6. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	5.34E-01	-	-	-	-	-	1.33E-02	-	-	5.47E-01
7. PVC plastic	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	-	-	2.17E-03	-	3.76E-02	-	-	-	5.71E-02	9.68E-02
8. ABS and ABSPC	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	-	2.75E-01	-	-	-	2.80E-01	-	1.22E+00	-	1.78E+00
9. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	8.40E-02	-	-	-	-	-	-	-	-	8.40E-02
10. other(plastics)	Disposal, plastics, mixture, 15.3% water,to sanitary landfill/CH U	-	-	9.62E-03	-	-	-	-	-	2.97E-02	3.93E-02
11. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	-	1.27E-02	-	-	-	7.89E-03	2.06E-02
12. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	1.96E-03	-	-	-	-	-	-	-	4.40E-02	4.60E-02

4.2.2 Recycling approach

Apart from landfilling approach, the mass inputs in recycling approach in this study considered from mechanical treatment of WEEE. Basically, television equipment mass had been divided into two steps as treatment level I and treatment level II as described in methodology chapter. The result in treatment level I occur from dismantled television devices are separated and sorted. The manual depollution step and mechanical sorting transfer coefficient were retrieved to calculate the distributed of fraction of waste which results differently in each specific device. This result is defined total input amount and recovering processes in treatment level 2. In this final stage, the treatment residues is detoxified and refine processing by chemical, thermal and metallurgical processes to produce secondary metal and to eliminate final residues. All outcomes are explained in this section below.

i. Treatment level one

- **Model 1: CRT television screen**

Table 15 showed the composition data of the CRT TV are used with the transfer coefficient and disintegrated fraction of device separating into four fractions. Cabinet is sent to proper incineration following working instruction. Regarding to this approach, the CRT television screen components was entered to 2nd treatment including: 70.86% CRT glass treatment unit, 17.24% to shredding process and 8.86% to incineration.

Table 15 Treatment level I –The transfer coefficients for the various components in mechanical depollution step of CRT television

Depollution components		Result of depolluted equipment input to further treatment (Kg)			
Sub-assembly	Components in Ecoinvent reference	PWBA for 2nd metal recycling (kg)	Shredding process (kg)	CRT glass treatment (kg)	Incineration (kg)
1. Cabinet	plastic parts, outside	-	2.06E+00	-	2.06E+00
2. Deflection yoke	CRT, deflection yoke	-	5.71E-01	-	-
3. Demagnetic coin	metal parts, inside	-	2.53E-01	-	-
	plastic parts, inside	-	3.34E-02	-	-
4. Electrical wire	metal parts, inside	-	8.63E-02	-	-
	plastic parts, inside	-	2.77E-02	-	-
5. PWBA	high quality, mounted	7.09E-01	7.09E-01	-	-
6. Anode connection	metal parts, inside	-	4.64E-02	-	-
	plastic parts, inside	-	1.72E-02	-	-
7. Main CRT	CRT tube, without gun	-	-	1.65E+01	-
	CRT, electron gun	-	1.58E-01	-	-
8. other	metal parts, inside	-	4.00E-03	-	-
	plastic parts, inside	-	4.40E-02	-	-
Total		**7.09E-01**	**4.01E+00**	**1.65E+01**	**2.06E+00**

Furthermore, CRT television screen shredding fraction had input as illustrated in previous table was calculated with transfer coefficients of WEEE shredder. Then, the summation of final fraction is output in different amount including: 14.21% of Ferro-fraction, 22.57% of copper fraction, 2.66% aluminum fraction and 60.56% of other residue. This separation would be taken as the input to treatment level 2.

Table 16 Composition of the depolluted of CRT television screen for the shredder and resulting fractions after the shredder process

Input substances	Input data (kg)	Resulting fraction			
		Ferro fraction (kg)	Aluminum fraction (kg)	Copper fraction (kg)	Residue (kg)
Aluminum	5.98E-02	3.01E-04	4.95E-02	2.94E-03	7.17E-03
Copper	7.58E-01	7.10E-03	3.80E-02	5.93E-01	1.20E-01
Ferro	5.59E-01	5.31E-01	5.58E-03	5.58E-03	1.67E-02
Glass	8.85E-02	4.92E-04	4.92E-04	8.85E-03	7.87E-02
Plastics	2.41E+00	2.91E-02	1.20E-02	2.41E-01	2.12E+00
Ag	1.48E-03	1.46E-05	1.46E-05	1.26E-03	1.93E-04
Au	5.16E-04	5.10E-06	5.10E-06	4.13E-04	9.28E-05
Pb	1.10E-02	1.29E-04	1.29E-04	8.79E-03	1.93E-03
others	1.23E-01	8.43E-04	8.26E-04	4.32E-02	7.78E-02
Total	**4.01E+00**	**5.69E-01**	**1.07E-01**	**9.04E-01**	**2.43E+00**

➢ Model 2: LCD television screen

Similar to level I, Table 17 showed number of LCD device fractions separating into six fractions. According to the mass flow calculation, the LCD television screen components was entered further treatment processes including : 50.11% shredding process treatment, 24.06%to metal scrap , 2.56% cable scrap recycling, 5.25% to PWBA recycling and 17.01% , 1.00% to incineration and Backlight lamp treatment respectively.

Table 17 Treatment level I – The transfer coefficients for the various components in mechanical depollution step of LCD television

Depollution components		Result of depolluted equipment input to further treatment (Kg)					
Subassembly	Components in Ecoinvent reference	PWBA for 2nd metal recycling	Shredding process treatment	Metal scrap recycling	Cable scrap Recycling	Backlight lamp treatment	incineration
1. Backlight unit	Backlight lamp	-	-	-	-	1.44E-01	-
	Metal parts, outside	-	1.92E+00	1.92E+00	-	-	-
	Plastic parts, inside	-	3.62E-01	-	-	-	-
	Plastic parts, outside	-	4.35E-01	-	-	-	4.35E-01

Depollution components	Result of depolluted equipment input to further treatment (Kg)						
Subassembly	Components in Ecoinvent reference	PWBA for 2nd metal recycling	Shredding process treatment	Metal scrap recycling	Cable scrap Recycling	Backlight lamp treatment	incineration
2. Base/Stand	Metal parts, outside	-	7.14E-01	7.14E-01	-	-	-
	plastic parts, outside	-	3.21E-01	-	-	-	3.21E-01
3. Inverter	Cable (power, w/o plugs)	-	2.30E-01	-	-	-	-
4. LCD Cell	LCD module, to incineration	-	-	-	-	-	2.70E-01
	cable (power, w/o plugs)	-	-	-	2.00E-04	-	-
	high quality, mounted	5.88E-01	5.88E-01	-	-	-	-
5. LCD controller	cable (power, w/o plugs)	-	-	-	3.10E-02	-	-
6. Outer frame	plastic parts, outside	-	6.01E-01	-	-	-	6.01E-01
7. Power Supply Assembly	Metal parts, inside	-	7.17E-02	-	-	-	-
	Metal parts, outside	-	2.68E-01	2.68E-01	-	-	-
	Plastic parts, inside	-	4.25E-02	-	-	-	-
8. Power Switch	Plastic parts, outside	-	1.20E-02	-	-	-	6.00E-03

Depollution components	Result of depolluted equipment input to further treatment (Kg)						
Subassembly	Components in Ecoinvent reference	PWBA for 2^{nd} metal recycling	Shredding process treatment	Metal scrap recycling	Cable scrap Recycling	Backlight lamp treatment	incineration
9.. Printed wiring boards	PWB, high quality, mounted	1.65E-01	1.65E-01	-	-	-	-
10. Rear Cover	Metal parts, outside	-	5.48E-01	5.48E-01	-	-	-
	Plastic parts, outside	-	8.05E-01	-	-	-	8.05E-01
11. 0ther	cable (others, with plugs)	-	-	-	1.87E-01	-	-
	cable (power, w/o plugs)	-	-	-	1.48E-01	-	-
	metal parts, inside	-	1.01E-01	-	-	-	-
Total		**7.53E-01**	**7.18E+00**	**3.45E+00**	**3.66E-01**	**1.44E-01**	**2.44E+00**

The shredding fraction of LCD television screen also calculated into sub-fractions with transfer coefficients of shredder (Table 18). As this matter, the different amount of this processing is including: 47.69% of Ferro-fraction, 7.33% of copper fraction, 1.89% aluminum fraction and 43.09% of other residue. These several fractions would be taken as inputs to appropriate treatment level 2.

Table 18 Composition of the depolluted of LCD television screen for the shredder and resulting fractions after the shredder process

Input substances	Input data (kg)	Resulting fraction			
		Ferro fraction	Aluminum fraction	Copper fraction	Residue
Aluminum	9.13E-02	4.59E-04	7.56E-02	4.49E-03	1.10E-02
Copper	1.39E-01	1.30E-03	6.97E-03	1.09E-01	2.21E-02
Ferro	3.56E+00	3.38E+00	3.55E-02	3.55E-02	1.06E-01
Glass	1.88E-01	1.05E-03	1.05E-03	1.88E-02	1.67E-01
Plastics	3.12E+00	3.77E-02	1.56E-02	3.12E-01	2.75E+00
Ag	5.04E-03	4.50E-05	4.50E-05	4.28E-03	6.60E-04
Au	6.73E-03	6.64E-05	6.64E-05	5.38E-03	1.21E-03
Pb	2.61E-02	3.06E-04	3.06E-04	2.09E-02	4.60E-03
others	4.58E-02	3.15E-04	3.08E-04	1.61E-02	2.90E-02
Total	**7.18E+00**	**3.42E+00**	**1.35E-01**	**5.26E-01**	**3.09E+00**

- Model 3: LED television screen

In case of LED television screen, Table 19 presented whole LED television screen fractions mass flow analysis. The further treatment processes from LED television fractions include: 539.23% shredding process treatment, 8.74% to metal scrap, 2.97% cable scrap recycling, 45.82% to incineration and 3.24% backlight lamp treatment respectively

Table 19 Treatment level I – The transfer coefficients for the various components in mechanical depollution step of LED television

Depollution components		Result of depolluted equipment input to further treatment (Kg)				
Subassembly	Components in Ecoinvent reference	Shredding process treatment	Metal scrap recycling	Cable scrap Recycling	Backlight lamp treatment	incineration
1. Backlight unit	Backlight lamp	-	-	-	1.43E-01	-
	Plastic parts, outside	2.92E-01	-	-	-	2.92E-01
2. Base/Stand	Metal parts, outside	1.71E-01	1.71E-01	-	-	-
	plastic parts, outside	1.38E-01	-	-	-	1.38E-01
3. Inverter	Cable (power, w/o plugs)	-	-	1.40E-02	-	-
4. LED controller	cable (power, w/o plugs)	-	-	7.30E-02	-	-
5. LED cell	cable (power, w/o plugs)	-	-	6.00E-03	-	-
	LCD module, to incineration	-	-	-	-	8.42E-01
6. Outer frame	plastic parts, outside	1.40E-01	-	-	-	1.40E-01
7. Power Supply Assembly	Metal parts, inside	2.20E-02	-	-	-	-
	Metal parts, outside	8.41E-02	8.41E-02	-	-	-
	Plastic parts, inside	1.33E-02	-	-	-	-
8. Rear Cover Assembly	Metal parts, outside	1.32E-01	1.32E-01	-	-	-
	Plastic parts, outside	6.11E-01	-	-	-	6.11E-01

Depollution components	Result of depolluted equipment input to further treatment (Kg)					
Subassembly	Components in Ecoinvent reference	Shredding process treatment	Metal scrap recycling	Cable scrap Recycling	Backlight lamp treatment	incineration
9. 0ther	cable (others, with plugs)	8.60E-02	-	-	-	-
	cable (power, w/o plugs)	-	-	3.80E-02	-	-
	metal parts, inside	4.40E-02	-	-	-	-
Total		1.73E+00	3.86E-01	1.31E-01	1.43E-01	2.02E+00

The shredding process of LED television can divided into useful sub-fractions based on transfer coefficients of shredder (Table 20). Finally, the different output amount from this processing is including: 1.21% of Ferro-fraction, 1.11% aluminum fraction, 79.43% of copper fraction, and 18.35% other residue. After that, this sorted fraction would be taken as inputs to further treatment level 2, respectively.

Table 20 Composition of the depolluted of LED television screen for the shredder and resulting fractions after the shredder process

Input substances In this study	Input data (kg)	Resulting fraction			
		Ferro fraction	Aluminum fraction	Copper fraction	Residue
Aluminum	2.25E-02	1.25E-04	1.25E-04	2.25E-03	2.00E-02
Copper	2.29E-02	2.77E-04	1.15E-04	2.29E-03	2.02E-02
Ferro	4.30E-01	4.26E-03	4.26E-03	3.66E-01	5.63E-02
Glass	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plastics	1.26E+00	1.47E-02	1.47E-02	1.01E+00	2.21E-01
Au	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
others	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**1.73E+00**	**1.94E-02**	**1.92E-02**	**1.38E+00**	**3.18E-01**

ii. Treatment level two

In this final stage, the second level for the treatment of television is presented as the further treatment of various fractions. Overall, results was showed in Table 21,22, and 23 included the amount of recycled material and potential revenue profits. The outcomes were described in this section below.

- **Model 1: CRT television screen**

Table 21, showed the recovered material from CRT screen recycling. The recycling one of CRT device could provide secondary Ferro and nonferrous metal about 2.29 kg and 2.55 kg. Interestingly, metal outcome possibly recover from recycling the model presented in Table22 which are; 2^{nd} steel production (20.20% of non-Ferro and Ferro recycled amount), 2^{nd} copper (45.00%), 2^{nd} aluminum (4.06 %), 2^{nd} nickel (2.52%), 2^{nd} lead (0.44%), 2^{nd} silver (25.59%), 2^{nd} palladium (1.41%), and 2^{nd} gold (0.78%). However, glass cullet from this recycling scheme is also generated from this at highest weight or 85.11% of total recycled material but less in value. As potential recovering revenue, the total value of monetary benefits is account for 3050 Thai baht. Copper is precious element perfectly bought to the highest revenue (43.57%) in just few amount as similar as Silver (33.14%). Nevertheless, the other recycled can also indicate to the benefits as well.

Table 21 Amount of recovered materials and potential profits in CRT television screen during treatment level II.

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2^{nd} Precious metal recovery from PWBA fraction	PWBA scrap	7.09E-01	2^{nd} Lead	1.13E-02	7.56E-01
			2^{nd} Nickel	6.43E-02	2.54E+01
			2^{nd} Copper	4.58E-01	1.04E+02
			2^{nd} Gold	1.98E-02	8.95E+02
			2^{nd} Palladium	3.60E-02	3.53E+01
			2^{nd} Silver	6.53E-01	1.80E+03
2. Shredding fraction Scrap metals recycling	Iron fraction recovery	5.69E-01	2^{nd} Steel	5.15E-01	1.03E+01
	Aluminum fraction recovery	1.07E-01	2^{nd} Aluminum	1.03E-01	6.08E+00
	Copper fraction recovery	9.04E-01	2^{nd} Copper	6.90E-01	1.57E+02
3. CRT Glass sorting	Mixed glass, culets	1.64E+00	Glass cullet	1.46E+01	1.38E+01
	Panel glass, culets	9.73E+00	-	-	-
	Funel glass, culets	5.02E+00	-	-	-
4. Disposal treatment	CRT coatings	9.26E-02	-	-	-
	Shredding residue	2.43E+00	-	-	-
	Plastics waste	2.06E+00	-	-	-
Total		2.33E+01	Total output 2^{nd} treatment	1.71E+01	3.05E+03

***Price of materials comes from 2 sources:**

1. Wongpanit (http://www.wongpanit.com/wpnnew/ 24/09/2013)

2. World Scrap (http://th.worldscrap.com/price/lme.php?&type=1&lang=th 24/09/2013)

➢ **Model 2: LCD television screen**

The total outcome of LCD television screen recycling is presented in Table 22. The overall scrap 14.32 kg can be recycled into new secondary metal which yield about 9.02 kg (62.99% recovered from total scrap). These total secondary resources can be classified into several types of materials (Table 23), 2nd steel production (68.60%) , (11.88%) 2nd copper, (1.46%) 2nd aluminum, (1.42%) glass cullet, (0.76 %) 2nd nickel, (0.13%) 2nd lead, (7.68%) 2nd palladium , (7.68%) 2nd silver, (0.01%) 2nd mercury, (0.02%) 2nd zinc sulfide and (0.23%) 2nd gold respectively

The potential recovering revenue from this scheme is around 2920 Thai baht. Especially, this majority of benefits came from 2nd steel which contributed about 62.92% of total revenue, following by 2nd palladium about 14.13%, 2nd silver about 10.37% and etc. However, gold and palladium have higher price than other trace elements and potential to make high potential benefit.

Table 22 Amount of recovered fraction material and potential profit in LCD television screen during treatment level II.

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2^{nd} steel recovery	Metal scrap	3.45E+00	2^{nd} Steel	3.10E+00	6.16E+01
2. 2^{nd} precious metal recovery	Printed wired board assembly scrap	7.53E-01	2^{nd} Lead	1.20E-02	8.03E-01
			2^{nd} Nickel	6.83E-02	2.69E+01
			2^{nd} Copper	4.86E-01	1.11E+02
			2^{nd} Gold	2.10E-02	1.27E+00
			2^{nd} Palladium	6.93E-01	6.80E+02
			2^{nd} Silver	6.93E-01	1.91E+03
3. Shredded fraction Scrap metals recycling	Iron fraction recovery	3.42E+00	2^{nd} Steel	3.10E+00	6.16E+01
	Aluminum fraction recovery	1.35E-01	2^{nd} Aluminum	1.31E-01	7.73E+00
	Copper fraction recovery	5.26E-01	2^{nd} Copper	4.01E-01	1.46E+01
4. Cable recycling treatment	Copper fraction recovery	3.66E-01	2^{nd} Copper	1.84E-01	4.21E+01
5. Fluorescent lamp recycling unit (mercury recovery , glass cullet, non-specific 2nd metal , phosphor recovery units)	CCFL lamp in LCD screens.	1.44E-01	2nd Mercury	7.20E-04	1.09E+00
			Glass cullet	1.28E-01	1.22E-01
			2^{nd} metal (No-specific type)	1.15E-02	-
			2^{nd} phosphor(assumed as ZnS)	2.16E-03	-

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
6. Disposal proportion	LCD module, to incineration	2.70E-01	-	-	-
	Shredding residue	3.09E+00	-	-	-
	Plastics waste	2.17E+00	-	-	-
	Phosphor waste (backlight lamp)	1.44E-03	-	-	-
Total		**1.43E+01**	Total output 2nd treatment	**9.02E+00**	**2.92E+03**

***Price of materials comes from 2 sources:**

1. Wongpanit (http://www.wongpanit.com/wpnnew/ 24/09/2013)

2. World Scrap (http://th.worldscrap.com/price/lme.php?&type=1&lang=th 24/09/2013)

➢ **Model 3: LED television screen**

Regarding to the LED television recycling, the overall outputs from recovering processes is presented in Table 23. The recycling efficiency expressed that they can turn 1.64 kg of inputs can be recovered into new secondary metal about 4.42 kg (approximately 37.10 % of treatment level II inputs). Total recycled metals were classified into 2nd steel (22.34%), 2nd copper (67.91%), 2nd aluminum (1.14%), 2nd glass cullet (7.75%), 2nd metal (0.70%) and 2nd ZnS (0.13%), respectively.

The potential recovering revenue, this obsolete LED television recycled materials can probably made profits around 264 Thai baht. A significant material contributing to revenue came from broad recycled traces; especially, from 2nd copper about 81.93% of total revenue, 17.92% from 2nd steel and 0.15% from 2nd aluminum.

Table 23 Amount of recovered fraction material and potential profit in LED television screen during treatment level II.

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2nd steel recovery	Metal scrap	3.86E-01	2nd Steel	3.49E-01	6.96E+00
2. Shredded fraction Scrap metals recycling	Iron fraction recovery	1.94E-02	2nd Steel	1.75E-02	3.49E-01
	Aluminum fraction recovery	1.92E-02	2nd Aluminum	1.87E-02	1.10E+00
	Copper fraction recovery	1.38E+00	2nd Copper	1.05E+00	2.39E+02
3. Cable recycling treatment	Copper fraction recovery	1.31E-01	2nd Copper	6.60E-02	1.51E+01
4. LED lamp recycling unit (mercury recovery , glass cullet, non-specific 2nd metal , phosphor recovery units)	LED lamp in LED screens.	1.43E-01	2nd Mercury	7.15E-04	1.08E+00
			Glass cullet	1.27E-01	1.21E-01
			2nd metal (No-specific type)	1.14E-02	-
			2nd phosphor(assumed as ZnS)	2.15E-03	-

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
5. Disposal proportion	LED module, to incineration	8.42E-01	-	-	-
	Shredding residue	3.18E-01	-	-	-
	Plastics waste	1.18E+00	-	-	-
	Phosphor waste (backlight lamp)	1.43E-03	-	-	-
Total		**4.42E+00**	Total output 2nd treatment	**1.64E+00**	**2.64E+02**

***Price of materials comes from 2 sources:**

1. Wongpanit (http://www.wongpanit.com/wpnnew/ 24/09/2013)

2. World Scrap (http://th.worldscrap.com/price/lme.php?&type=1&lang=th 24/09/2013)

4.3 Amount of recycled material in different models

Type and amount of recycled materials were estimated to declare the avoided process following the expanded system in LCA modeling. The Table 24 described the quantity level and types of primary processes which could be avoided. In facts, these occurred differently depending on amount of recycled matters in each of equipment. Ultimately, these flows will be calculated with background data and released into recycling inventory for further step in environmental impact assessment.

Table 24 The avoided primary production processes: data entering processes into SimaPro program

Recycled materials	Name of Avoided primary metal production in Ecoinvent database	Avoided amount of primary production		
		CRT (kg)	LCD (kg)	LED (kg)
2nd Aluminum	Aluminum, primary, at plant/RER U	1.03E-01	1.31E-01	1.87E-02
2nd Steel	Steel, low-alloyed, at plant/RER U	5.15E-01	6.19E+00	3.67E-01
2nd Copper	Copper, primary, at refinery/GLO U	6.90E-01	4.01E-01	1.12E+0
2nd Lead	Lead, primary, at plant/GLO U	1.13E-02	1.20E-02	-
2nd Nickel	Nickel, 99.5%, at plant/GLO U	6.43E-02	6.83E-02	-
2nd Silver	Silver, at regional storage/RER U	6.53E-01	6.93E-01	-
2nd Gold	Gold, primary, at refinery/GLO U	1.98E-02	2.10E-02	-
2nd Palladium	Palladium, primary, at refinery/ZA U	3.60E-02	6.93E-01	-
2nd Mercury	Mercury, liquid, at plant/GLO U	-	7.20E-04	7.15E-04
2nd unspecific metal	Steel, low-alloyed, at plant/RER U	-	1.15E-02	1.14E-02
2nd phosphor	Zinc sulphide, ZnS, at plant/RER U (proxy assumption	-	2.16E-03	2.15E-03
Glass cullet	Glass cullet, sorted, at sorting plant/RER U	1.46E+01	1.28E-01	1.27E-01
Total		**1.71E+01**	**9.02E+00**	**1.64E+00**

4.4 The scenario analysis: the total amount of recycled material output

The scenario analysis also explored situation during 2014-2023 through three scenarios. Two scenarios are modeled to apply appropriate recycling approach in Thailand included either 5% or 20% collecting to recycling processes. The study assumed 39,592,143.85 television units will be disposed as explained in chapter III. The results were estimate the potential recovered and potential revenues.

4.4.1 Model 1: CRT television screen

Table 25 the amount of recycled materials according to the end of life managing scenario in CRT television screen for 10 years timeframe

CRT television screen recovered fractions	S2: recycling 5%		S3: recycling 20%	
	recycled mass amount (kg)	potential revenue (THB)	recycled mass amount (kg)	potential revenue (THB)
2nd Steel	1.02E+06	2.03E+07	4.08E+06	8.12E+07
2nd Aluminum	2.04E+05	1.02E+07	8.16E+05	4.79E+07
2nd Copper	1.37E+06	3.12E+08	5.46E+06	1.25E+09
2nd Gold	3.92E+04	2.36E+06	1.57E+05	9.45E+06
2nd Lead	2.24E+04	1.49E+06	8.95E+04	5.98E+06
2nd Nickel	1.27E+05	5.02E+07	5.09E+05	2.01E+08
2nd Palladium	7.13E+04	6.99E+07	2.85E+05	2.80E+08
2nd Silver	1.29E+06	3.56E+09	5.17E+06	1.42E+10
Glass cullet	2.89E+07	2.75E+07	1.16E+08	1.10E+08
Total	**3.30E+07**	**4.06E+09**	**1.32E+08**	**1.62E+10**

CRT television screen, the results from two scenarios showed mass of recycled material and potential revenue. Recycling 5%, silver cullet is the most mass from recycling process follows by copper, nickel and others. The potential revenue of silver is the highest money value and total money of 5% recycling about 4.06E+09 bath Thai. Apart from this, 10% recycling generated glass cullet is the most mass of recycling 5% and silver can sell in highest money value. Results of comparing from two scenarios in 10 years showed 20% recycling can generate higher material mass and potential revenue more than 5% recycling.

4.4.2 Model 2: LCD television screen

Table 26 the amount of recycled materials according to the end of life managing scenario in LCD television screen for 10 years timeframe

LCD television screen recovered fractions	S2: recycling 5%		S3: recycling 20%	
	recycled mass amount (kg)	potential revenue (THB)	recycled mass amount (kg)	potential revenue (THB)
2nd Steel	1.23E+07	2.44E+08	4.90E+07	1.20E+09
2nd Aluminum	2.59E+05	1.52E+07	1.04E+06	4.10E+06
2nd Copper	7.94E+05	1.81E+08	3.18E+06	1.16E+08
2nd Gold	4.16E+04	2.51E+06	1.66E+05	1.00E+07
2nd Lead	2.38E+04	1.59E+06	9.50E+04	2.35E+04
2nd Nickel	1.35E+05	5.33E+07	5.41E+05	2.06E+06
2nd Palladium	1.37E+06	1.35E+09	5.49E+06	2.69E+08
2nd Silver	1.37E+06	3.78E+09	5.49E+06	1.97E+08
2nd Mercury	1.43E+03	2.15E+06	5.70E+03	8.61E+06
Glass cullet	2.53E+05	2.41E+05	1.01E+06	2.23E+04
Total	**1.65E+07**	**5.26E+09**	**6.60E+07**	**2.25E+10**

LCD television screen, recycling 5% showed steel is the most mass and silver showed highest potential revenue from recycling process in both scenarios. But when compare total of recycled mass and money value from 20% of recycling can generate recycled mass and potential revenue higher than recycling 5% same CRT model.

4.4.3 Model 3: LED television screen

Table 27 the amount of recycled materials according to the end of life managing scenario in LED television screen for 10 years timeframe

LED television screen recovered fractions	S2: recycling 5%		S3: recycling 20%	
	recycled mass amount (kg)	potential revenue (THB)	recycled mass amount (kg)	potential revenue (THB)
2nd Steel	7.27E+05	1.45E+07	2.91E+06	5.79E+07
2nd Aluminum	3.70E+04	2.18E+06	1.48E+05	8.70E+06
2nd Copper	2.22E+06	5.06E+08	8.87E+06	2.02E+09
2nd Mercury	1.42E+03	2.14E+06	5.66E+03	8.55E+06
Glass cullet	2.51E+05	2.39E+05	1.01E+06	9.55E+05
Total	**3.24E+06**	**5.25E+08**	**1.29E+07**	**2.10E+09**

LED television screen generate copper as the highest mass and the highest potential revenue from recycling process. In two scenarios, the total mass recycled and potential revenue same previous models is 20% recycling more benefit than 5%.

For estimating scenario analysis results of television models in 10 years found that 20% of recycling scenario can get the most benefits following by recycling 5% scenario when consider upon mass recycled and potential revenue..

The analysis assumed 2 hypotheses (1) this study includes impact from collecting and taking TV back to recycling. Number of television equipment forecasted in Thailand is only recycling step without material loss. (2) The potential revenue from this recycling does not take into account the operational cost and other relevant aspect.

CHAPTER V
LIFE CYCLE IMPACT ASSESSMENT

5.1 Life cycle impact assessment of End-of-life management (per unit impact)

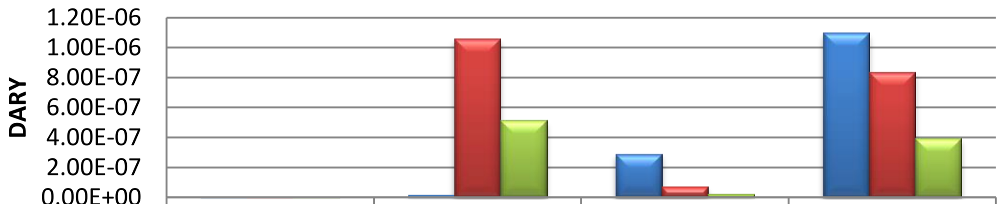
Environmental impact assessment was done by Recipe 2008 method. This study calculated and performed overall impacts from treating different model of television equipment by landfilling and recycling. Overall, this study reported endpoint impact score based on the three environmental impact including human health, ecosystem quality and resource availability. Then, three impacts would be aggregated via through weighting calculation into one single score which helpful to comparison between different managing approach.

5.1.1 The Human health endpoint impact category

The human health impact calculated using Recipe 2008 method were integrated from relevant six midpoint environmental impacts including climate change human health, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation and ionizing radiation. These midpoints were aggregated into DALY or disability-adjusted life year unit with the endpoint characterization factor. This study only showed some of midpoint impact indicator which contributed top four ranks of environmental burdens or benefits to the human health endpoint impacts. Overall, the results are described below.

i. Landfilling burdens contributing to human health impact

Impacts from landfilling of television screens to human health are estimated as the endpoint score. Top four midpoint impacts are presented as the main proportion contributed to endpoint impact including the ionizing radiation impact, particulate matter impact, human toxicity impact and climate change in human health impact as shown in Figure 24.



	Ionising radiation	Human toxicity	Particulate matter formation	Climate change Human Health
CRT	1.69E-10	1.74E-08	2.90E-07	1.10E-06
LCD	1.66E-10	1.06E-06	7.26E-08	8.37E-07
LED	6.95E-11	5.16E-07	2.38E-08	3.97E-07

Figure 24 The characterized of human health impact according to CRT, LCD, and LED television screen landfilling approach

For CRT television screen in proper landfilling affected to human health with endpoint score about 1.42E-06 DALY. The highest midpoint attributed to the human health endpoint is ***climate change human health impact*** burdens about 78.14% of overall human health impact category (1.1E-06 DALY). The result found that the disposal of cabinet containing ABS plastic to the sanitary landfill contributed almost 57.26% of all human toxicity. For ***particulate matter formation impact*** category, this environmental impact contributed only 2.90E-07 DALY (20.60%) of total human health categories. This particulate matter formation impact for human impact generated around 76.61% from disposed hazardous waste, 12.29% from disposed glass and 6.64% from disposed polystyrene. ***Human toxicity impact*** generated about 1.24 % of total human health impact. This impact mainly came from the sanitary landfill of polystyrene (71.13% of this impact), following by incineration of coatings in CRT screen (10.37%) and other toxic substances (18.50%). The least contributor is ***ionizing radiation impact***; the ionizing radiation impacts are contributes less in this category (0.01% or 1.69E-10 DALY). These are come from disposal hazardous waste (70.28%) and polystyrene landfill (18.90%).

Disposal of LCD television screen in landfilling affected to human health with endpoint score about 1.98E-06 DALY .The four midpoint impact are performed as the main proportion contributed to endpoint impact (as shown in Figure 24) including the human toxicity impact, climate change in human health impact , particulate matter and ionizing radiation impact, respectively. The ***human toxicity impact*** category displayed as the highest midpoint attributed to endpoint human health burdens about 1.06E-06 DARY (53.81%) of overall human health impact category. Disposal of plastics parts to landfilling could generate tremendous of human toxicity than other parts (about 56.61 % of total burdens). Especially, the ABS plastics inside LCD screen provided largest impact than other plastics. The ***climate change human health impact*** affected to the human health category by contributing burdens about 8.37E-07 DALY (42.49%) of total human health categories. This category generated from plastics of LCD landfilling approximately 63.90% of entire climate change impact. In facts, the disposals of ABS plastics contribute high proportion of this impact. The ***particulate matter formation impact*** contributes to human health impact about 7.26E-08 DALY (3.69%). The severity of particulate matter formation impact are different relied on types of waste in which 34.21% of impact from hazardous waste, 24.26 % from ferrous metal and 22.30 % from other toxic substances. As the least contribution of human health impact, the ***ionizing radiation impact*** (0.01% or 1.66E-10) came from LCD plastics burdens for 54.4% of this sub impacts.

LED television screen landfilling, this human health impact is about 9.37E-07 DALY. The overall results are performed as shown in Figure 24. This are aggregated from all relevant midpoint impact of human health impact; however the major proportion of human health impact (DALY unit) was generated from top four impacts including human toxicity, climate change in human health, particulate matter and ionizing radiation. The ***human toxicity impact*** displayed as the highest midpoint contributed to the human health endpoint burdens which contributed 5.16E-7 DALY (55.08 %) to this endpoint category. The result showed that the disposal of plastics to sanitary landfilling can cause human toxicity at high level. Plastic landfilling contributed for 90.05% (PE and PS plastics as main impact contributor) and 3.74% for other plastic. For ***climate change human health impact*** category, this environmental impact contributed for 3.97E-07 DALY (42.37 %) of total human health categories. The plastics parts from disposed LED screen provided the high numbers of burdens which contributed from diesel burned in processes during operated the landfill. Burdens from landfilling plastic about 89.46 % of climate change affecting to human health; especially, in PE and ABS plastic landfilling. Apart from this, the disposed of hazardous waste contributed to human health climate change for 2.83 % and dispose from the other about 7.53 The ***particulate matter formation impact*** results represented as significant impact which contributed for 2.54% of entire human health impact (2.38E-08 DALY). The particulate matter information was generated for 34.97 % from polystyrene, 30.20 % from hazardous waste and 10.69 % from ABS plastics landfilling. ***Ionizing radiation impact*** has the least contribution comparing to top 4 impacts of human health impacts which contribute only 6.95E-11 DALY (0.01 %). These also came mainly from plastic approximately 73.74 % as well as PE and PS to landfill.

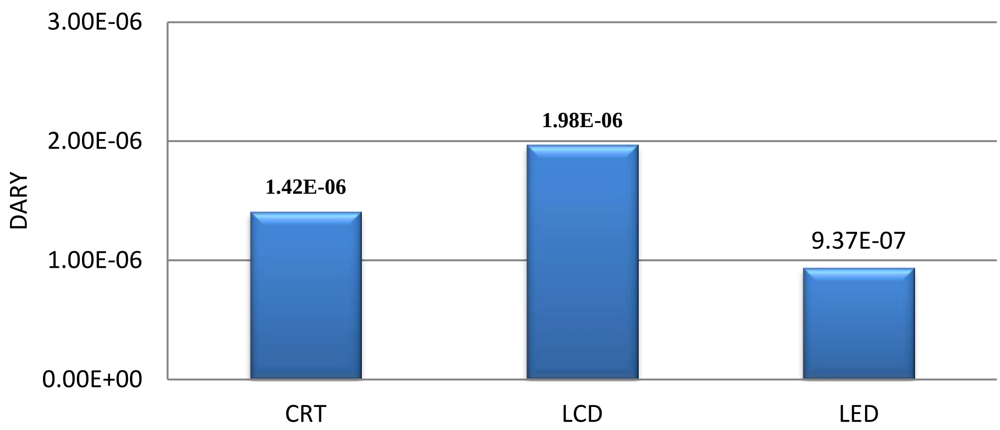
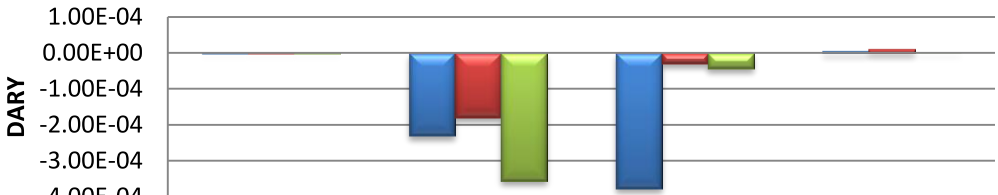


Figure 25 The human health comparison between television equipment contributing from landfilling approach

According to the landfilling approach when compared the human health impact between three devices (Figure 25), the LCD television screen has highest potential to impact human health. The study found that LCD television screen contributed human health impact about 28.28% higher than CRT screen 52.68% of LED television screen.

ii. The recycling approach burden contributing to human health impact



	Ionising radiation	Human toxicity	Particulate matter formation	Climate change Human Health
CRT	-1.04E-07	-2.30E-04	-3.77E-04	5.18E-06
LCD	-1.83E-08	-1.79E-04	-2.93E-05	1.12E-05
LED	-1.59E-08	-3.55E-04	-4.32E-05	1.51E-06

Figure 26 The avoided of human health impact according to CRT, LCD, and LED television screen recycling approach

The CRT recycling scheme can avoid overall impacts on human health as shown in negative impact DALY about -6.02E-04 DALY (Figure 26). The recycling processes can cause -3.77E-04 DALY (62.62%) of human health impact through the midpoint ***particulate matter formation impact***. In facts, this ia an advantage of CRT from subtraction impact of copper production and PWBA recycling from subtraction of palladium. Two main processes are avoided impact from blasting substances emission mainly including sulfur dioxides, particulate matter. ***Human toxicity impact*** help avoid -2.30E-04 DALY (38.22%) of human health problem when apply recycling scheme. The majority of this subtraction came from the elimination of landfilling of sulfuric tailing producing in mining. Furthermore, when focused on substance contribution to this impact, recycling can avoid the impact mainly from manganese waterborne, arsenic waterborne, arsenic airborne emission and lead substances, respectively. The ***ionization radiation impact*** on human health category can avoid about (-1.04E-07 DALY (0.02%) of entire human health endpoint impact. In facts, recycling scheme can help avoid the radon-122 emission due to the electricity producing which mainly founded in palladium production. Due to recycling scheme, the midpoint ***climate change human health impact*** affected to human health impact about -0.86% (5.18E-08 DALY) of overall avoided endpoint impact. When focusing on the impact contribution, it help recover of the precious metal from PWBA and avoided from recovering the shredded fraction (recycling of steel, aluminum and copper).

The benefit of LCD recycling scheme to human health is shown in Figure 26. This LCD screen recycling can avoid this kind of impact about-2.06E-04 DALY. The largest contribution of the advantages to human health in LCD television screen recycling came from avoided the ***human toxicity impact***. Particularly, recycling or reduction of human toxicity impact provide benefits about 90.82% to human health impact (-1.79E-04 DALY). Particularly, this avoided impact provided the benefits of human health impact from recovery of copper from PWBA, shredded fraction and cable because recycling scheme eliminated the pollution emitted from disposal of tailing from mining processes. Next, ***particulate matter formation impact*** also showed the -2.93E-5 DALY (14.85%) of avoided human health endpoint impact.

Overall, recycling avoided the formation of particulate matter from sulfur dioxide, particulate matter, and non-ferrous smelter. The recycling of LCD screen can reduce small amounts of human health impact from avoided ***ionization radiation impact*** 0.01% which came from avoided of some radiation in electricity producing which hazard to human health through the uranium tailing. The ***climate change human health impact*** affected to human health impact around 1.12E-05 DALY. Interestingly, recycling of steel from LCD ferrous scrap and shredder fraction can provide precious metal recovery. This is because recycling can eliminate carbon dioxide and methane emission.

LED recycling scheme can avoid overall impacts on human health as the results shown in Figure 26. The avoided human health impact is described as negative results on different impact categories. For overall benefits, this recycling are avoided adversely affect to human health about -3.97 E-04 which particularly came from different significant impacts. It is apparent that ***human toxicity impact*** would be enormously reduced by recycling which is totally sink the negative impact about -3.55E-04 DALY (89.48%). Eventually, the avoided of human toxicity impact significantly performed through cable recycling (mainly benefits from copper production and shredded fraction recycling) For ***particulate matter formation impact***, it distributed to human health impact for -4.32E-05 DALY (-10.89%). Focusing on processes, recycling can avoid the particulate matter impact causing from copper production following by palladium production and other processes. Because of the avoided substances in recycling scheme, this can reduce coagulation of particulate matter from sulfur dioxide. The recycling can avoided impact from ***ionization***

radiation impact in the process of primary metal production for -1.59E-08 DALY of total human health impact. The recycling scheme was avoided the impact from releasing of radon and carbon-14. The ***climate change human health impact*** which potential affected to human health category contributed around 1.51E-06 DALY of human health impact category. Recycling can reduce the burning processes from precious metal recovery shredded fraction recycling.

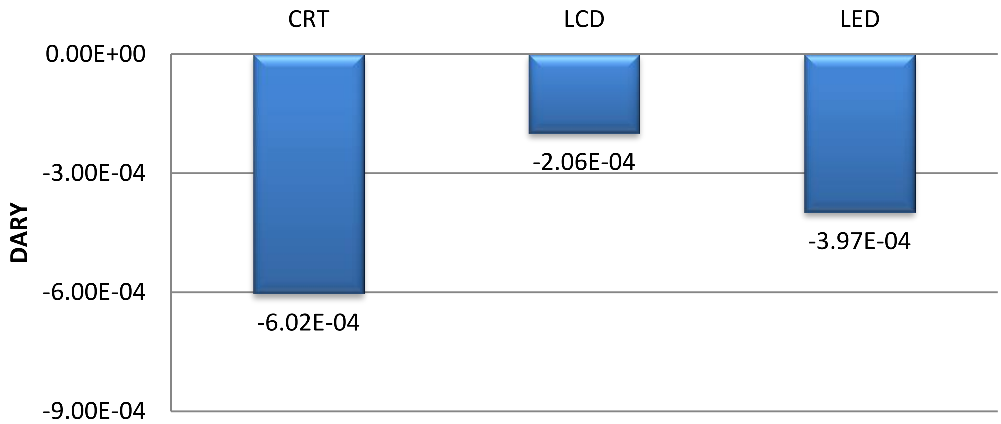


Figure 27 The Human health comparison between television equipment contributing from recycling approach

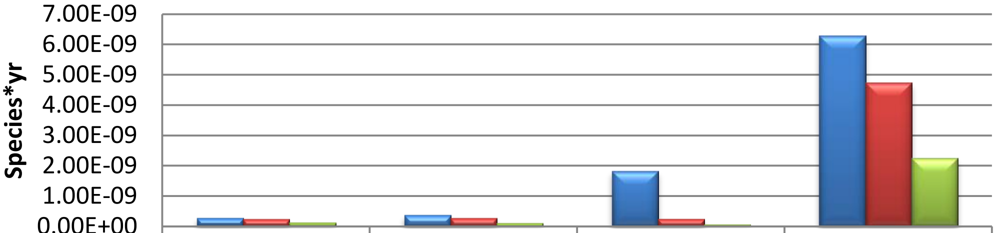
According to the overall result, the human health endpoint impact mainly distributed from the same types of mid-impacts. As shown in Figure 27, recycling of CRT has highest potential to avoid the human health impact, and higher than LED recycling about 34.05%and LCD recycling about 65.78%.

5.1.2 The Ecosystem endpoint impact category

In this study, the ecosystem quality was revealed by showing the loss of species per year. In this case, the damaging of ecosystem diversity will be shown as the unit of "species * yr." This study only showed some of midpoint-impact indicator which contributed top four ranks of environmental burdens to the ecosystem endpoint impacts. Overall, the results are described below.

i. Landfilling burdens contributing to ecosystem impact

The results of landfilling impact to the ecosystem are shown in the Figure 28. There are revealed the loss of diversity in ecosystem. For this endpoint impact score matter, there was distributed from top four midpoint impacts are presented as the main proportion contributed to end point impact including agricultural land occupation impact, urban land occupation impact, terrestrial ecotoxicity impact and climate change eco system impact.



	Terrestrial ecotoxicity	Urban land occupation	Agricultural land occupation	Climate change Ecosystem
CRT	2.76E-10	3.75E-10	1.83E-09	6.29E-09
LCD	2.34E-10	2.69E-10	2.47E-10	4.74E-09
LED	1.19E-10	1.06E-10	7.16E-11	2.25E-09

Figure 28 The characterized of ecosystem impact according to CRT, LCD, and LED television screen landfilling approach

For CRT, the results of landfilling affected to overall ecosystem with endpoint score about 7.15E-09 species*yr. The ***climate change eco system impact*** displayed as the highest midpoint impact affected to ecosystem category around 6.29E-09 species*yr. (87.98%). ***Agricultural land occupation impact*** attributed to the ecosystem endpoint about 1.83E-09 species*yr. (25.74%) of overall ecosystem impact category. The result found that disposal of hazardous waste to underground deposit around 95.53% and 2.46% from disposal glass to landfill. For ***urban land occupation impact*** category contributed about 3.75E-10 species*yr. (5.27 %) of total ecosystem impact. This urban land occupation impact for ecosystem impact generated around 37.16% from plastic parts to landfilling, 35.20% for CRT glass to landfilling and 14.33% from hazardous waste management. The ***terrestrial ecotoxicity impact*** contributed about 2.76E-10 species*yr. (3.88%) to ecosystem quality deterioration.

Disposal of LCD television screen in landfilling, the results affected to ecosystem with endpoint score about 4.36E-09 species* yr. The ***climate change eco system impact*** displayed as the highest midpoint attributed to endpoint ecosystem burdens about 4.74E-09 species*yr. (81.41%) of overall ecosystem impact category. Disposal of plastics to landfilling could generate tremendous of ecosystem category (about 84.31% of total berdens). Especially, the ABS plastic and PE provide largest impact than other plastics. The ***urban land occupation impact*** effected to the ecosystem category by contributing burdens about 2.69E-10 species*yr. (6.13%) of total ecosystem categories. Almost 54.35% of this impact generated from plastic landfilling approximate and 24.26% from ferrous metal. As ***agricultural land occupation impact*** contribute to ecosystem impact about 2.47E-10 species*yr. (5.63%) of total ecosystem impact, mainly from LCD toxic substances landfilling (79.27%) The ***terrestrial ecotoxicity impact*** affected to ecosystem category contributed around 2.34E-10 species*yr.

LED television screen landfilling can generate negatively affected to ecosystem which reflected as the loss of species about 2.210E-09 species* yr. (Figure 28). The ***climate change ecosystem impact*** displayed as the highest midpoint contributed the ecosystem endpoint burdens which contributed 25E-209 Species* yr. (85.05 %) of ecosystem quality. The result showed that disposal of PS plastics waste to landfill can cause ecosystem at high level about 69.19 % following by PE plastic (about 20.26%) and toxic substance (about 2.84%). For ***terrestrial ecotoxicity impact***, this impact distributed about 1.19E-10 species* yr.5.39 % (5.39 %) of total ecosystem category. The plastics contribute approximately 99.33 % of overall impact such as PE plastic, PS plastic and others. The ***urban land occupation impact*** category distributed 1.06E-10 species* yr. (4.80 %.) to the ecosystem for endpoint impact. The urban land occupation impact was generated for 74.51% from plastics, 7.66 % from glass and 7.02 % from ferrous metal. ***Agricultural land occupation impact*** has the least contribution comparing to top 4impacts of ecosystem which contributed 7.16E-11 species* yr. (3.24 %) of ecosystem impact. This impact contributed mainly from toxic substance (about 78.80%), ABS plastic landfilling (9.06 %) and glass landfilling (3.86%).

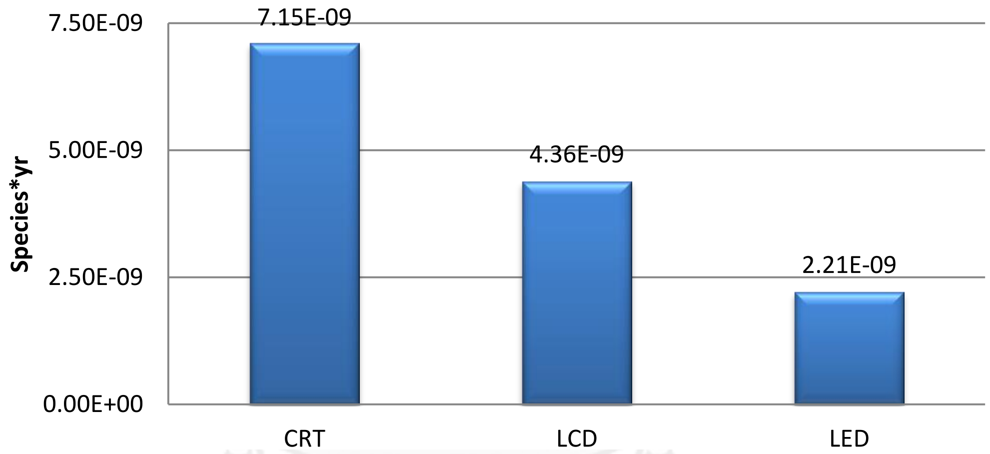
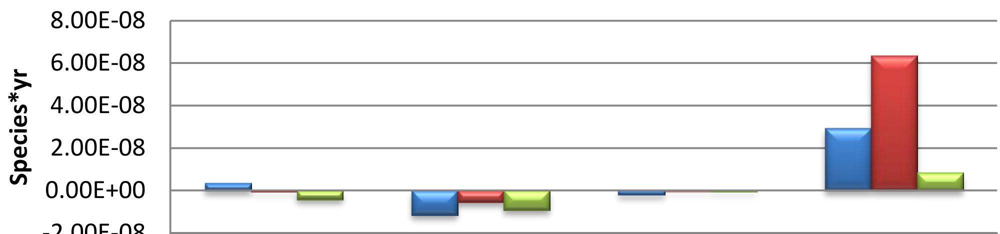


Figure 29 The Ecosystem impact comparison between television equipment contributing from landfilling approach

According to the landfilling approach, when compared the ecosystem impact between three models (Figure 29). The CRT television screen has highest potential to impact ecosystem following by LCD landfilling and LED landfilling. The CRT television contributed ecosystem impact about 39.02% higher than LCD, 69.09% of LED television screen.

ii. The Recycling approach burden contributing to ecosystem impact

The recycling scheme can avoid overall impacts on ecosystem negative impact Species*yr. due to the avoided primary material acquisition (Figure 30). These benefits came from four midpoint impacts are presented and described below.



	Terrestrial ecotoxicity	Urban land occupation	Agricultural land occupation	Climate change Ecosystems
CRT	3.57E-09	-1.16E-08	-1.91E-09	2.93E-08
LCD	-5.20E-10	-5.42E-09	-3.61E-10	6.35E-08
LED	-4.13E-09	-9.15E-09	-5.42E-10	8.57E-09

Figure 30 The avoided of ecosystem impact according to CRT, LCD, and LED television screen recycling approach

For CRT, the benefit from recycling scheme to ecosystem can avoid this kide of impact about -3.37E-08. The recycling processes can cause -1.16E-08 species*yr (34.44%) of ecosystem impact through the midpoint ***urban land occupation ecosystem impact.*** When focused into recycling processes, this can significantly avoid urban land occupation impact from palladium, gold, and copper from avoided mineral extraction site. ***Agricultural land occupation impact*** help avoid -1.91E-09 species*yr. (5.70%) of ecosystem problem when apply recycling scheme. Land uses are reducing agricultural production, mineral extraction and human settlement. The ***terrestrial ecotoxicity impact*** on ecosystem category affected to this impact about 3.57E-09 species*yr of entire ecosystem endpoint impact. This calculates the toxic substances can contaminate to the ecosystem through fate and exposure factors by reduced 14DCB to industrial soil. Due to recycling scheme, the midpoint ***climate change ecosystem impact*** affected to ecosystem impact only 2.93E-08 species*yr of overall avoided endpoint impact. The recycling can reduce this impact; especially, from recovered gold and palladium following by other shredding fraction recycling including steel, aluminum and copper.

The benefit of LCD screen recycling can avoid overall ecosystem impacts about 4.95E-08 species*yr. The highest contribution of the advantages to ecosystem come from ***urban land occupation impact*** approximately -5.42E-09 species* yr. (36.84 %.) of total endpoint ecosystem impact. Typically, PWBA recycling can avoid this impact following by LCD shredded fraction recycling, and cable recycling. In other words, this management scheme can reduce dumpsite and mineral extraction site land use. The ***terrestrial ecotoxicity impact*** showed -5.20E-10 species*yr. (10.99%) of benefit from avoided of ecosystem impact. In fact, recycling can totally prevent the impact from land transformation during the primary metal extraction including from sulfuric tailing impact. The toxic substances can contaminate to the ecosystem through fate and exposure factors by reduced 14DCB to industrial soil. The ***agricultural land occupation impact***, LCD television screen recycling can reduce amount of ecosystem impact about -3.61E-10 species* yr. (2.47%). Land uses are reducing agricultural production, mineral extraction and human settlement. The ***climate change ecosystem impact*** affected to ecosystem impact around 6.35E-08 species*yr. of ecosystem impact. The system contribution results revealed that recycling can avoided many process leading to climate change such as the intermediate producing of iron or pig iron, natural gas burning, diesel burning and etc.

LED recycling scheme can avoid overall impacts on ecosystem as shown in Figure 30. The ecosystem endpoint category overall can reduce ecosystem impact about -2.04E-08 species*yr. ***Urban land occupation impact*** would be enormously reduced by recycling which is totally sink negative impact about -9.15E-09 species*yr. (44.93%). This recycling approach generated the positive ecosystem quality which mainly came from recovering gold, copper, silver, and other via cable and shredded fraction recycling. For the processes contribution can avoid the mineral extraction site occupational impact The recycling can avoided impact from ***terrestrial ecotoxicity impact,*** it distributed to ecosystem impact about -4.13E-09 species* yr. (14.76%) This calculates the toxic substances can contaminate to the ecosystem through fate and exposure factors by reduced 14DCB to industrial soil. For the ***agricultural land occupation impact***, LED recycling can avoid this impact and consequently reduce ecosystem endpoint impact about -5.42E-10 species* yr. (2.66%) Land uses are reducing agricultural production, mineral extraction and human settlement. The ***climate change ecosystem impact*** affected to ecosystem impact only 8.57E-09 species*yr. of overall ecosystem impacts. Interestingly, the total impact was avoided according to recovery from gold and palladium production. The recycling of shredded fraction (copper, aluminum, steel) can also avoid this climate change impact.

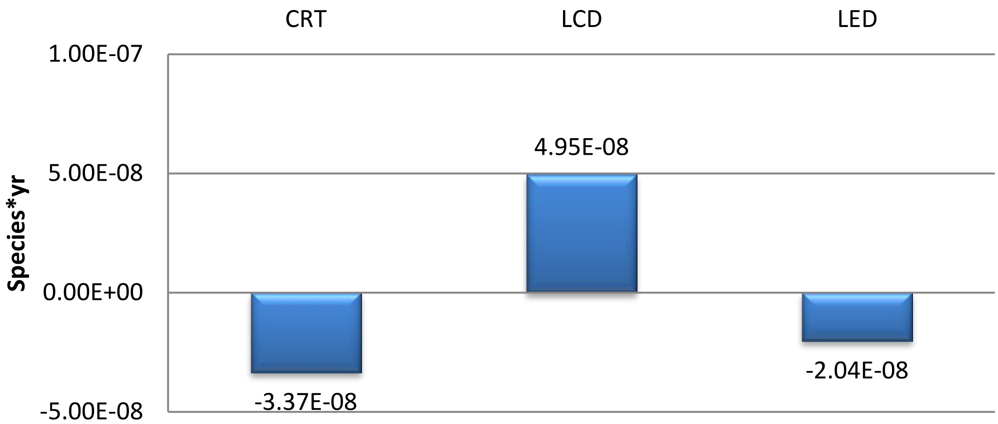


Figure 31 The Ecosystem impact comparison between television equipment contributing from recycling approach

According to the recycling of all television models, the ecosystem endpoint score can avoid which largely contributed from urban land occupation impact. It can be seen that recycling of CRT can reduce ecosystem impact more than LED and LCD screen (Figure 31). In facts, recycling of CRT would gather the ecosystem benefit more than LED screen for 141.21% and also 246.88% than LCD television screen. This is because the amount of recyclable material existing in CRT than other two equipment.

5.1.3 The Resource depletion endpoint impact category

The resource depletion impact category was presented as the money value ($) which referring to the increasing of additional cost according to the resource extraction in the future. The resource depletion score is aggregated from both metal depletion impact and fossil depletion impact which established on the criteria of

Recipe 2008 method and this was different depended on each equipment landfilling and recycling scheme as describes in the section below.

i. The landfilling burdens contributing to resource depletion impact

The result of this study indicate these television screen landfilling can impact to the resource which brought about to the surplus cost from the depletion fossil and metal resource as shown in Figure 32

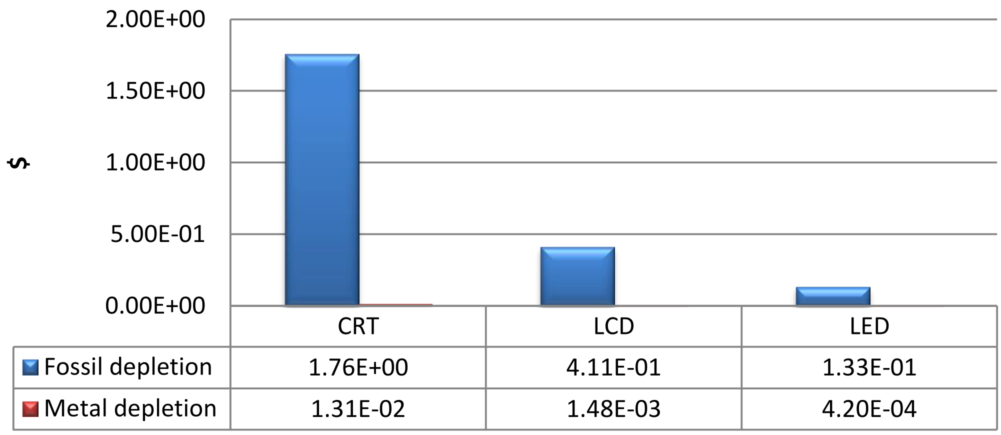


Figure 32 The contribution of resource depletion impact due to CRT, LCD, and LED screen landfilling approach

CRT television screen landfilling can cause impact to the resource which brought about to the surplus cost about 1.77E00 $ (as shown on Figure 32) which came from the depletion fossil and metal resource. 1.76E+00 (99.26%) of overall resource depletion impacts contributed from ***fossil depletion impact***. When focus on the waste type management, the result found that the fossil depletion impact was utilized in plastic parts landfilling following by CRT glass coating, toxic substance landfilling and etc. The ***metal depletion impact*** from CRT television screen landfilling contributed to the overall resource depletion about 1.31E-02 $0.74% (0.74%) As this result, a large proportion of metal depletion impact came from landfilling of CRT toxic substance around 99.24%

LCD television screen in landfilling affected to overall resource depletion about 6.51E-03 $ (as shown on Figure 32). The ***fossil depletion impact*** displayed as the highest midpoint attributed to endpoint impact 4.11E-01$ (99.64 %). The result found that LCD screen management can significantly lead to fossil resource depletion contributed from toxic substances 41.13% landfilling, ferrous metal 23.18% and plastics 20.73 landfilling. Apart from previous impact, ***metal depletion impact*** contributed to endpoint resource depletion impact about 1.48E-03 (0.36%) by contributed from toxic substances 98.41%, silicon 1.49%, and plastic 0.06%.

The LED screen landfilling can contribute to overall the resource depletion impact about 1.33E-01 $ from fossil and metal depletion (Figure 32). The ***fossil depletion impact*** can contribute about 1.33E-01 $ (99.69%) of overall resource impact. The result showed that some waste type management can affect to the fossil resource depletion including plastics and toxic substance about 43% and 33.80% respectively. For ***metal depletion impact*** contributed to overall resource depletion impacts about 4.20E-04 $ (0.31 %). As this result, majority of metal depletion impact came from toxic substance and plastics part about 99.84% and 0.14% respectively in landfilling scheme.

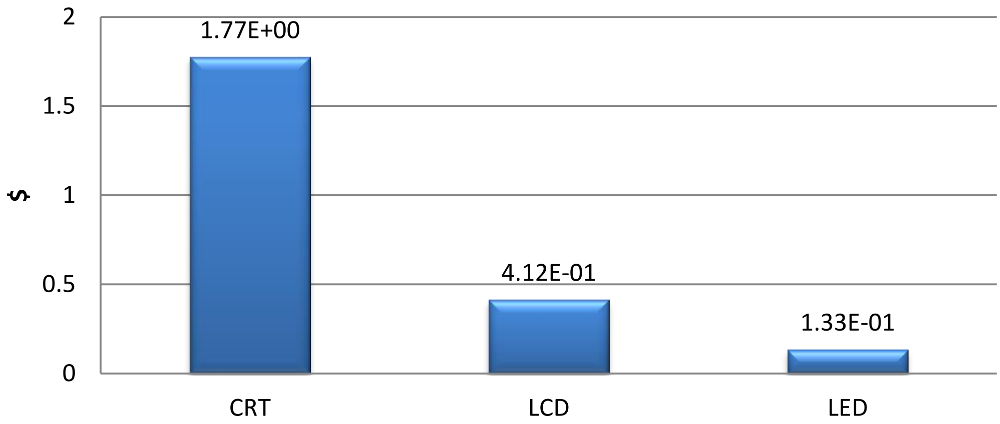
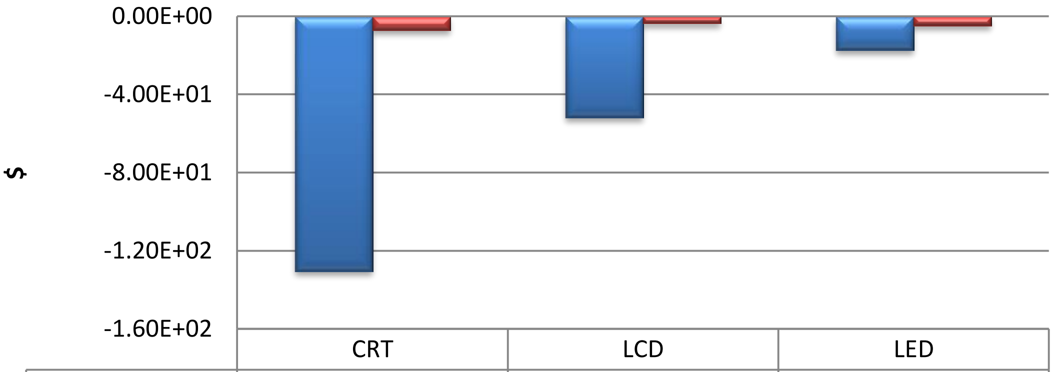


Figure 33 The resource depletion impact comparison between television equipment contributing from landfilling approach

Overall models, CRT television screen landfilling can cause highest resource depletion (Figure 33), from the components in CRT television screen are complicate and higher than LCD about 76.72%, 92.49% in LED screen. All of three equipment landfilling showed the same tend that fossil depletion impact contributed higher impact score than metal depletion impact.

ii. The Recycling approach burden contributing to resource depletion impact

This study found that recycling can avoid the resource depletion impact showing as the subtraction of the resource extraction surplus cost. Overall, there are contributed from prevention of losing two types of resources as shown in Figure 34 below.



	CRT	LCD	LED
Fossil depletion	-1.30E+02	-5.16E+01	-1.71E+01
Metal depletion	-6.95E+00	-3.54E+00	-4.64E+00

Figure 34 The contribution of resource depletion impact due to CRT, LCD, and LED screen recycling approach

For CRT television screen found that recycling can avoid the resource depletion impact by the subtraction of the resource extraction surplus cost about -1.37E+02 ($) .Overall, there are contributed from prevention of losing two type of resources as shown in the Figure 34. The recycling scheme can subtract the total surplus cost; especially, from ***fossil depletion impact*** which it can subtract the -1.30E+02$ (94.93%) of total resource depletion impact. Moreover, this total benefits from recovery CRT scrap fraction from steel recycling following by copper, gold and palladium. Overall, the recycling scheme can cut down the energy acquisition impact in primary production, which required a several type of energy source including hard coal, petroleum oil, and natural gas. And ***metal depletion impact*** can avoid impact about -6.95E+00 $ or approximately 5.17% of total impact. Total impact subtraction came from copper recycling. In facts, this can avoid surplus cost of the chain process of primary copper production in future.

The benefit of LCD recycling to resource depletion is shown in Figure 34. This can avoid the surplus cost about -5.51E+01 $ in overall resource availability. This avoided score from ***fossil depletion impact*** can avoid about -5.16E+01 $ (93.61%) When focusing on the scrap recycling, it apparently shown that recovered copper fraction can bring the large proportion of benefits by subtracting of fossil depletion from steel recycling and precious metal recycling. The energy extraction impact using in the primary production would be spontaneously avoided which consisting of hard coal, petroleum oil, and natural gas. For ***metal depletion impact***, the recycling scheme can reduce this kind of impact about -3.53E+00 $ or approximately 6.39% of total impact. The recycling of LCD screen scrap could be subtracted of total impact from copper recycling, precious metal group recycling (especially from gold) and steel recycling.

LED recycling showed this avoided resource depletion impact through negative surplus cost totally -2.17E+01 $. The ***fossil depletion impact*** would be enormously reduced by recycling about -1.71E+01 (78.68%) to total avoided resource depletion impact. The most benefits came from aluminum scrap recycling, gold, palladium and copper recycling. When focused on the root of impact contribution, the entire recycling scheme can totally subtract the fossil resources impact from including: petroleum oil, hard coal, and natural gas. For ***metal depletion impact,*** it distributed to resource depletion impact for -4.64E+00$ (21.32%). Interestingly, reduction came from copper recycling which can avoid chain process of primary copper production following by gold, and steel.

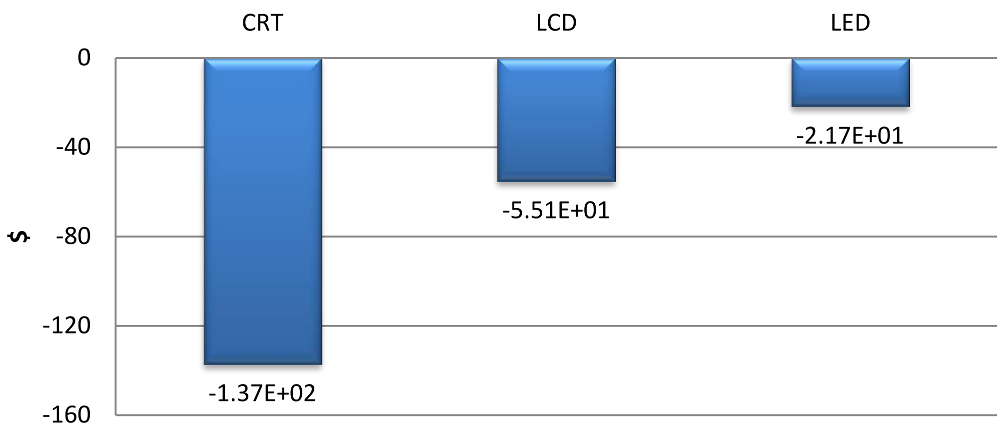


Figure 35 The resource depletion impact comparison between television equipment contributing from recycling approach

According to the overall result, the CRT recycling scheme can avoided resource depletion impact higher than LCD recycling about 59.85% and LED recycling about 84.16%. As a result, it can describe that one unit of CRT television can produce large amount of secondary precious metal than other device.

5.1.4 Environmental Single Score Comparison

To analyze the overall impact results, the three endpoint impacts were aggregated into a single score indicator through weighting calculation. Eventually, this is helpful to compare the environmental burden between landfilling and recycling approaches among these three devices. When the single score represent the positive value, it means that the device causes burdens to the environment which opposite to the negative value of single score, it showed as avoided environmental burdens.

i. CRT television screen landfilling VS recycling scheme

As shown on (Table 28), the characterized single score consists of three main endpoint categories. Overall, the CRT television screen landfilling generated total environmental impact about 0.08 pt. of single score point, whereas the recycling approach can reduce about 15.30 pt. as shown in negative environmental impact. Recycling would be better than landfilling about 190.59-fold.

Table 28 The environmental single score contribution of CRT television screen landfilling VS recycling approach impact

Damage category	CRT landfilling	CRT recycling
Human Health (pt.)	5.34E-02	-1.34E+01
Ecosystems (pt.)	3.31E-03	-1.56E-02
Resources (pt.)	2.41E-02	-1.86E+00
Total (pt.)	**8.07E-02**	**-1.53E+01**

ii. LCD television Screen Landfilling VS Recycling Scheme

LCD television screen as shown on Table 29, three main endpoints are weighted into one environmental single score. The LCD landfilling generated environmental impact which contributed about 0.02 pt. of single score point, whereas the recycling approach can reduce about 8.71 pt. Recycling would be better than landfilling about 368.51-fold.

Table 29 The environmental single score contribution of LCD television screen landfilling VS recycling approach impact

Damage category	LCD landfilling	LCD recycling
Human Health (pt.)	2.08E-02	-8.44E+00
Ecosystems (pt.)	1.03E-03	2.20E-02
Resources (pt.)	1.81E-03	-2.09E+00
Total (pt.)	**2.37E-02**	**-8.71E+00**

iii. LED television screen landfilling VS recycling scheme

LED television screen (as shown on Table 30), three main endpoints are weighted into one environmental single score. The LED landfilling generated small environmental impact which contributed about 0.005 pt. of single score point, whereas the recycling approach can reduce about 5.09 pt. Recycling would be better than landfilling about 989.35-fold.

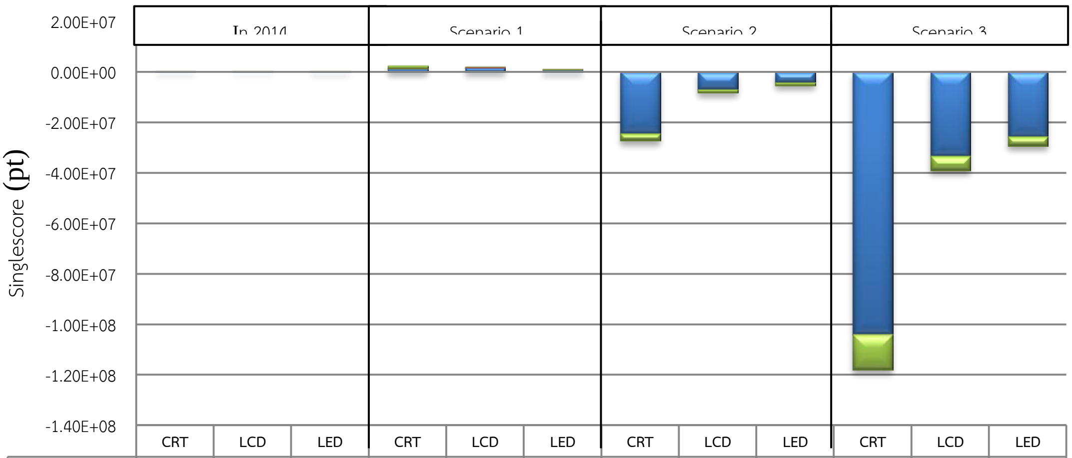
Table 30 The single score results comparison between LED Landfilling and recycling management approach

Damage category	LED landfilling	LED recycling
Human Health (pt.)	4.39E-02	-4.37E+00
Ecosystems (pt.)	2.04E-03	2.23E-02
Resources (pt.)	5.60E-03	-7.44E-01
Total (pt.)	**5.15E-03**	**-5.09E+00**

5.2 The End of life scenario analysis: projection of the potential environmental impact during to 2014-2023 of CRT, LCD, and LED television

The single scores were applied for analyzing possible future projections. There are 3 scenarios on various situation of different percentage of collection and recycling rate including: scenario 1 (100% landfilling dumping rate), scenario 2 (95% landfilling rate, 5%recycling) and scenario 3 (80% landfilling rate, 20 %recycling). Overall, the comparison between scenarios was done in each of equipment.

Current scenario (in year 2014), the amount of television wastes around 2,587,000 units (PCD, 2012) are calculated in term of weight (kg) for enter into program. Moreover, this current situation not have recycling process and all amount of telelvision wastes sent to landfillinng burden (100%).



	CRT	LCD	LED	CRT	LCD	LED	CRT	LCD	LED	CRT	LCD	LED
Resources	6.22E+04	1.46E+04	4.69E+03	9.52E+05	2.23E+05	7.17E+04	-2.78E+06	-1.27E+06	-1.01E+06	-1.40E+07	-5.75E+06	-3.75E+06
Ecosystem	8.15E+03	5.30E+03	2.65E+03	1.25E+05	8.11E+04	4.06E+04	9.35E+04	1.23E+05	1.98E+04	-1.90E+04	2.48E+05	2.31E+05
Human Health	8.16E+04	1.14E+05	5.39E+04	1.25E+06	1.75E+06	8.25E+05	-2.45E+07	-7.03E+06	-4.39E+06	-1.04E+08	-3.34E+07	-2.57E+07

Figure 36 The projection of end of life of CRT, LCD, and LED television screen impact

The CRT television screen results showed three scenarios compare with sceanario 1 has the highest environmental impact,while scenario 2 and scenario 3 showed negative environmental single score when both scenaros implemented recycling scheme (Figure 36). The scenario 1 (100 % landfilling dumping rate) was compared to other alternative scenarios. The results, scenario 2 single score contributed environmental benefit higher than that of scenario 1 about 12.67 -fold. As well as scenario 3, this also consequently contributed higher level of environmental advantage than scenario 1 about 51.64-fold of scenario 1 impact. When compare three scenarios with current scenario (100% landfilling dumping rate in 2014), the result found that scenario 1 has total single score environmental impact higher than baseline scenario about 14.32-fold. Scenario 2 and scenario 3 can avoid overall environmental impact higher than baseline scenario around 179.95-fold and 777.32-fold respectively.

Future scenario of LCD television screen scenario results as shown in Figure 36 The LCD television screen results showed three scenarios compare with sceanario 1 has the highest environmental impact,while scenario 2 and scenario 3 showed negative environmental single score when both scenaros implemented recycling scheme. The scenario 1 (100 % landfilling dumping rate) was compared to other alternative scenarios. The results, scenario 2 single score contributed environmental benefit higher than scenario 1 about 4.99 -fold. As well as scenario 3, this also consequently contributed higher level of environmental advanrtage than scenario 1 about 20.36-fold of scenario 1 impact. When compare three scenarios with current scenario (100% landfilling dumping rate in 2014), the result found that secnario 1 has total single score environmental impact higher than baseline scenario about 14.30-fold. Scenario 2 and scenario 3 can avoid overall environmental impact higher than baseline scenario around 62.04-fold and 297.27-fold respectively.

As the results showed in Figure 36, The LED television screen results showed three scenarios compare with sceanario 1 has the highest environmental impact,while scenario 2 and scenario 3 showed negative environmental single score when both scenaros implemented recycling scheme. The scenario 1 (100 % landfilling dumping rate) was compared to other alternative scenarios. The results, scenario 2 single score contributed environmental benefit higher than scenario 1 about 6.74 -fold. As well as scenario 3, this also consequently contributed higher level of environmental advanrtage than scenario 1 about 32.16-fold of scenario 1 impact. When compare three scenarios with baseline scenario (100% landfilling dumping rate in 2014), the result found that secnario 1 has total single score environmental impact higher than baseline scenario about 14.31-fold. Scenario 2 and scenario 3 can avoid overall environmental impact higher than baseline scenario around 88.91-fold and 478.12-fold respectively.

In this scenario analysis, there have a similar trend in the avoided impact of recycling system. Therefore, LCA perspective apparently showed recycling scheme is possible to improve the environmental performance of television.

5.3 The sensitivity analysis

The sensitivity analysis was done to assess the sensitivity of the significant data and errors could that influence the analysis. The objective of the sensitivity check evaluated the reliability of the results by determining whether the uncertainty in the significant issues that affect the decision-maker's ability to confidently draw comparative conclusions. In this study, the sensitivity checked on the measures that changes in the LCI results and characterization models that may affect the impact results.

The possible error might occur during component mass measurement step. It can possibly effect to the result analysis. Consequently, the one-way sensitivity analysis was used by varying only parameter that could have high impact while other parameter is constant in order to show the sensitivity of this parameter to overall result. Therefore, this study investigated consequence to the level of single score according to the ±5% to ±10% of weight variation.

Therefore, the data that used for sensitivity analysis is only one main part in each device that can cause highest effect to single score of environmental impact as shown in Figure 37, 38 and 39. So, weight of main CRT in CRT model, backlight unit in LCD model and rear cover assembly in LED model are selected as parameter.

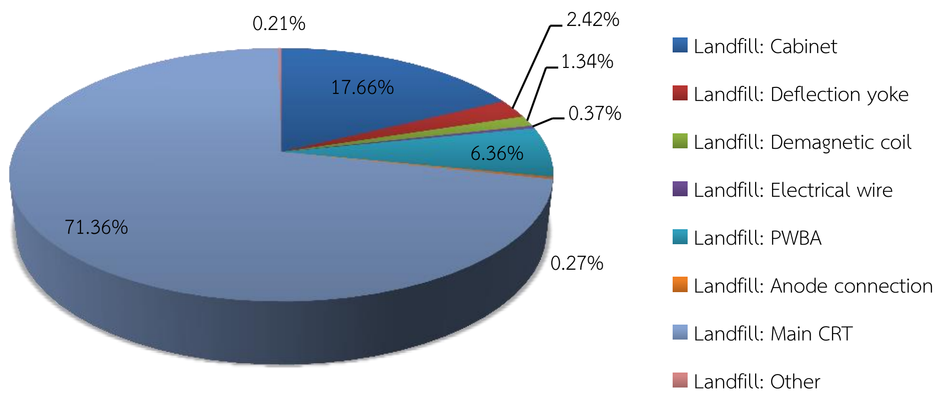


Figure 37 The environmental impact single score characterization result from main parts of CRT television screen

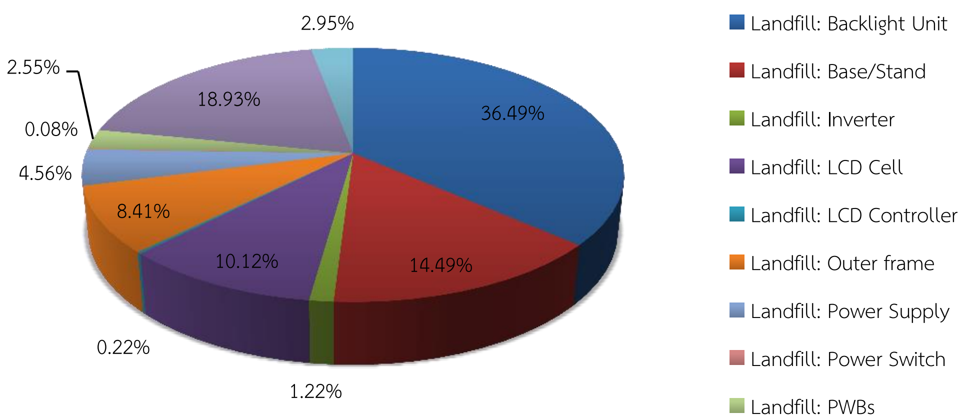


Figure 38 The environmental impact single score characterization result from entire parts of LCD television screen

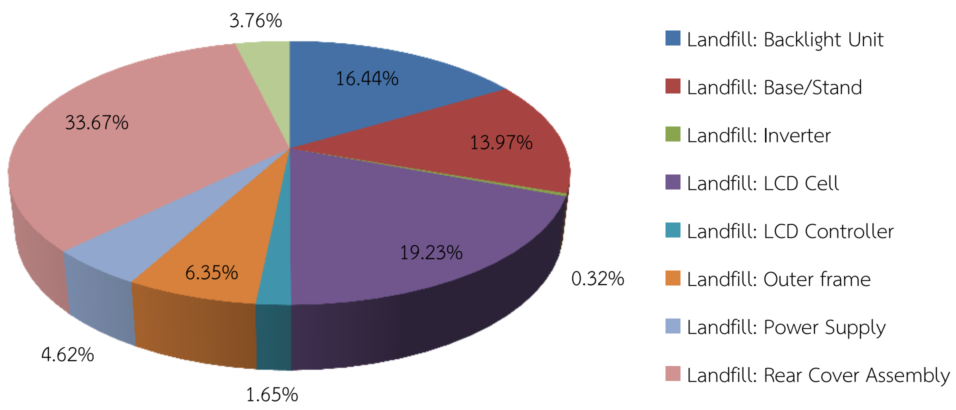


Figure 39 The environmental impact single score characterization result from entire parts LED television screen

5.3.1 Landfilling approach

For landfilling burden as shown in Figure 40, ±5 % of mass weight error occurred, and this effected on the environmental single score. The highest and the lowest single score values of CRT model were 8.45E-02 (+4.50%) and 7.68E-02 (-4.82%) respectively. Therefore, the errors were acceptable because they were during ±5%. ±10% of mass weight error found that 8.81E-02 (+8.40%) and 7.27E-02 (-9.91%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

LCD device in landfilling burden (Figure 40), ±5 % of mass weight error found that the highest and the lowest single score values were 2.47E-02 (+4.05%) and 2.26E-02 (-4.64%) respectively. Therefore, the errors were acceptable because they were during ±5%. ±10% of mass weight error found that 2.59E-02 (+8.49%) and 2.14E-02 (9.70%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

LED television to landfilling activity from ±5% and ±10% of mass weight errors as shown in Figure 40.The results found that the highest and the lowest single score values were 5.38E-03 (+4.28%) and 4.91E-03 (-4.66%) respectively. Therefore, the errors were acceptable because they were during ±5%. 10% of mass weight error found that 5.63E-03 (+8.53%) and 4.67E-03 (-9.32%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

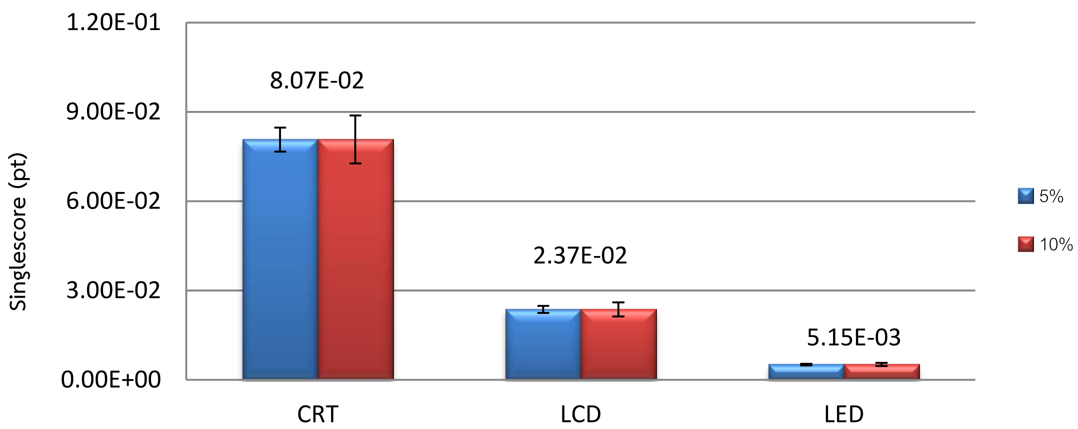


Figure 40 The Sensitivity analysis of landfilling scheme

5.3.2 Recycling approach

For the recycling scheme, the 5 % and 10% mass errors rate can affect to the singe score of environmental impact as shown in Figure 41. 5 % of mass weight error found the highest and the lowest single score values of CRT model were 1.59E+1 (+3.77%) and 1.47E+1 (-3.92%) respectively. Therefore, the errors were acceptable because they were during ±5%. 10% of mass weight error found that 1.65E+01 (+7.27%) and 1.41E+01 (-7.84%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

LCD device in recycling activity (Figure 41), 5 % of mass weight error found that the highest and the lowest single score values were 9.03E+00 (+3.54%) and 8.31E+00 (-4.59%) respectively. Therefore, the errors were acceptable because they were during ±5%. 10% of mass weight error found that 9.47E+00 (+8.03%) and 7.88E+00 (9.53%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

LED television to recycling scheme from 5% and 10% of mass weight errors as shown in Figure 41.The results found that the highest and the lowest single score values were 5.31E+00 (+4.41%) and 4.93E+00 (-3.14%) respectively. Therefore, the errors were acceptable because they were during ±5%. 10% of mass weight error found that 5.48E+00 (+7.12%) and 4.59E+00 (-9.78%) as the highest and the lowest single score values respectively. Therefore, the errors were acceptable because they were during ±10%.

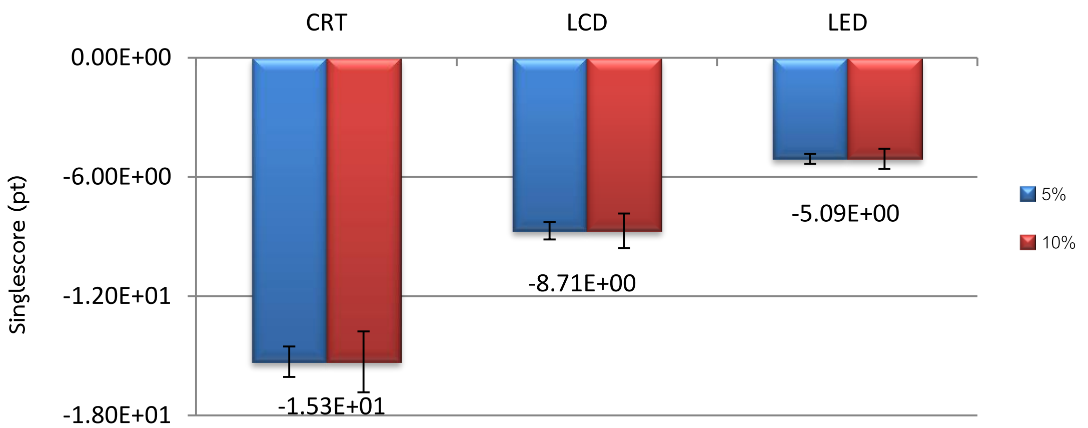


Figure 41The Sensitivity analysis of recycling scheme

CHAPTER VI
RECOMMENDATION FOR EoL TELEVISIONMANAGEMENT

To develop recommendations for improving television waste management scheme in Thailand, this study also conducted public surveys to investigate existing situations of TV wastes and opinions about preferable solutions from the public. Accordingly, the recommendation plans also suggested including comprehensive issues relevant to TV equipment management scheme.

6.1 The results from questionnaire survey

Based on the questionnaires, there are two parts of information obtained from the survey. The first part is results on current manner of obsolescence TV management. The second part is results on the potential alternatives for management plan in coping with waste collection to recycling system. There were total of 514 questionnaires participants through online surveying (122 persons) and paper surveying (396 persons). The result analysis can be described as following:

6.1.1 Current TV waste management practice

About situation of digital TV in Thailand, the results showed that 59.92% of participants know that Thailand will change signal of transmission from analog TV to digital TV in near future and 73.54% of participants will use old television with set top box for receiving new system. The remaining ones will buy new model television as digital TV.

This surveying part firstly asked about the possession of the TV equipment and how the discarded TV equipment is managed. As the results, 53.70% of all participants have CRT TV equipment in their possession, 29.96% having old LCD TV screen and 16.34% having LED TV screen.

As shown in Figure 42-44 about end of life management practice for TV equipment, there are three main options which most participants did in practice including (1) **keeping at home** (33.57 % for CRT TV, 39.83% for LCD, and 38.36% for LED TV screen, respectively), (2) **giving or donation to others** (19.86 % for CRT contribution, 22.94 % for LCD, and 21.92% for LED TV screen, respectively) and followed by (3) **selling to tri-cycler waste buyer** (Sa-leang) as the third priority (29.79 % for CRT contribution, 19.05% for LCD and 18.49% for LED TV screen, respectively)

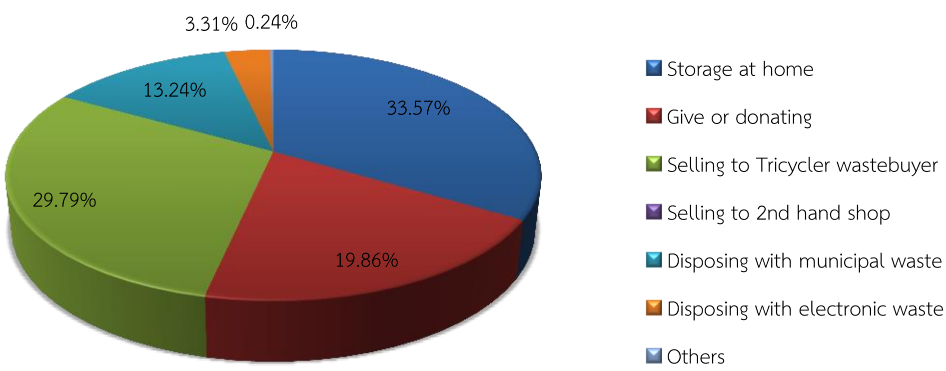


Figure 42 The current managing approach of discarded CRT TV

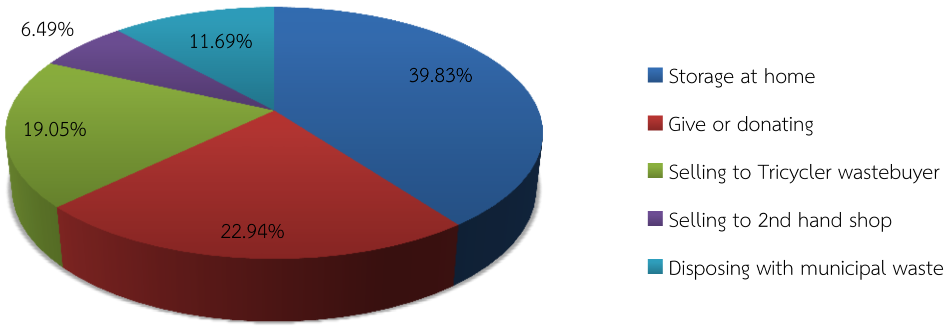


Figure 43 The current managing approach of discarded LCD TV

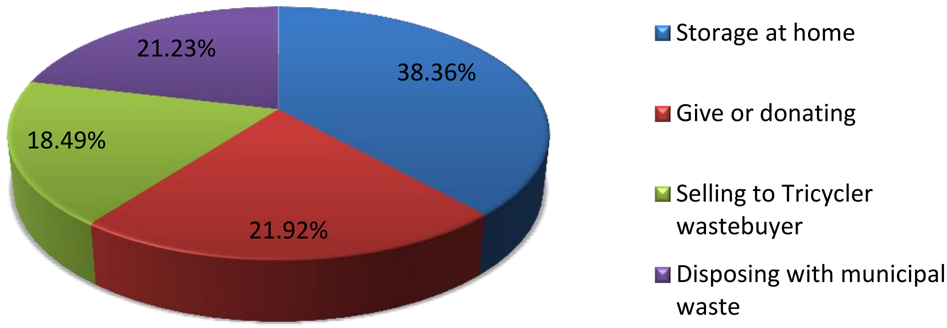


Figure 44 The current managing approach of discarded LED TV

The end of life stage of television was considered for each individual depending on the different reasons. Therefore, the question of *how* do you indicate that your television equipment reached end of its useful were conducted in this survey. Participants who responded to this question have to own obsolescence television and give priority rating based on their own opinion.

Response for considering television equipment reached end of life stage was analysis as shown in Table 31. A majority of participants (49.22%) indicated the reason that television defective equipment is the most important reason people decide to discard their television equipment. Similarly, the replacing the old equipment for using new and latest model equipment because it has an affordable price. This is also important reason for reaching end of use phase about 46.69 % of higher related level. For other reasons, low effective of processing in television can affect productivity also considered as the end of life phase, which contributed about 45.91% of low related level. Apart from this, the reason that television cannot work with higher technology equipment is a preferred reason to end the use of television (36.77 % of moderate relevant reason).

In order to provide information for supporting the main reason of discarded television, the most related reason according to the survey were analyzed. Almost forty-nine percent (49.22%) of participants indicated that defective is the main reason to discard the television. This can be concluded that people tend to discard television earlier than expected design and physical lifespan. Moreover, people tend to replace their old equipment by using new model because of low affordable price contributing as second rank (23.54%). In addition, low efficiency, and compatibility with higher technology are the third and the last factor for change television model.

Table 31 The reasons to discard existing television

Options	highest	higher	moderate	low
1. Defective equipment	49.22%	17.32%	18.87%	14.59%
2. Decreasing price in new models	23.54%	46.69%	17.90%	11.87%
3. Low effective working	18.48%	9.14%	26.46%	45.91%
4. Working disability with higher technology	8.75%	26.85%	36.77%	27.69%

6.1.2 Public opinions on television waste management

This part aims to evaluate the people perception in benefit of waste management useful for providing the further recycling campaign. This questionnaire conducted three aspects in evaluation criteria including: awareness on precious substances, toxic substances and proper recycling benefits.

The results showed that most of the participants (97.47%) have already known that there are precious metals contained in the television. The existing of toxic substances in television equipment is also the important issue. Majority of participants who already know about this information 89.88 % of overall participants, except for the rest of 10.12 % did not know about this fact. Last, 78.99% of total respondents already known the benefit from proper recycling process which possibly recover a large amount of primary resource and can help avoiding the environmental impacts to human health and ecosystem. However, there is still more than 20% percent does not know this information.

The results show that majority of respondents already known about the substances containing in the television and advantage of recycling process. However, only a small proportion of respondents who are willing to increase their awareness and knowledge about proper management. Therefore, providing useful information through recycling campaign will be useful.

6.1.3 Preferred policy and management plan

To set up an appropriate management plan for discarded television equipment collection system, this survey questions aims to identify feasibility of managing plan supporting by the public. The surveying results can be analyzed as following:

i. The effective approach for returning the discarded television back to collection center

Appropriate managing approach is necessary to achieve the goal of collection system which can later take most of waste into proper management. The policy instrument should be acceptable by people. Therefore, this survey asked about what the policy approach for operating discarded television collection system is preferable. Participants have to prioritize the choices as preference rating method to rank the most preferred approach including: (i) Using act or regulation to recycling, (ii) Paying a waste management fee after bought the product, and (iii) Keeping environmental tax for E-waste management

The result showed the proportion of preferred rating in 3 options (Table32). It was found that 50.97 % of participants mostly selected “Using act or regulation to recycling” as the most preferred option, about 49.02% preferred to “Keeping environmental tax for E-waste management” as moderate option, and about 42.41 selected mostly in “Paying a waste management fee after bought the product” as the least preferred option.

In Table 32 provides analyzed results about reasons from citizens for returning end-of-life of television waste management. The results show using act or regulation to recycling is the most preferred option (50.97%). Because it stringent to control television equipment returning to collection center and may be suitable for Thailand culture. The paying a waste management fee when buying a new model is the second preferred option. This system actually related to level of willingness to pay for waste management which very much depends on people awareness. The last option that people are selected is keeping environmental tax for E-waste management. Moreover, it can increase expense to citizens, so this option maybe difficult to implement in Thailand in the near future.

Table 32 The preferred approaches for returning end-of-life television waste management

Options	high	moderate	low
1. Using act or regulation to recycling	50.97%	27.24%	21.79%
2. Paying a waste management fee after bought the product	33.85%	23.74%	42.41%
3. Keeping environmental tax for E-waste management	15.18%	49.02%	35.80%

ii. The preferred incentive for promoting electronic waste collection for recycling system

The incentive is an important factor to motivate action to achieve the policy target. Therefore, this survey also included the question asking participants what kind of incentives that can convince people to participate television waste collecting scheme. Hence, participants have to prioritize the scale of satisfaction in every option including: Granted monetary subsidy from reselling TV waste to collection system, tax reduction credit when returning back TV waste to collection system, and the convenient facilities supporting to the returning discarded equipment to collection center.

The survey result shows the contribution of satisfied levels for different options in Table 33. Interestingly, people are interested in monetary benefits because participants highly satisfied to option 1 as “most preferred option (47.08 % of entire high option priority)” and “moderate preferred option” (45.14% of option 3). In additions, the convenient facilities supporting to return discarded equipment to collection center (option 2), was selected for “low preferred option”, and contributed 42.61 %.

According to previous described results (Table 33) and contribution of particular “most preferred option” it indicated that monetary motivation might be effective in convincing public to participate in recycling program by providing price discount as an incentive. The administrative body of television waste collection management should offer monetary in return or special privilege back to people after their return discarded equipment to the collection system. Further studies may need to investigate the feasibility of monetary rates for returning television wastes to the collection system. The collection system of television waste is also need to be located near convenient areas for implementation. In addition, tax reduction credit when returning back TV waste to collection system may difficult because of tax rate value is complicate.

Table 33 The preferred incentive for promoting electronic waste collection for recycling system

Options	high	moderate	low
1. Granted monetary subsidy from reselling TV waste to collection system	47.08%	29.38%	23.54%
2. The convenient facilities supporting to the returning discarded equipment to collection center	31.19%	25.49%	42.61%
3. Tax reduction credit when returning back TV waste to collection system	21.01%	45.14%	33.85%

iii. The television waste or E-waste collection system administrative body

Typically, the administrative body is important institution to manage the collected television waste to collection center and bring into proper recycling system. The survey asked who would be the appropriate operator of this system based on the citizen opinion. The result showed that the majority of respondents

(39.30%) suggested that private sector is preferred to be the main body in the waste management, and also many people gave their trusts to community sector for 33.85% and 26.46% for government sector (Table 34). However, there is about 0.39% preferred the other options. Moreover, there are additional opinions in e-management system which should be cooperated in every social sector.

Table 34 The administrative body surveying result for television waste collecting for recycling in Thailand

Options	Percentage
1. Private sector	39.30%
2. Community sector	33.85%
3. Government sector	26.46%
4. Others	0.39%

iv. The proper approach for returning television waste into collection system

The television waste collecting system is the key factor to achieve the recycling goal. The effective collecting plan is set up to ensure that enough amounts of wastes are properly collected to be recycled. The question asked "what is the most comfortable way to return the discarded television equipment back to collection center" to identify preferred collection system. This question requires all participants prioritize the different options of returning back of the television equipment.

In response to this question, the participants rank top three level of satisfaction according to the results which consisted of highest, medium and least preferred options (Table 35). The most preferable options of returning television waste is by staff picking up from municipal (57.98% of overall score in this option). As the same trend, people prefer to return to owner brand in shop or near shopping mall (for 42.02% of entire option score). For the low level of satisfaction, people prefer the choices to return their television equipment to main local collecting center near their home, which contributed for 65.76% of overall level in this option.

To select the best option of returning television equipment, this survey also compared only most preferred option from people references which already showed on the table below (Table 35). The results show that most selected option is the picking up directly by staff picking up from municipal. Due to different lifestyle of people, the collection system may be flexible and offer several options (based on the survey results) to maximize the collection rate.

Table 35 Surveying result for selecting the comfortable and suitable option for returning disuse television to waste collection system

Options	high	moderate	low
1. Staff picking up from municipal	59.98%	33.27%	8.75%
2. Self-returning to owner brand in shop or near shopping mall	32.49%	42.02%	25.49%
3. Local collecting center near their home	9.53%	24.71%	65.76%

v. The concerning issues in waste collection process

This surveying effort also identifies the possible concerns that would occur after establishing the collection center. Participants answered by choosing the choices or writing their own opinions in the space provided in the survey.

As shown in Table 36, the results found that the most important concerns about 46.89% have a concern on people lack of knowledge or disadvantage about incorrect TV waste management while 22.57 % are afraid of the problem in financial supports. About 22.18 concerned about the improper transportation system to collection center. This can be a possible problem of treatment company operator lack of knowledge or understanding about correct recycling (about 8.37 % of people concerned in this topic).

Table 36 Surveying result for potential obstacles occurring in waste collection process

Options	highest	higher	moderate	low
1. People lack of knowledge or disadvantage about incorrect TV waste management	46.89%	24.71%	22.37%	6.03%
2. Lack of sufficient finance to operate the collection system	22.57%	18.09%	37.16%	22.18%
3. Improper transportation system to collection center	22.18%	16.93%	19.65%	41.25%
4. Enterprise lack of knowledge or understanding about correct recycling	8.37%	40.27%	20.82%	30.54%

vi. The proper approach for effective collection system

This surveying from citizens can help develop create suitable alternative for increasing efficient for collection system.

Moreover, these options will make correct technical of collection system management and increase amount of waste into recycling system. The survey result shows the contribution of satisfied levels for different options in Table 37. Interestingly, people selected option 1 is the most proper approach about 43.97% because easier more than other options and the manufacturers will know the best practices for managing own waste. In addition, some part of waste can return to use as primary resource so it can avoid raw material for produce new product.

Table 37 Surveying result for decrease collection problem

Options	highest	higher	moderate	low
1. Manufacturers should be responsible for collecting TV waste and sent it to proper management	43.97%	10.89%	14.59%	30.54%
2. Government, manufacturers and consumers should engage in responsible cost of TV waste management in the right proportion.	25.49%	19.65%	32.68%	22.18%
3. Government should promote and create awareness to the public about the dangers of TV waste to people and environmental.	20.04%	38.52%	19.26%	22.18%
4. Should promote awareness about recycling or waste management TV correct to enterprise	10.51%	30.93%	33.46%	25.10%

vii. Recommendation from participants to improve the television waste collection plan

Information from participants' opinion from this survey is useful to develop recommendation as explained in the following.

➢ **Suggestion in television waste / electronic waste collecting strategies**

- Participants recommended that television or other electronic waste collection system should be initially implementation in large organization, private firms or institutions before apply this strategy to public households because it can be implemented directly through the organization policy which is easy to manage it.

- Government must provide electronic waste collecting guidance to employers about safe and healthy of worker and including facilities for people in that area on disposing television waste.

- Training of electronic waste workers completed before actual work by government, relate organization and employers.

- Establish approaches to gather, track, and provide public access to information on quantities and movement of used electronics.

➢ **Suggestion in television waste / electronic waste management administrative body**

- Establish multi-stakeholder groups to share knowledge and design waste system management for accelerating development and investment of electronics waste treatment plant on standards

- The government establishes a comprehensive and transparent policy.

- In local province, provincial administrative organization or provincial municipality can play the important role in electronic waste collection before returning to the central administrator.

➢ **Suggestion in television waste / electronic waste campaign for collection system to recycling**

- Government support the processes to build institutional capacity concerning electronic waste management by provide financial support or send specialist person for training on suitable electronic management. It needs to launch the campaign and exhibition to school or community to state problem of E-waste in order to create more awareness to people.

- Promote consumer purchasing of green electronics that are certified by environmental standard organization.

In conclusion, this surveying result would be helpful to use as source for making recommendation for television collecting system. However, this result may not necessary related to other type of equipment.

6.2 Recommendation to increase efficiency of television waste to management

This study developed strategy and a roadmap to the government, private sector, community sector and others can use as resources for support decision making. There are four recommendations: first recommendation develops from results impact in this study and three recommendations is also developed from three sources. The first came from questionnaire survey in previous section, the second came from PCD about project done already in the past, what project doing in currently and what project will do in the future. And the last one of three recommendations came from EPA about policy management of electronic equipment for developing courtiers. These recommendations are summarized below and described in more detail in the main body of this document and divide into short term (less than 1 year) and long term (over 1 year) as explained in the following.

6.2.1 Strategy I: Recommendation from life cycle impact assessment to reduce overall impact from television equipment

This strategy used the results from previous chapter to create recommendation for decreasing main source of impact including develop or change materials that less impact and environmental friendly. Moreover, some parts of television which affected to overall impacts and some toxic substances inside equipment will be considered.

Main CRT component which can cause the highest potential effect to single score of environmental impact is glass following by backlight unit which mainly contributed from cold cathode fluorescent tube and rear cover which mainly came from plastic ABS in LCD and LED screen respectively. Toxic substance in each device is necessary to be considered because it may be harmful to environment and human health. Lead oxide, cadmium, antimony oxide, mercury, barium oxide, and liquid crystal are mostly contributed in three television screens.

Objective in this strategy for linkage between overall impact results and recommendation because it very specific for Thailand situation.

i. Short term plan

➢ **Implementation plan by government administrative body**

- Require regular reporting and auditing of data and information relating to material used in production stage from the persons; agencies, institutions, groups, or businesses involved.

- Audit quality of products in each year especially evaluate environmental impact that release to soil, water, and air in cradle-to-grave.

➢ **Implementation plan by private sector**

- Check machine in production stage every 6 months to reduce defective that can cause material loss during this stage.

- Monitoring and evaluating their products after sell about types and size that mostly used including lifespan for planning suitable manufacturing in the future.

- Change or reduce some materials in television that can cause environmental impact. For example, CRT television screen used recycled glass mix with virgin glass in main CRT part for reduce severe of impact. LCD television screen change fluorescent tube to light emitting diode because it smaller, lower used amount, and lower impact including get more quality of screen. LED television screen reduce ABS plastic material in rear cover part by designing for using this plastic as much as necessary.

- Control types and amount of toxic substance in electronic equipment under law regulation.

ii. Long term plan

➢ **Implementation plan by government administrative body**

- Set central database about definition of toxicity, types of toxicity, measuring toxicity, factor influencing toxicity cover in electronic equipment.

- Specify types and amount of toxic substance in electronic device especially lead oxide, cadmium, antimony oxide, mercury, barium oxide, and liquid crystal in television equipment for prevent impact from these toxic substances that will occur later.

➢ **Implementation plan by community sector**

- Buy electronic equipment that have been certified by relate organization focus on green product and low energy consumption.

- Reduce, Reuse, and Recycle concept before buying new make a habit to television.

6.2.2 Strategy II: Build people awareness and participation in television waste management

From public opinion about management practice for television equipment in nowadays, the result showed that most participants keeping television waste at home. The concerning issues in waste collection process of the largest groups person is a lack of knowledge or disadvantage about incorrect television waste management so, this strategy aims to increase people knowledge and awareness in environmental performance from proper and improper television waste management. Government administrative body should use the authority to set up the policy framework for further implementing as planned.

Objective in this strategy for create opportunities to develop people's understanding, skills and general knowledge to increase their awareness, responsibility and cooperation to concerning environmentally sound E-waste management, including the potential impacts from improper management.

i. Short term plan

➢ **Implementation plan by government administrative body and academic sector**

- Open short course work about proper electronic waste management for treatment company operator and informal sector. Government sent professional person for help workers involved in electrical and electronic goods recycling should be provided with training and information about handling E-waste as well as about its safe disposal. This training should include simple and easy-to-understand information that describes what E-waste is what the hazards are, and how to handle, package, store and dispose of it safely.

- Organize event (every 6 months) in school, university and community for give basic information including toxic substances and valuable material existing in television equipment, reduce, Reuse , recycling strategy concept (3Rs) for waste management advantage of proper end-of-life management resource recovery and disadvantages of improper end-of-life management effect to human health and environmental.

- Promote and support researching from academic and private sector about developing new materials in electronic equipment (green product) that can reduce environmental impact in all life span. Create database network and data research for exchange information between government sector, private sector, community sector and other people who are interest in this information by upload all data in online website include update relate news and activity.

ii. Long term plan

- **Implementation plan by government administrative body**

  - Establish central database to create comprehensive information about electronic equipment in Thailand. The example information are the quantity of import-export electronic equipment ,quantity of electronic selling in our country, type of material used in electronic product, toxic material, valuable material, averaging life of electronic types, quantity of electronic equipment collected for recycling or disposed, treatment technology for electronic waste and policy and regulation of electronic waste management in Thailand.

- **Implementation plan by private sector**

  - Manufacturing, and supplier in Thailand requesting to showing their own policy and planning

  - Improve tracking of their electronics throughout the lifecycle and post comprehensive data sets by publicly accessible websites

➢ **Implementation plan by community sector**

- Receive information from news, advertisement or internet about electronic product and join with activity from government to increase basic knowledge, understanding, and proper electronic waste management.

6.2.3 Strategy III: Increase effective management and collecting of used electronics in Thailand

Strategy II represents the systematic management of products in efficient and sustainable by involvement of every sector in all operation. Public opinion suggests that private sector should responsible for collecting electronic waste and sent it to proper management. Moreover, almost people choose staff picking up electronic waste from municipal for returning television waste into collection system as the most preference.

Objective in this strategy, all sectors has the particular opportunity and responsibility to purchase, use, and recycle its electronics with the goals of protecting public health and the environment; creating new and strengthening existing markets for reused, refurbished, and recycled electronic equipment and materials improving electronics design and management practices

i. Short term plan

- **Implementation plan by government administrative body**

  - Establishment and application of appropriate standards, guidelines, and safeguards for the handling, collection, transportation, storage and disposal of electronic waste which ensures environmental and public health protection

  - Support the processes to build institutional capacity concerning electronic waste management and introduce measures to encourage the establishment of WEEE recycling and disposal enterprises.

  - Encourage the development of relevant and/or best available technology for WEEE management.

ii. Long term plan

- **Implementation plan by government administrative body**

  - Provide technical assistance and establish partnerships with developing countries to better manage used electronics.

- Establish electronic waste collecting site separate from municipal waste in each community and enough to storage capacity of electronic waste before transport to another area for next operation. Moreover, collecting site must design from accurate information standard.

- Allocation clearly extended Producer Responsibility (EPR) for the entire life cycle of the product and especially for the take back, recycling and final disposal of the product. It can reduce overlap working and decrease confusing of people.

➢ **Implementation plan by private sector**

- Private sector should create products that capable of being recycled to maximize the recovery of the rare or valuable materials they contain and minimize the amount of waste, especially hazardous waste, they could ultimately generate.

- They should designed products to have long useful lives and facilitate reuse through multiple users.

- Generate minimal emissions which are harmful to public health or the environment during the manufacturing, use, recycling, and disposal phases.

- Take-back their products for manage in proper method including responsible for all cost.

➢ **Implementation plan by community sector**

- Community sector involvement as electronic equipment user. To separation, storage and collection of their product that provide accurate information.

- Extend life span of electronic equipment in their house by maintaining or reparation instead of changing to new model.

- Collect electronic waste out of municipal waste before dispose in electronic waste storage site in their community

- Pay environmental fee to electronic waste management

6.2.4 Strategy IV: Increase incentive for promoting electronic waste collection for recycling system

The incentive is an important factor to motivate action to achieve the policy target. The preferred incentive for returning television waste include granted monetary subsidy from reselling TV waste to collection system, tax reduction credit when returning back TV waste to collection system, and convenient facilities supporting to the returning discarded equipment to collection center. So, these recommendations under public opinion and add some choices that can increase incentive of people and increase amount of television waste sent to recycling process.

Objective in this strategy are use financial and monetary to promote investment for support green electronic production and electronic waste management including enhancing the effectiveness of law enforcement and develop legal systems to facilitate for electronic waste management

i. Short term plan

➢ **Implementation plan by government administrative body**

- Design green electronics competitions to stimulate innovations in green product design, recycling solutions, and other phases of the electronics lifecycle.

- Set practice guidelines for controlling the operation of sorting and recycling plant.

➢ **Implementation plan by private sector**

- Establish " the privileged coupon campaign" reward to people who return electronic waste

- Set up the campaign framework activities in short term.

ii. Long term plan

➢ **Implementation plan by government administrative body**

- Sustainable user-pays financial framework for E-waste disposal implemented and enforced at a national level

- Promote and enforce responsible E-waste management through extended producer responsibility (EPR), advanced recycling fee and other appropriate tariffs and duties to ensure that environmentally appropriate E-waste disposal is sustainably financed.

- Develop the recycling fee policy to supporting.

- Develop the international law to support the collecting of waste and control low-quality products import.

- Require manufacturers and importers report the type and quality of materials that used in the production and identify amount of hazardous substance and recyclable material

- Establish the tax-reduction policy as monetary incentive.

- Forcing the improper scrap collecting and recycling waste to pay higher tax to support the collection scheme

- Set up the remanufacturing plant in Thailand by using the recycled resource from this scheme

➢ **Implementation plan by private sector**

- Promote CSR through the applying the collection scheme.

- Support the government to create the regulations and law relating to recycling practice

- Set up the remanufacturing plant in Thailand by using the recycled resource from this scheme

- Make the environmental surveillance program as well as occupational health

In conclusion, the recommendation for waste management planning addressed concerning topics in television waste management. It is recommended to focus in details study on the social-behavior in disposal of television, the financial planning in establish both of collection and recycling system to identify the practical implementation plan.

CHAPTER VII
CONCLUSIONS

This chapter summarizes all results of this study. The research applied life cycle assessment to evaluate the environmental impacts at the end of life stage of television waste management. Furthermore, the research recommends strategies to better improve the television waste management in Thailand. The key findings from this research are explained as follows:

7.1 Life cycle inventory development

Three television equipment inputs (including CRT, LCD and LED television screen) were used as case studies as television-waste. There are variations of residues and weights of the equipment after dissembling depending on the technology and electronic and electric components inside each device. According to material characteristics, there was summarized as the following;

- As the initial manual disassembly step, the CRT television screen has the highest weight due to the panel and funel glass components. For LCD and LED television screen, the weights come from structural part which mainly contributes from ferrous-metal and plastic fraction respectively. Nevertheless, both CRT and LCD equipment found plastic components embedded inside as the second most substances. And LED found glass components as the second most substance.

- Copper notable is the significant toxic substance in CRT television. Copper compounds are contained in deflextion yoke, anode connection, printed wiring board and demagnetic coil approximately 47.36 % of total weight. For copper in LCD device is about 58.77% of total weight which commonly found as the LCD cell. And LED screen found aluminum compounds are established in almost every sub-part of this devices such as a fan-cooled heat sink and Power supply.

- According to the final disposal of CRT and LCD television devices, there are mostly distributed their substance into inert material landfill type scheme following by sanitary and underground, respectively. Except for CRT screen, the incineration is responding as the fourth. And LED television device shown sanitary material landfill type, inert and underground respectively.

- Focusing on recycled materials, these all equipment are contained with various amounts of valuable material that could be recovered. The CRT television monitor has highest % of recoverable material per device (73.3%) following by LCD (63.1%) and LED (37.1%), respectively.

7.2 Life cycle impact assessment

This study used the ReCiPe 2008 methodology, which embedded in SimaPro 7.3.3 program to analyze the environmental impacts from End-of-life of waste management. Throughout the entire end of life analysis, the results are described below.

7.2.1 Endpoint impact assessment

i. Human health endpoint impact summary

- Disposing three television devices by landfilling causes the highest human toxicity burden, which apparently perform as DALY score in human health endpoint. For CRT screen landfill, there also significantly contributed DALY score from climate change human health impact. Overall, the landfilling of LCD television screen can bring the highest potential to effect human health compared to other two devices.

- Besides landfilling approach, the recycling of CRT equipment can help avoid particulate matter formation impact. the recycling of both LCD and LED can help avoid human toxicity which showed as negative DALY score in major the human health indicator. However, recycling the CRT television potential to avoid the highest human health impact, compared to LCD recycling and LED recycling, respectively.

ii. Ecosystem endpoint impact summary

- Ecosystem endpoint impact score (species*yr.) is mostly distributed from agricultural land occupation impact regarding to the CRT television screen landfilling. In case of LCD and LED landfill, these are different from CRT because their burden greatly contributed from climate changes ecosystem impact. Overall, it clearly reveals that CRT contributes the highest adversely affect to the ecosystem than the other equipment.

- Recycling scheme can avoid significant impacts on human ecosystem. All recycling scheme greatly reduce the ecosystem impact mostly from avoided urban land occupation. Nevertheless, recycling of CRT can contribute the highest benefits to the ecosystem compared to the other two devices.

iii. Resource depletion endpoint impact summary

- The landfilling of all television equipment affects fossil resource depletion and metal depletion. But there is lower impact on metal depletion. Particularly in CRT television screen landfilling, there lead to the highest resource depletion compared to the other equipment due to incineration of coating substances.

- Recycling approach helps reduce the total environmental impact based on endpoint score. All televisions screen recycling can gains the benefits mostly from avoiding fossil depletion. And CRT television screen can contribute the highest benefits to the resource depletion compared to the other two devices.

7.2.2 Environmental single score comparison: landfilling vs. recycling approach

- **CRT television single score comparison**

The comparison reveals that landfilling approach highly affects to the environment compared to recycling approach. Two approaches have greatly different approximately 99.47 %

- **LCD television single score comparison**

LCD television screen landfilling provides the positive environmental impact single score. Recycling help reducing the environmental impact compared to landfilling which greatly different approximately 99.91% approach single score.

- **LED television single score comparison**

The single score of LED regarding to landfilling approach causes only few amount of impact, while negative single score from recycling conduct enormous benefits to environment. In other words, two approaches have greatly different approximately 99.90% pt.

In summary, system processes in landfilling approach and other background system (e.g. energy and resource extraction) release pollutants during operation. For recycling approach, if recovered material can use as the same inherent, these can completely compensate to avoid the primary metals acquisition steps. Hence, recycling could provide significant benefits from all television equipment.

7.2.3 The End of life scenario analysis

The forecasting of future impacts during 2014-2023 according to different scenario analysis can conclude that the increasing of recycling rate as well as decreasing of dumping rate to the landfill can bring higher benefits to the environmental performance.

- All television landfilling scenario (S1) is the cause of enormous environmental impacts arising in Thailand during future tens year situation. The single score impact continuously increase according to the number of television equipment.

- The environmental benefits can initially start up by only applying 5% recycling rate (S2) in all equipment. Due to comparing with the scenario 1, the CRT television can greatly reduce environmental impact compared to baseline scenario (11.69-fold), following by LCD (3.99-fold) and LED screen (5.74–fold), respectively.

- Generally, the attempt to increase the recycling rate to 20% can enhance total environmental benefit. Comparing with the baseline scenario, CRT recycling greatly provide benefits from Scenario 3 (50.88 fold) more than LCD (18.96-fold) and LED screen (30.12-fold), respectively.

Interestingly, this correlation between recycling rate of television equipment is directly related to overall single score impact in this study such as the increasing of recycling rate can directly contribute negative environmental single score.

7.3 Sensitivity analysis

The sensitivity analysis evaluated in case of measurement error occurred in disassembly analysis. Single score in this study is only slightly changed after altering ±5% or ±10% of measurement error. Therefore, the single score in this study sensitive to the mass parameter.

7.4 Public opinion and recommendation for EoL television management summary

7.4.1 The results from questionnaire survey

i. Current television waste management practice and public opinions on television waste management

- The survey found that a large groups of people know that Thailand will change signal of transmission from analog TV to digital TV and they will use old television with set top box for receive new system.

- People prefer to keep their television equipment at their household without do anything.

- Focusing on the people awareness in television waste, this study almost participants have already known about precious metal and toxicity in television as well as benefits from proper recycling.

ii. Preferred policy and management plan

- Managing plan of the television collection system should set up based on acceptability from the public. In this study, using act or regulation to recycling television waste is the most preferred option.

- Surveying of best incentive for stimulating the collection system found that people preferred monetary incentive such as returning fee or money discount coupon and other privilege. Nevertheless, the other motivation also showed such as convenient system for returning device, and tax reduction credit when returning back TV waste to collection system.

- For television collection system management, there necessary to set up the central administrative body to operate overall activities and budgets as well as collaborate all of stakeholder into system. The private sector should play this important role in operating of collection system, while other stakeholder in social segment should assist in this framework to develop the operating mechanism.

- About the best option of returning television equipment, people preferred collecting scheme that convenience for them to return item back such as the picking up directly by collecting staff from households. However, it is necessary to set up various collecting options according to their lifestyle.

- It difficult to operates the collecting system without any obstacles because a large group of people lack of knowledge or disadvantage about incorrect television waste management. Nevertheless, manufacturers should be responsible for collecting television waste and sent it to proper management

7.4.2 The television management recommendations from this research

The three strategies are recommended for enhancing practicality and effectiveness of television waste management system. There is necessary to integrate the disposal system from relevant stakeholder. Three strategies for motivating and generating the proper television waste management in Thailand are as following;

i. Strategy I: Recommendation from life cycle impact assessment to reduce overall impact from television equipment

This strategy used the results from previous chapter to create recommendation for decreasing main source of impact including develop or change materials which have less impact and environmental friendly. Moreover, some parts of television which affected to overall impacts and some toxic substances inside equipment should be improved.

ii. Strategy II: Build people awareness and participation in television waste management

This strategy has to implement together and concurrently by government administrative body, private sector. To follow this plan; government and private sector should to set up the campaign and database about the appropriate approach for disposal of E-waste, harmful of improper recycling and other, for giving useful knowledge to people.

iii. Strategy III: Increase effective management and collecting of used electronics in Thailand

To promote the appropriate waste collection center/scheme, the several strategies are involved which including Extended Producer Responsibility (EPR) for electronic waste management and_establishing the suitable site and service of collection system for developing the safety plans during operating

iv. Strategy IV: Incentive for promoting electronic waste collection for recycling system

The national framework such as law and regulation are necessary for proper recycling scheme. Furthermore, financial and technology supports also useful to achieve the gradually changing into proper recycling scheme.

REFERENCES

Arora, R. (2008). Best Practices for E-waste Management in developing Nations (pp. 25): GTZ-ASEM

Baudin, R. H. a. I. (2010). LCA study of a plasma television device. *Life Cycle Assessment, 201010.1007/s11367-010-0169-2,* .

Cheyney, A. C. (1983). Settlement of landfill. *Symposium Proceedings*, 13-29.

Classen, M., Althaus, H. J., Blaser, S., and Scharnhorst, W. (2009). Life Cycle Inventories of Metals. Ecoinvent report No.10. . Retrieved 23/01, 2014, from http://www.ecoinvent.ch

Dodbiba, G., Takahashi, K., Sadaki, J. and Fujita, T. (2008). The recycling of plastic wastes from discarded TV sets: comparing energy recovery with mechanical recycling in the context of life cycle assessment. *Cleaner Production, 16*, 458-470.

Doka, G. (2009). Life Cycle Inventories of Waste Treatment Services *2.* Final

Report Ecoinvent Database v.2.1. Retrieved 4/05, 2013, from http://www.ecoinvent.ch

Doka G. (2007). Life Cycle Inventories of Waste Treatment Services. ecoinvent report No. 13,v2.0. Dubendorf,Switzerland: EMPA St.Gallen, Swiss Centre for Life Cycle Inventories.

E., C. J. a. F. (2003). Mechanical recycling of waste electronic and electronic equipment. *Hazardous Materials, 99*, 243-263.

EC. (2006). *Implementation of the Waste Electric and Electronic Equipment Directive in the EU 25*. Seville Spain: European Commission Directorate-General Joint Research Centre

EPA. (2008). Electronics waste management in the United States.

EPA. (2009). Electronics Waste Management in the United States *Resource Conservation and Recovery*.

EUorganization. (2002). waste electrical and electronic equipment (WEEE)-joint declaration of the European parliament. Retrieved 18/04, 2013, from http://europa.eu.int/eur-lex/en/

EuropeanCommission. (2000). Draft proposal for a European parliament and council directive on waste electric and electronic equipment. Retrieved 12/04, 2013, from http://www.eia.org/download/eic/21

F.O. Ongondo, I. D. W., T.J. Cherrett. (2011). How are WEEE doing? A global review of the management of electrical and electronic wastes. *Waste Management, 31*, 714-730.

Gabriel.R. (2000). lEITFADEN FUR DIE BEHANDLUNG VON ELEKTRO-UND ELEKTRONIKGERATEN. *bUNDESMINISTERIUM FUR LAND UND FORSWIRTSCHAFT*.

Garrity ER, C. M. (1994). CRT-glass optimization by selective X-ray filtration. *International Symposium Digest of Technical*, 897-900.

Gheewala, S. H. a. N., P.H. (2003). Beyond energy efficiency - application of LCA for integrated environmental assessment. *Energy Technology Towards a Clean Environment, 7*.

Goforth DE, M. L., Gulati ST. (1994). Lead extraction from CRT glasses. 905.

Goosey, M. (2004). End-of-life electronics legislation – an industry perspective. *Circuit World, 30*(2), 41-45.

Hedemalm, P., Carlsson, P., Palm, V. (1994). Survey of the Contents of Materials and Hazardous Substances in Electric and Electronic Products. *Nordic Council of Ministers*.

Hedemalm P, C. P., Palm V. (1995). A Survey of theContents of Materials and Hazardous Substances in Electric and Electronic Products. *Nordic Council of Ministers*.

Hischier R., C. M., Lehmann M., and Scharnhorst W. (2005). Life cycle inventories of Electric and Electronic Equipment: Production, Use and Disposal *Ecoinvent report No. 13*.

Hischier R., C. M., Lehmann M., and Scharnhorst W. (2007). Life cycle inventories of Electric and Electronic Equipment: Production, Use and Disposal *Final Report Ecoinvent Database v.2.1* Retrieved 21/03, 2013

Hoornweg, D., & Bhada-Tata, P. . (2012). A Global Review of Solid Waste Management. *What a Waste, 15*.

Huisman, J. (2003). The QWERTY/EE concept, quantifying recyclability and eco-efficiency for end-of-life treatment of consumer electronic products.

ISRI. (1991). Scrap recycling: where tomorrow begins.   Retrieved 19/03, 2014

James, S. C. (1997). The indispensable sometimes intractable landfill. *Technology reviews*, 39-47.

Jirang Cui, E. F. (2003). Mechanical recycling of waste electric and electronic equipment: a review. *Hazardous Materials, 99*, 243-263.

Johannessen , L. M., & Boyer , G. . (1999). Observations of Solid Waste Landfills in Developing Countries. *Waste Age*, 211-227.

Kellner, M. G. a. R. (2003). Recycling technologies for the treatment of end of

life printed circuit boards (PCBs). *Circuit World, 29*(3), 33-37.

Lacoma, T. (2014). LED TV Technology. *Science & Nature.* Retrieved 8/03, 2014, from http://www.ehow.com/about_6647052_led-tv-technology.html

LCDguild. (2014). How LCD TV panels work. Retrieved 18/03, 2014, from http://lcdtvbuyingguide.com/howlcdtvworks.shtml

Lundgren, K. (2012). *The global impact of e-waste: addressing the challenge*.

Menad, N. (1999). Cathode ray tube recycling. *Resources, Conservation and Recycling, 26*, 143-154.

Mutasem El-Fadel, A. N. F. a. J. O. L. (1995). Environmental Impacts of Solid Waste Landfilling. *Environmental Management, 50*, 1-25.

Nectec. (2009). Policy guidelines for the transition to digital television system for Thailand,. 33-48.

PCD. (2008). Handing manual for electrical and electronic waste management. 12-21.

PCD. (2012). Stategy of electrical and electronic equipment management (pp. 24-32).

Productecology. (2006). Introduce LCA. P;otterweg 12, 3821 BB Amersfoart the Natherlands.

Qingbin Songa, Z. W., , Jinhui Li b, Xianlai Zeng b. (2012). Life cycle assessment of TV sets in China: A case study of the impacts of CRT monitors. *Waste Management, 32*, 1926-1936.

Qingbo Xu, G. L., Wenzhi He, Juwen Huang, Xiang Shi. (2012). Cathode ray tube (CRT) recycling: Current capabilities in China and research progress. *Waste Management, 32*, 1566-1574.

Rao, S. K., Moulton, L. K. and Seals, R. K. (1997). Settlement of refuse landfills. *Proceedings of the*

Conference on Geotechnical Practice for Disposal of Solid Waste Materials, 574-598.

Rolf Widmer, H. O.-K., Deepali Sinha-Khetriwal,Max Schnellmann, Heinz Bo¨ ni. (2005). Global perspectives on e-waste. *Environmental Impact Assessment Review, 25*, 436-458.

Rolf Widmera, H. O.-K., Deepali Sinha-Khetriwal, Max Schnellmanm, Heinz Bo¨ nia. (2005). Global perspectives on e-waste. *Environmental Impact Assessment Review, 25*, 436-358.

Senior, E. (1990). Microbiology of landfill sites: Boca Raton Florida.

SEONG-RIN LIM, D. K., OLADELE A. OGUNSEITAN, AND JULIE M. SCHOENUNG. (2011). Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification. *Environ. Sci. Technol., 45*, 320-327.

Siliconvalley. (2003). Just say no to E-waste: Background document on hazards. Retrieved 29/04, 2013, from http://www.svtc.org/cleancc/pubs/sayno.htm

Soderstrom. (2004). Alte Handys und PCs sind wertvolle Kupferminen. Retrieved 19/03, 2014, from http://www.neuematerialien.de/alle_fachbereiche/nachrichten/

Sowers, G. F. (1968). Foundation problems in sanitary landfills. *Sanitary Engineering Division, 94*, 103-116.

Sowers, G. F. (1973). Settlement of waste disposal fills. *Proceedings of the Eighth International Conference on Soil Mechanics and Foundation Engineering*, 207-210.

Srisarakarm, S. (2003). History of television in Thailand (pp. 1-4).

Statisticaloffice. (2010). Indicators of developing information technology and communication of Thailand (pp. 16-39).

Stearns, R. K. (1987). Settlement and gas control: two key post-closure concerns. *Waste Age, 3*, 55-60.

Swanson, C. E. J., Robert L. (2013). Television owning and its correlates. *Applied Psychology, 35*(5), 352-357.

T.E. Norgate, S. J., W.J. Rankin. (2007). Assessing the environmental impact of metal production processes. *Cleaner Production, 15*, 838-848.

Technologycenter, R. p. M. e. (2004). WEEE & Hazardous waste, AEA Technology (pp. 13-16).

TheBaselActionNetwork. (2002). The High-Tech Trashing of Asia (pp. 10-12).

Williams, R. (1994). Technology and Cultural Form. (0-415-31456-9), 3-15.

Wongpanit. (2013). Retrieved 14/09, 2013, from http://www.wongpanit.com/wpnnew/

APPENDIX

APPENDIX A
Bill of material

Bill of material using for CRT, LCD and LED disassembly analysis

Due to the inaccessible material data from television equipment manufacturing, this study has to adopt the bill of materials for disassembly analysis from other literature as the reference sources. The number of disassembly list of each device is described below. All CRT, LCD and LED television screen disassembled following the material list in previous research by Socolof et. al (2001). LCA and LED used same data because they have very similar components but different only one part. In LED used light emitting diode tube instead of fluorescent tube in LCD screen for light source. So, the USEPA data of light emitting diode tube component are used as bill of material. This studied shown the comprehensive view of material and appropriate for this study also.

Table A-1: Bill of material using in CRT disassembly

Subassembly	Components
1. cabinet	1.1 Base 1.2 Front 1.3 Back cover 1.4 Back metal sheet 1.5 Inner cover
2. De-magnetic coil	2.1 Copper coil around CRT tube 2.2 Coated wrapped
3. anode connection	3.1 Anode steel 3.2 Anode rubber cap 3.3 Anode cap insert 3.4 Copper wire
4. Deflection Yoke	4.1 Top neck 4.2 Neck ring large 1 4.3 Neck ring small 1 4.4 Neck ring small 2 4.5 Neck ring large 2 4.6 Ferrite magnet 4.7 Copper line (attached to ferrite magnet) 4.8 Copper line (attached to neck) 4.9 Extraneous copper 4.10 Insulating rings (4 pieces) 4.11 Brass ring 4.12 Brass ring 4.13 Rubber gaskets (2 pieces)
5. Electron Gun	5.1 Gun body 5.2 Brackets 5.3 Attachment to glass 5.4 Attachment to board 1 5.6 Attachment to board 2 5.7 Connectors 5.8 Control box shield
6. Controller, switch and power supply board	6.1 Printed Wired Board Assembly 6.2 Fly-back Transformer 6.3 Heat sink (electron gun PWBA board) 6.4 Heat sink (Power supply PWBA board)
7. CRT Tube	7.1 Funel glass 7.2 Panel glass 7.3 Frit 7.4 Glass coated (aquadag**) 7.5 Shadow mask(invar) 7.6 Phosphor
8. miscellaneous	8.1 Aluminum connector 8.2 Rubber feet 8.3 Screws

Table A-2: the bill of components in LCD and LED television screen

Subassembly	Components
1. Cabinet	1.1 Font cover-Plastic parts 1.2 Rear Cover -Metal parts 1.3 Rear Cover -Plastic parts 1.4 Base/Stand plastic parts 1.5 Base/Stand metal parts
2. Backlight Unit	2.1 Front frame -Metal 2.2 Front frame-Plastic 2.3 Back frame-Metal 2.4 Film Set -secondary reflective foil 2.5 Film Set -prism foil 2.6 Film Set -primary reflective foil 2.7 Film Set -thick reflective diffuser 2.8 Light guide 2.9 Reflector 2.10 Cold cathode fluorescent tube
3. Active matrix liquid crystal display cell	3.1 Connection flex
	3.2 Row/column driver TAB (integrated circuit, IC logic type)
	3.3 Liquid Crystal
	2.1 Other
4. LCD Controller	4.1 LDVS/LCD interface cable
5. Power Supply Assembly	5.1 Metal housing
	5.2 Insulator plate in housing
	5.3 Aluminum heat sink
6. LCD Inverter	6.1 Inverter cable line
7. Power Switch	7.1 Human interface button
8. Controller Board	8.1 Printed wired board assembly (controller board , Universal LVDS/LCD interface board, Power supply control board, Inverter board Switch console board)
9. Miscellaneous components	9.1 Signal cable - inner line 9.2 Input Signal cable 9.3 Bracket materials, 9.4 Holding Screws 9.5 LCD frame screw 9.6 Power Cord

Types of toxic substance in different television model (PCD, 2008)

Table A-3: Main component and types of toxic substance in CRT television

Main component	Types of toxic substance
1. Reinforced Band: metal	1. Cadmium
2. Shadow Mask	2. Coatings of panel: zinc and others metal
3. Fluorescent material: sulfide of zinc and others metal	3. Antimony oxide
4. Panel glass: glass and antimony	4. Barium oxide5. Lead oxide
5. Cabinet: plastic and flame retardant	6. Flame retardant
6. Electron gun: barium oxide	
7. Deflection yoke	
8. Glass filter: glass, antimony, oxide of lead	
9. Printed circuit board: plastic, metal, baririum, and flame retardant	

Table A-4: Main component and types of toxic substance in LCD television

Main component	Types of toxic substance
1. Monitor: plastic and flame retardant	1. Mercury
2. TCP drivers	2. Liquid crystal
3. Transmission equipment	3. Flame retardant
4. Source of light	4. Barium oxide5. Lead oxide
5. Diffuser: glass	6. Cadmium
6. Rear bezel: metal	
7. LCD panel: plastic and liquid crystal	
8. Inverter	

Table A-5: Main component and types of toxic substance in LED television

Main component	Types of LED substance
1. Monitor: plastic and flame retardant	1. Mercury
2. TCP drivers	2. Liquid crystal
3. Transmission equipment	3. Flame retardant
4. Source of light	4. Barium oxide5. Lead oxide
5. Diffuser: glass	6. Cadmium
6. Rear bezel: metal	
7. LED panel: plastic and liquid crystal	
8. Inverter	

APPENDIX B

ReCiPe 2008 methodology

The ReCiPe Endpoint methodology

According to ISO14044:2006, LCI results should be classified into impact categories which each indicator can possible to address at any point between the LCI results and the category endpoints. This approach already embedded in SimaPro 7.3.3 software (Goedkopp et al., 2009). Typically, the principle of this approach were briefly described by international reference life cycle data system as showed in the table below **(ILCD, 2010)** Focusing on the impact assessment, there can align as two families of methods for LCIA: the midpoint-oriented CML 2002 method and the endpoint-oriented Eco-indicator 99 method (Goedkoop and Spriensma, 2001). Therefore, ReCiPe approach offers user to choose between mid or endpoint of their evaluation.

Table B-1: General principles of ReCiPe methodology

List of Topic	Details
Intended purpose of the method:	Combining midpoint and endpoint methodologies in a consistent way
Midpoint/endpoint	Midpoint and endpoint characterization factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources
Handling of choices	Cultural perspectives are used to distinguish three different sets of subjective choices. User can choose which version to apply.
Data uncertainties	Data uncertainties are discussed in the text but not always quantified.
Regional validity	Europe. Global for Climate change, Ozone layer depletion and resources
Temporal validity	Present time
Time horizon	20 years, 100 years or indefinite, depending on the cultural perspective
How is consistency ensured in the treatment of different impacts In characterization , In normalization and weighting?	all emission based categories similar principles and Choices are used. All impacts are marginal. All categories of the same area of protection have same indicator unit. Moreover, Same environmental mechanism for midpoint and endpoint calculations is used.
number of substances covered	Estimated about 3000 substances
The impact normalization (based on Eco-indicator 99)	European normalizations data are calculated with the method for each area of protection (damage category)
The endpoint Weighting (based on Eco-indicator 99)	There are three options : 1. Panel method is used for default weights 2. Weighting triangle has been developed for decision-making without explicit weighting (i.e. equal weighting) 3. Some authors proposed monetization methods, but these are not widely used

Impact calculation perspectives

As same as Eco-indicator 99 approach, three scenarios, or perspectives, have been developed in the ReCiPe method. These scenarios reflect the various sources of uncertainty in the models used to link midpoint and endpoint categories. According to the “Cultural Theory” The perspectives are:

- **Individualist (I):** a short-term perspective, using only undisputed impacts based on the optimistic scenario with regards to technological developments and human adaptation.

- **Hierarchist (H):** middle-ground perspective. Uses most common approach for time-frame and included impacts. This based on the most common policy principles

- **Egalitarian (E):** the most conservative perspective. Uses the longest time perspective and includes impacts that include some uncertainty.

B.3 Details of midpoint impact related to endpoint impact of this study

Table B-2: General principles of ReCiPe methodology

Impact Categories	Details
Climate change	The characterization factor of climate change is the global warming potential. The characterization factor is global warming potential (kg CO 2 to air) equivalents.
Ozone depletion	Ozone depletion refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions. The characterization factors is Ozone Depleting Potential (kg CFC-11 emission to air)
Terrestrial acidification	Acidifying pollutants (e.g. SO_2, NO_X , HCl and NH_3) have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. characterization factors is terrestrial acidification potential (kg SO_2 emission to air)
Freshwater eutrophication Marine eutrophication	Eutrophication is generally associated with the environmental impacts of excessively high levels of nutrients that lead to shifts in species composition and increased biological productivity e.g. as algal bloom. characterization factors are including freshwater eutrophication potential (kg P to water) and marine eutrophication potential (kg N emission to water)
human toxicity	The characterization factor of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The characterization factor is human toxicity potential (kg 14 DCB to urban air)
photochemical oxidant formation	Photo-oxidants are secondary pollutants formed in the lower atmosphere from NO_X and hydrocarbons in the presence of sunlight. These substances are characteristic of photo-chemical Smog. The characterization factor is photochemical oxidant formation potential (kg NMVOC [6] to air)
particulate matter formation	The primary emissions that can cause to the respiratory effect. The characterization factor is particulate matter formation potential (kg PM 10 to air)
Impact Categories	Details
terrestrial ecotoxicity freshwater ecotoxicity marine ecotoxicity	This calculates the toxic substances can contaminate to the ecosystem through fate and exposure factors. Three ecotoxicity characterization factor are including terrestrial ecotoxicity potential (kg 14DCB to industrial soil), freshwater ecotoxicity potential (kg 14DCB to freshwater) and marine ecotoxicity potential kg (14-DCB [7] to marine water)
ionizing radiation	The impact category Radiation covers the impacts arising from releases of radioactive substances as well as direct exposure to radiation. The characterization factor is ionizing radiation potential (kg U^{235} to air)
agricultural land occupation urban land occupation natural land transformation	Traditionally life cycle assessment has focused on two different classes of land use: transformation (land use change) and occupation (land use).In other words, land use are agricultural production, mineral extraction and human settlement. Land transformation is the conversion of land from one state to another state. Particularly, the characterization factor are including agricultural land occupation potential (m^2 xyr. of agricultural land) urban land occupation potential (m^2 xyr. urban land), and natural land transformation (m^2 natural land)
Depletion of fossil fuel resources Depletion of mineral resources	Abiotic resources are natural resources (including energy resources) such as iron ore, crude oil which are regarded as non-living. the characterization factor are including mineral depletion potential (kg -Fe) and fossil depletion potential (kg-oil)

Details endpoint impact of this study

Table B-3: Endpoint impact category

Impact categories	Indicator name	Characterization
Human Health	Disability-adjusted life years (DALY)	Human Health; Under this category we include the number and duration of diseases, and life years lost due to premature death from environmental causes. Indicator
Ecosystems	Loss of species during a year due to environmental impacts (species*yr.)	Under this category It included the effect on losing of species diversity
Resources surplus costs	increased costs for future extractions($)	Under this category we include the surplus energy needed in future to extract lower quality mineral and fossil resources.

APPENDIX C

Disassembly analysis results

Table C-1: Disassembly Analysis of CRT

Component	Sub-component	Amounts(kg)
1. carbinet	1.1back cover	2.08000000
	1.2 front	2.04000000
2. deflection yoke	2.1 brass ring	0.00192225
	2.2 Cu attached to magnet	0.12311558
	2.3 Cu attached to neck	0.09968243
	2.4 extraneous copper	0.00036614
	2.5 ferrite magnet	0.27057967
	2.6 insulating rings(4)	0.01501186
	2.7 neck ring large 1	0.01373036
	2.8 neck ring large 2	0.01327268
	2.9 neck ring small 1	0.00411911
	2.10 neck ring small 2	0.00366143
	2.11 rubber gaskets(2)	0.01098429
	2.12 top neck	0.01455418
3. demagnetic coin	-	0.28600000
4. electrical wire	4.1 electric conductor	0.08632430
	4.2 plastic insulator	0.02767570
5. main control board	5.1 switch,electron gun controller and power supply board	0.98704840
	5.2 Transformer, high voltage use, at plant/GLO U	0.42995160
6. main CRT	6.1 frit	0.10872270
	6.2 panel	11.5341660
	6.3 funel	4.37499850
	6.4 anode connection	0.06358860
	6.5 phosphor	0.01661010
	6.6 shadow mask(invar)	0.44375780
7. electron gun	7.1 attachment to board 1	0.00669236
	7.2 attachment to board 2	0.01736828
	7.3 attachment to glass	0.00462092
	7.4 brackets	0.00924184
	7.5 connectors	0.00127474
	7.6 control box	0.08804572
	7.7 gun	0.03091235
8. screws	-	0.04400000
9. other plastic	-	0.00400000
Total		**23.2560000**

Table C-2: material composition in CRT

Component	Sub-component	material	material specific	amount
1. carbinet	1.1back cover	ABS	plastic	2.080000
	1.2 front	ABS	plastic	2.040000
2. deflection yoke	2.1 brass ring	Cu	non-ferrous	0.001922
	2.2 Cu attached to magnet	Cu	non-ferrous	0.123116
	2.3 Cu attached to neck	Cu	non-ferrous	0.099682
	2.4 extraneous copper	Cu	non-ferrous	0.000366
	2.5 ferrite magnet	Fe	ferous	0.270580
	2.6 insulating rings(4)	other plastic	plastic	0.015012
	2.7 neck ring large 1	PS	plastic	0.013730
	2.8 neck ring large 2	PS	plastic	0.013273
	2.9 neck ring small 1	PS	plastic	0.004119
	2.10 neck ring small 2	PS	plastic	0.003661
	2.11 rubber gaskets(2)	rubber	rubber	0.010984
	2.12 top neck	PS	plastic	0.014554
3. demagnetic coin	3. demagnetic coin	Cu	non-ferrous	0.252633
	3. demagnetic coin	PU	plastic	0.033367
4. electrical wire	4.1 electric conductor	Cu	non-ferrous	0.086324
	4.2 plastic insulator	PVC	plastic	0.027676
5. main control board	5.1 switch,electron gun controller and power supply board	iron	ferous	0.042208
		steel	ferous	0.000900
		Glass	Glass	0.121129
		$BaSo_4$	inorganic	0.010475
		other(inorganic)	inorganic	0.011428
		Al	non-ferrous	0.116992
		Cu	non-ferrous	0.259513
		Mb	non-ferrous	0.000352
		Mn	non-ferrous	0.000049
		Ni	non-ferrous	0.003531
		Si	non-ferrous	0.000082
		Si	non-ferrous	0.000001
		Sn	non-ferrous	0.014810

Table C-2: (continue) material composition in CRT

Component	Sub-component	material	material specific	amount
5. main control board	5.1 switch,electron gun controller and power supply board	Ta	non-ferrous	0.000501
		Zn	non-ferrous	0.005569
		other(organic)	organic	0.005035
		SiO_2	oxide ceramic	0.055878
		paper	paper	0.003363
		Epoxy	plastic	0.057745
		LLDPE	plastic	0.000579
		LLDPE	plastic	0.000579
		other(plastics)	plastic	0.051130
		PC	plastic	0.110057
		PE	plastic	0.080508
		PET	plastic	0.003130
		PMMA	plastic	0.000066
		PP	plastic	0.002570
		PU	plastic	0.000013
		PVC	plastic	0.002117
		Ag	precious metal	0.002953
		Au	precious metal	0.001031
		Pd	precious metal	0.000029
		rubber	ribber	0.001313
		Cr	toxic	0.000009
		Pb	toxic	0.021977
	5.2 Transformer, high voltage use, at plant/GLO U	Fe	ferous	0.191945
		steel	ferous	0.001917
		Cu	non-ferrous	0.040306
		Epoxy	plastic	0.141980
		PC	plastic	0.053803
6. main CRT	6.1 frit	Zn	non-ferrous	0.014659
		SiO_2	oxide ceramic	0.002443
		Pb	toxic	0.091620
	6.2 panel	Ni	non-ferrous	0.334004
		Zn	non-ferrous	0.334004
		SiO_2	oxide ceramic	10.86616

Table C-2: (continue) material composition in CRT

Component	Sub-component	material	material specific	amount
6. main CRT	6.3 funel	SiO_2	oxide ceramic	3.063436
		Pb	toxic	1.311563
	6.4 anode connection	steel	ferous	0.003779
		rubber	rubber	0.017214
		steel	ferous	0.003464
		Cu	non-ferrous	0.039131
	6.5 phosphor	zn	non-ferrous	0.016610
	6.6 shadow mask(invar)	steel	ferous	0.283754
		ni	non-ferrous	0.160004
7.electron gun	7.1 attachment to board 1	PC	plastic	0.006692
	7.2 attachment to board 2	PC	plastic	0.017368
	7.3 attachment to glass	plastic	plastic	0.004621
	7.4 brackets	PC	plastic	0.009242
	7.5 connectors	Al	non-ferrous	0.001275
	7.6 control box	Zn	non-ferrous	0.088046
	7.7 gun	steel	ferous	0.030912
8.screws	8.1 .screws	steel	ferous	0.044000
9. other plastic	9. 1 other plastic	other plastic	plastic	0.004000
Total				23.25658

Table C-3: Disassembly Analysis of LCD

Component	Sub-component	Amounts(kg)
1. Backlight Unit	1.1 cold cathode fluorescent tube	0.1440000
	1.2 back of frame bacllight unit	3.0580000
	1.3 flexible diffuser	0.1470000
	1.4 front frame of back light unit	0.7800000
	1.5 light guide	0.0840000
	1.6 plastic frame	0.3620000
	1.7 thick reflective diffuser	0.6390000
2. Base/Stand Assembly	2.1 monitor base plastic part	0.6420000
	2.2 monitor Base Steel part	1.4280000
3. Inverter	3.1 inverter line link backlight lamp and LCD video cable	0.2300000
4. LCD Cell - liquid crystal assembly	4.1 connection flex	0.0002000
	4.2 Glass,TFT	0.2667790
	4.3 other	0.0036440
	4.4 Row/column driver TAB-integrated circuit,IC,logic type	1.1750000
5. LCD Controller	5.1 LDVS/LCD interface cable	0.0310000
6. Other Miscellaneous Parts	6.1 electricity cable line plug	0.1870000
	6.2 inner signal cable	0.1480000
	6.3 structural screw	0.1010000
7. Outer frame	7.1 Plastic part	1.2010000
8. Power Supply Assembly	8.1 aluminium heat sink	0.0717429
	8.2 insulator plate in housing	0.0425143
	8.3 metal housing	0.5367429
9. Power Switch	9.1 Human interface button	0.0120000
10 Printed wiring boards	10.1 Printed wiring board, mixed mounted, unspec., solder mix, at plant/GLO U(Adjustment)	0.3300000
11 Rear Cover Assembly	11.1 Plastic rear cover	1.6100000
	11.2 Structural Metal plate	1.0950000
Total		14.325623

Table C-4: material composition in LCD

Component	Sub-component	material	material specific	Amount(kg)
1. Backlight Unit	1.1 cold cathode fluorescent tube	Cu	non-ferrous	0.001662
		glass	glass	0.127461
		HDPE	Plastic	0.007250
		Hg	Toxic (Hg)	0.000013
		Pb	Toxic (Pb)	0.005971
		PVC	Plastic	0.001634
		Zn	non-ferrous	0.000011
	1.2 back of frame bacllight unit	steel(Fe)	Ferrous	3.058000
	1.3 flexible diffuser	PE	Plastic	0.147000
	1.4 front frame of back light unit	steel	Ferrous	0.780000
	1.5 light guide	PMMA	Plastic	0.084000
	1.6 plastic frame	PC	Plastic	0.362000
	1.7 thick reflective diffuser	PE	Plastic	0.639000
2. Base/Stand Assembly	2.1 monitor base plastic part	ABS/PC	Plastic	0.642000
	2.2 monitor Base Steel part	steel	Ferrous	1.428000
3. Inverter	3.1 inverter line link backlight lamp and LCD video cable	Cu	non-ferrous	0.036156
		HDPE	Plastic	0.157965
		PVC	Plastic	0.035650
		Zn	non-ferrous	0.000228
4. LCD Cell - liquid crystal assembly	4.1 connection flex	Cu	non-ferrous	0.00020
	4.2 Glass,TFT	AMLCD	glass	0.266779
	4.3 other	rubber	rubber	0.003644
	4.4 Row/column driver TAB-integrated circuit,IC,logic type	Ag	Precious metal(Ag)	0.009092
		Au	Precious metal(Au)	0.013105
		Cu	non-ferrous	0.102390
		epoxy	plastic	0.214653
		Ni	non-ferrous	0.003981
		Nylon	plastic	0.384082
		Pb	Toxic(Pb)	0.044905
		SiO2	oxide ceramic	0.317361
		Sn	non-ferrous	0.076275
		Zn	non-ferrous	0.009156
5. LCD Controller	5.1 LDVS/LCD interface cable	Cu	non-ferrous	0.009314
		PU	Plastic	0.000321
		PVC	Plastic	0.015960
		rubber	rubber	0.005405

Table C-4: (continue) material composition in LCD

Component	Sub-component	material	material specific	Amount(kg)
6. Other Miscellaneous Parts	6.1 electricity cable line plug	Cu	non-ferrous	0.045206
		HDPE	Plastic	0.007759
		PU	Plastic	0.001016
		PVC	Plastic	0.111254
		rubber	rubber	0.017151
		Zn	non-ferrous	0.004614
	6.2 inner signal cable	Cu	non-ferrous	0.023276
		HDPE	Plastic	0.101643
		PVC	Plastic	0.022934
		Zn	non-ferrous	0.000147
	6.3 structural screw	Cr	Toxic (Cr)	0.101000
7. Outer frame	7.1 Plastic part	ABS/PC	Plastic	1.201000
8. Power Supply Assembly	8.1 aluminium heat sink	Al	non-ferrous	0.071743
	8.2 insulator plate in housing	PE	Plastic	0.042514
	8.3 metal housing	steel	Ferrous	0.536743
9. Power Switch	9.1 Human interface button	ABS	Plastic	0.012000
10 Printed wiring boards	10.1 Printed wiring board, mixed mounted, unspec., solder mix, at plant/GLO U(Adjustment)	Ag	Precious metal	0.000988
		Al	non-ferrous	0.039114
		Au	Precious metal	0.000345
		Cr	Toxic	0.000003
		Cu	non-ferrous	0.086762
		epoxy	plastic	0.019306
		glass	glass	0.040497
		iron	Ferrous	0.014111
		LLDPE	plastic	0.000193
		Mb	non-ferrous	0.000117
		Mn	non-ferrous	0.000016
		Ni	non-ferrous	0.001180
		Nylon	plastic	0.011858
		other(inorganic)	inorganic	0.005896
		other(organic)	organic	0.003026
		other(plastics)	plastic	0.005236
		Pb	Toxic	0.007348
		PC	plastic	0.036795
		Pd	precious metal	9.56E-06
		PE	plastic	0.026916
		PET	plastic	0.001046
		PMMA	plastic	0.000022
		polymer	organic	0.000085
		PP	plastic	0.000859

Table C-4: (continue) material composition in LCD

Component	Sub-component	material	material specific	Amount(kg)
10 Printed wiring boards	10.1 Printed wiring board, mixed mounted, unspec., solder mix, at plant/GLO U(Adjustment)	PU	plastic	0.000005
		PVC	plastic	0.000708
		rubber	rubber	0.000439
		Si	non-ferrous	0.000003
		Si	non-ferrous	0.000001
		SiO_2	oxide ceramic	0.018681
		Sn	non-ferrous	0.004951
		steel	Ferrous	0.000301
		Ta	non-ferrous	0.000167
		Zn	non-ferrous	0.001862
11 Rear Cover Assembly	11.1 Plastic rear cover	ABS	plastic	1.610000
	11.2 Structural Metal plate	steel(Fe)	Ferrous	1.095000
Total				14.32562

Table C-5: Disassembly Analysis of LED

Component	Sub-component	Amounts(kg)
1. Backlight Unit	1.1 Array (9 LEDs in 1 array) 1.5 1.80%	0.001962
	1.2 Edison base and leads	0.016132
	1.3 Edison base insulator Acrylic, polycarbonate 4.2 5.10%	0.005559
	1.4 flexible diffuser	0.083000
	1.5 Glass bulb Glass 10.7 13.0%	0.014170
	1.6 Heat sink inner cylinder Aluminum 13.1 15.8%	0.017222
	1.7 Heat sink outer cone Aluminum 18.1 22.0%	0.023980
	1.8 Inner insulator and adhesive connections Acrylic, polycarbonate 6.6 8.00%	0.008720
	1.9 LED board connectors Gold plated copper 0.5 0.60%	0.000654
	1.10 light guide	0.084000
	1.11 Local heat sink ring Aluminum 5.7 6.90%	0.007521
	1.12 primary reflective foil	0.034000
	1.13 Printed circuit board, capacitors, resistors, transistors, diodes 10.1 12.2%	0.013080
	1.14 thick reflective diffuser	0.417000
2. Base/Stand Assembly	2.1 monitor base plastic part	0.275000
	2.2 monitor Base Steel part	0.341000
3. Inverter	3.1 inverter line link backlight lamp and LED video cable	0.014000
4. LED Cell - liquid crystal assembly	4.1 connection flex	0.006000
	4.2 Glass,TFT	0.842000
5. LED Controller	5.1 LDVS/LCD interface cable	0.073000
6. Other Miscellaneous Parts	6.1 electricity cable line plug	0.086000
	6.2 inner signal cable	0.038000
	6.3 structural screw	0.044000
7. Outer frame	7.1 Plastic part	0.280000
Power Supply Assembly	7.2 aluminium heat sink	0.022482
	7.3 insulator plate in housing	0.013322
	7.4 metal housing	0.168196
8. Rear Cover Assembly	8.1 Plastic rear cover	1.222000
	8.2 Structural Metal plate	0.263000
Total		**4.415000**

Table C-6: material composition in LED

Component	Sub-component	material	material specific	Amount(kg)
1. Backlight Unit	1.1 Array (9 LEDs in 1 array) 1.5 1.80%	Hg	Toxic (Hg)	0.0019620
	1.2 Edison base and leads	Sn	non-ferrous	0.0161320
	1.3 Edison base insulator Acrylic, polycarbonate 4.2 5.10%	Acrylic	Plastic	0.0027795
		PC	Plastic	0.0027795
	1.4 flexible diffuser	PE	Plastic	0.0830000
	1.5 Glass bulb Glass 10.7 13.0%	glass	glass	0.0141700
	1.6 Heat sink inner cylinder Aluminum 13.1 15.8%	Al	non-ferrous	0.0172220
	1.7 Heat sink outer cone Aluminum 18.1 22.0%	Al	non-ferrous	0.0239800
	1.8 Inner insulator and adhesive connections Acrylic, polycarbonate 6.6 8.00%	Acrylic	non-ferrous	0.0043600
		PC	Plastic	0.0043600
	1.9 LED board connectors Gold plated copper 0.5 0.60%	Au	precious metal	0.0006540
	1.10 light guide	PMMA	Plastic	0.0840000
	1.11 Local heat sink ring Aluminum 5.7 6.90%	Al	non-ferrous	0.0075210
	1.12 primary reflective foil	PE	Plastic	0.0340000
	1.13 Printed circuit board, capacitors, resistors, transistors, diodes 10.1 12.2%	steel	Ferrous	0.0130800
	1.14 thick reflective diffuser	PE	Plastic	0.4170000
2. Base/Stand Assembly	2.1 monitor base plastic part	ABS/PC	Plastic	0.2750000
	2.2 monitor Base Steel part	steel	Ferrous	0.3410000
3. Inverter	3.1 inverter line link backlight lamp and LED video cable	Cu	non-ferrous	0.0022008
		HDPE	Plastic	0.0096152
		PVC	Plastic	0.0021700
		Zn	non-ferrous	0.0000135
4. LED Cell - liquid crystal assembly	4.1 connection flex	Cu	non-ferrous	0.0060000
	4.2 Glass,TFT	AMLCD	glass	0.8420000
5. LED Controller	5.1 LDVS/LCD interface cable	Cu	non-ferrous	0.0219340
		PU	Plastic	0.0007556
		PVC	Plastic	0.0375822
		rubber	rubber	0.0127282
6. Other Miscellaneous Parts	6.1 electricity cable line plug	Cu	non-ferrous	0.0207899
		HDPE	Plastic	0.0035681

Table C-6: (continue) material composition in LED

Component	Sub-component	material	material specific	Amount(kg)
6. Other Miscellaneous Parts	6.1 electricity cable line plug	PU	Plastic	0.000467445
		PVC	Plastic	0.051165083
		rubber	rubber	0.007887482
		Zn	non-ferrous	0.002121933
	6.2 inner signal cable	Cu	non-ferrous	0.005976277
		HDPE	Plastic	0.026097432
		PVC	Plastic	0.005888584
		Zn	non-ferrous	0.00003771
	6.3 structural screw	Cr	Toxic (Cr)	0.04400000
7. Outer frame	7.1 Plastic part	ABS/PC	Plastic	0.28000000
8. Power Supply Assembly	8.1 aluminium heat sink	Al	non-ferrous	0.02248163
	8.2 insulator plate in housing	PE	Plastic	0.01332245
	8.3 metal housing	steel	Ferrous	0.16819592
9 Rear Cover Assembly	9.1 Plastic rear cover	ABS	Plastic	1.22200000
	9.2 Structural Metal plate	steel(Fe)	Ferrous	0.2630000
Total				**4.4150000**

Table C-7: price of secondary metal or valuable materials

Material	baht/kg
2^{nd} Lead	66.78795
2^{nd} Nickel	394.2130
2^{nd} Copper	228.1326
2^{nd} Gold	60.29109
2^{nd} Palladium	980.5132
2^{nd} Silver	2755.092
2^{nd} Steel	19.91138
2^{nd} Aluminum	58.78173
2nd Mercury	1509.712
Glass cullet	0.950000

From:

1. Wongpanit (http://www.wongpanit.com/wpnnew/ 24/09/2013)

2. World Scrap (http://th.worldscrap.com/price/lme.php?&type=1&lang=th 24/09/2013)

APPENDIX D
Midpoint impacts

The characterization of environmental impact according to Recipe 2008 method

Table D-1: the distribution of midpoint impact of waste management in landfilling approach

Impact category	Unit	CRT landfilling approach	LCD landfilling approach	LED landfilling approach
Climate change Human Health	DALY	1.11E-06	8.37E-07	3.97E-07
Ozone depletion	DALY	3.86E-11	1.72E-11	5.85E-12
Human toxicity	DALY	1.74E-08	1.07E-06	5.16E-07
Photochemical oxidant formation	DALY	7.50E-11	3.46E-11	1.27E-11
Particulate matter formation	DALY	2.90E-07	7.3E-08	2.38E-08
Ionizing radiation	DALY	1.69E-10	1.67E-10	6.95E-11
Climate change Ecosystems	species.yr	6.29E-09	4.74E-09	2.25E-09
Terrestrial acidification	species.yr	7.85E-12	2.69E-12	9.01E-13
Freshwater eutrophication	species.yr	6.28E-12	7.8E-13	2.31E-13
Terrestrial Eco-toxicity	species.yr	2.76E-10	2.34E-10	1.19E-10
Freshwater Eco-toxicity	species.yr	6.42E-11	6.2E-11	3.23E-11
Marine Eco-toxicity	species.yr	1.02E-13	1.13E-13	6.00E-14
Agricultural land occupation	species.yr	1.83E-09	2.47E-10	7.16E-11
Urban land occupation	species.yr	3.75E-10	2.69E-10	1.06E-10
Natural land transformation	species.yr	-1.70E-09	-1.20E-09	-3.70E-10
Metal depletion	$	1.31E-02	1.48E-03	4.20E-04
Fossil depletion	$	1.76E+00	4.11E-91	1.33E-01

Table D-2: the distribution of Endpoint impact of waste management in recycling approach

Impact category	Unit	CRT recycling	LCD recycling	LED recycling
Climate change Human Health	DALY	5.18E-06	1.12E-05	1.51E-06
Ozone depletion	DALY	-5.22E-09	-1.04E-09	-6.64E-10
Human toxicity	DALY	-2.30E-04	-1.79E-04	-3.55E-04
Photochemical oxidant formation	DALY	-2.71E-08	-2.90E-09	-4.03E-09
Particulate matter formation	DALY	-3.77E-04	-2.93E-05	-4.32E-05
Ionising radiation	DALY	-1.04E-07	-1.83E-08	-1.59E-08
Climate change Ecosystems	species.yr	2.93E-08	6.35E-08	8.57E-09
Terrestrial acidification	species.yr	-3.99E-08	-1.61E-09	-3.00E-09
Freshwater eutrophication	species.yr	-9.49E-09	-4.27E-09	-8.48E-09
Terrestrial ecotoxicity	species.yr	3.57E-09	-5.20E-10	-4.13E-09
Freshwater ecotoxicity	species.yr	-3.78E-10	-1.67E-10	-8.86E-10
Marine ecotoxicity	species.yr	-2.48E-12	-1.55E-12	-3.78E-12
Agricultural land occupation	species.yr	-1.91E-09	-3.61E-10	-5.42E-10
Urban land occupation	species.yr	-1.16E-08	-5.42E-09	-9.15E-09
Natural land transformation	species.yr	-3.25E-09	-1.62E-09	-2.74E-09
Metal depletion	$	-6.95E+00	-3.54E+00	-4.64E+00
Fossil depletion	$	-1.30E+02	-5.16E+01	-1.71E+01

APPENDIX E

Surveying question form

แบบสอบถามสำหรับการพัฒนาและเพิ่มประสิทธิภาพของการจัดการซากโทรทัศน์

เมื่อสิ้นสุดอายุการใช้งานในประเทศไทย

โปรดใส่เครื่องหมาย ✓ ลงในช่อง ☐ ที่ท่านเลือกหรือเติมข้อความให้ตรงกับความเป็นจริงของท่านมากที่สุด

ตอนที่ 1 : ความรู้เบื้องต้น สถานการณ์ดิจิตอลทีวีในประเทศไทย

1. ท่านทราบหรือไม่ว่า ขณะนี้ประเทศไทยกำลังจะเปลี่ยนการรับสัญญาณโทรทัศน์ จากระบบอนาล็อกเป็นดิจิตอล

☐ ทราบ ☐ ไม่ทราบ

2. เมื่อเปลี่ยนการรับสัญญาณโทรทัศน์ เป็นระบบดิจิตอลแล้ว โทรทัศน์เครื่องเก่าของท่านจะไม่สามารถรับสัญญาณในระบบดิจิตอลได้ ดังนั้น ท่านคิดว่าจะมีวิธีการใดเพื่อให้ท่านสามารถรับสัญญาณ และรับชมโทรทัศน์ในระบบดิจิตอลได้

☐ ใช้โทรทัศน์ระบบอนาล็อกเครื่องเดิม เชื่อมกับกล่องอุปกรณ์ในการรับสัญญาณ (Set top box)

☐ ซื้อโทรทัศน์ใหม่ ที่เป็นระบบดิจิตอลเลย

ตอนที่ 2 : ลักษณะพฤติกรรมทั่วไปในการจัดการซากผลิตภัณฑ์ขอผู้ทำแบบสอบถาม

(กรอกข้อมูลเฉพาะอุปกรณ์ที่ท่านมีครอบครองเท่านั้น)

3. ในครัวเรือนของท่านมีหรือเคยมีโทรทัศน์ ชนิด CRT, LCD หรือ LED ที่สิ้นสุดอายุการใช้งานแล้วหรือไม่

☐ มีโทรทัศน์ที่สิ้นสุดอายุการใช้งาน ☐ ไม่มีอุปกรณ์ใดที่สิ้นสุดอายุการใช้งาน **(ข้ามไปทำตอนที่ 3)**

4.	ท่านจัดการกับซากโทรทัศน์เหล่านี้ ที่ไม่ได้ใช้งานแล้วอย่างไร		
	☐ 4.1 โทรทัศน์ชนิด CRT	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติมูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง ☐ ทิ้งรวมกับขยะชุมชน ☐ ทิ้งรวมกับขยะอิเล็กทรอนิกส์ ☐อื่นๆ.......................
	☐ 4.2 โทรทัศน์ชนิด LCD	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติ/มูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง ☐ ทิ้งรวมกับขยะชุมชน ☐ ทิ้งรวมกับขยะอิเล็กทรอนิกส์ ☐อื่นๆ.......................
	☐ 4.3 โทรทัศน์ชนิด LED	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติ/มูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง ☐ ทิ้งรวมกับขยะชุมชน ☐ ทิ้งรวมกับขยะอิเล็กทรอนิกส์ ☐อื่นๆ.......................

5. สาเหตุหลักใดที่ทำให้ท่านต้องเปลี่ยนโทรทัศน์เหล่านี้ (โปรดตอบโดยใส่ลำดับที่ตรงกับท่านมากที่สุด

โดย 1=น้อย 2= ปานกลาง 3=มาก 4=มากที่สุด)

____ ไม่สามารถใช้งานร่วมกับอุปกรณ์ที่มีเทคโนโลยีที่สูงกว่าได้ เพราะข้อจำกัดทางเทคโนโลยี

____ อุปกรณ์ภายในชำรุดจนไม่สามารถใช้งานได้

____ ประสิทธิภาพต่ำ

____ ปัจจุบันโทรทัศน์รุ่นใหม่มีราคาถูกลง

ตอนที่ 3 : สอบถามความรู้ทั่วไปเกี่ยวกับความรู้ความเข้าใจต่อการจัดการซากผลิตภัณฑ์โทรทัศน์

6. ท่านทราบหรือไม่ว่า ในส่วนประกอบของอุปกรณ์โทรทัศน์นั้นมีโลหะ และอโลหะที่มีค่าอยู่มากมายอาทิ เช่น ทอง เงิน ทองแดง เหล็ก แก้ว เป็นต้น

☐ ทราบ ☐ ไม่ทราบ

7. ส่วนประกอบของอุปกรณ์โทรทัศน์นั้นมีสารเคมีที่อันตรายเป็นองค์ประกอบอยู่ อาทิเช่น สารประกอบจำพวกโลหะ(ตะกั่ว ใน แก้วของจอ CRT และ แผงวงจรในอุปกรณ์โทรทัศน์ หรือ ปรอทในหลอดไฟของหน้าจอชนิด LCD และ LED) ซึ่งสามารถส่งผลเสียต่อสุขภาพ และสิ่งแวดล้อม ท่านทราบข้อมูลเหล่านี้มาก่อนหรือไม่

☐ ทราบ ☐ ไม่ทราบ

8. การรีไซเคิลอุปกรณ์โทรทัศน์โดยวิธีการที่เหมาะสมนั้นเป็นระบบที่จะสามารถจะนำวัตถุมีค่ากลับมาใช้ได้อีกครั้ง ซึ่งจะเป็นประโยชน์กับสิ่งแวดล้อมและทรัพยากรอย่างยั่งยืน ท่านทราบข้อมูลเหล่านี้มาก่อนหรือไม่

☐ ทราบ ☐ ไม่ทราบ

ตอนที่ 4 : นโยบายในการจัดการซากผลิตภัณฑ์อุปกรณ์โทรทัศน์ที่สิ้นสุดการใช้งาน

9. มาตรการใดที่ทำให้ท่านคิดว่าควรนำมาใช้เพื่อส่งเสริมให้เกิดความร่วมมือและลงมือนำขยะโทรทัศน์มารีไซเคิลมากขึ้น (โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่อง โดย 1=น้อย 2=ปานกลาง 3=มาก)

____ ออกกฎหมายบังคับในการรีไซเคิลซากผลิตภัณฑ์

____ มีการเก็บภาษีสิ่งแวดล้อมเพื่อนำมาจัดตั้งกองทุนในการกำจัดซากขยะโทรทัศน์ และอิเล็กโทรนิกส์อื่นๆ

____ การเก็บค่าจัดการซากผลิตภัณฑ์ทันทีเมื่อซื้อผลิตภัณฑ์

หากมีมาตรการอื่นๆที่ท่านเห็นว่าเหมาะสม โปรดให้รายละเอียด

..

10. อะไรถือเป็นปัจจัยสำคัญที่ท่านเห็นว่าจะสามารถช่วยเพิ่มแรงจูงใจให้นำซากผลิตภัณฑ์โทรทัศน์เข้าสู่ระบบรีไซเคิล (โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่อง โดย 1=น้อย 2= ปานกลาง 3=มาก)

___ เงินค่าตอบแทนจากการนำซากผลิตภัณฑ์ขายคืน

___ ได้รับสิทธิในการลดหย่อนภาษี

___ ความสะดวกสบายในการนำซากผลิตภัณฑ์ไปจัดการอย่างเหมาะสม

หากมีปัจจัยสำคัญอื่นๆที่ท่านเห็นว่าเหมาะสม โปรดให้รายละเอียด

....

11. หากมีการจัดศูนย์รวบรวมซากผลิตภัณฑ์เพื่อเพิ่มประสิทธิภาพในการรีไซเคิล ท่านคิดว่าใครควรจะเป็นผู้ดำเนินการ

☐ รัฐบาล ☐ เอกชน ☐ ตัวแทนชุมชน ☐ อื่นๆ

____

12. หากจะมีการจัดตั้งศูนย์รวบรวมซากโทรทัศน์ วิธีใดที่ท่านเห็นว่าสะดวกที่สุดในการนำขยะเข้าสู่ระบบการจัดการที่เหมาะสม (โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่อง โดย 1=น้อย 2= ปานกลาง 3=มาก)

___ นำมาส่งยังศูนย์รวบรวมซากโทรทัศน์ด้วยตนเองโดยตรง

___ พนักงานศูนย์รวบรวมซากโทรทัศน์มารับคืนในบริเวณชุมชนต่างๆ

___ นำอุปกรณ์โทรทัศน์ที่สิ้นสุดอายุการใช้งานไปคืนยังร้านค้าของยี่ห้อผู้ผลิตในห้างสรรพสินค้าหรือบริเวณใกล้เคียง

หากมีวิธีอื่นๆที่ท่านเห็นว่าเหมาะสม โปรดให้รายละเอียด

....

13. ท่านคิดว่าอะไรเป็นอุปสรรคสำคัญในการรวบรวมขยะโทรทัศน์ และการนำเข้าสู่กระบวนการจัดการของเสียที่เหมาะสม (โปรดตอบโดยใส่ลำดับที่ตรงกับท่านมากที่สุด โดย 1= น้อย 2= ปานกลาง 3=มาก 4=มากที่สุด)

____ การขนส่งซากอุปกรณ์ไปยังศูนย์รวบรวมที่ไม่เหมาะสม

____ ผู้ประกอบการขาดความรู้ ความเข้าใจเกี่ยวกับการรีไซเคิลการกำจัดซากขยะโทรทัศน์ที่ถูกต้องตามหลักวิชาการ

____ ประชาชนขาดความรู้ถึงผลเสียในการจัดการซากขยะโทรทัศน์อย่างไม่ถูกต้อง

____ เงินสนับสนุนไม่เพียงพอกับค่าใช้จ่ายทั้งหมดในการรวบรวมและจัดการของเสียอย่างถูกต้อง

หากมีอุปสรรคสำคัญอื่นๆที่ท่านเห็นว่าเหมาะสม โปรดให้รายละเอียด

...

14. จากข้อ 13 ท่านคิดว่าวิธีการใดที่สามารถลดอุปสรรคในการนำขยะโทรทัศน์เข้าสู่กระบวนการจัดการของเสียที่เหมาะสม (โปรดตอบโดยใส่ลำดับที่ตรงกับท่านมากที่สุด โดย 1= น้อย 2= ปานกลาง 3=มาก 4=มากที่สุด)

____ ผู้ผลิตควรเป็นผู้รับผิดชอบในการรวบรวมซากขยะโทรทัศน์รวมถึงนำเข้าสู่กระบวนการจัดการของเสียที่ เหมาะสม

____ ควรส่งเสริมการให้ความรู้เกี่ยวกับการรีไซเคิลการกำจัดซากขยะโทรทัศน์ที่ถูกต้องตามหลักวิชาการให้กับ ผู้ประกอบการ

____ ภาครัฐควรจัดโครงการส่งเสริมและสร้างจิตสำนึกให้ประชาชนทราบถึงอันตรายของซากขยะโทรทัศน์ต่อ มนุษย์และสิ่งแวดล้อม

____ ภาครัฐ ผู้ผลิต และผู้บริโภคควรมีส่วนร่วมในการรับผิดชอบค่าใช้จ่ายในการกำจัดซากขยะโทรทัศน์ในสัดส่วนที่ เหมาะสม

หากมีวิธีอื่นๆที่ท่านเห็นว่าเหมาะสม โปรดให้รายละเอียด

...

15. กรุณาให้คำแนะนำหรือข้อคิดเห็นเพิ่มเติม ที่ท่านคิดว่าจะเป็นการช่วยส่งเสริมเพื่อให้มีระบบการจัดการขยะโทรทัศน์ให้เกิดขึ้นได้หรือดำเนินการได้อย่างแพร่หลายในประเทศไทย

...

..

ขอบพระคุณที่กรุณาให้ความร่วมมือในการกรอกแบบสอบถาม

REFERENCES

VITA

NAME: Ms. Jakwida Choowongsirikul

DATE OF BIRTH: 29 January 1990

NATIONALITY: Thai

EDUCATION:

- Satreesamutprakarn school-Secondary school

- Chulalongkorn university, Faculty of science, Major in Environmental science-Bachelor degree

PRESENTATION:

1. Jakwida Choowongsirikul and Chanathip Pharino, Environmental Impact Assessment of End-of-Life Television Wastes in Thailand, The 6th ASEAN Civil engineering Conference(ACEC) & The 6th ASEAN Environmental Engineering Conference(AEEC), vol.(2013), E.43

2. Jakwida Choowongsirikul and Chanathip Pharino, Environmental Impact Evaluating of Television Waste Management: Recycling VS. Landfilling, The 3R International Scientific Conference on Material Cycles and Waste Management & 13th Expert Meeting on Solid Waste Management in Asia and Pacific Islands, vol.(2014), pp.21