Environmental Assessment of End of Life of Personal Computer and Recycling Strategies Development in Thailand

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บทคัดย่อและแฟ้มข้อมูลฉบับเต็มของวิทยานิพนธ์ตั้งแต่ปีการศึกษา 2554 ที่ให้บริการในคลังปัญญาจุฬาฯ (CUIR)
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การประเมินผลกระทบสิ่งแวดล้อมของคอมพิวเตอร์ส่วนบุคคลเมื่อสิ้นสุดอายุการใช้งาน และการพัฒนาแผนยุทธศาสตร์รีไซเคิลสำหรับซากคอมพิวเตอร์ในประเทศไทย

นาย ทัตเทพ วีระทัต

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาตรมหาบัณฑิต

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ปริมาณคอมพิวเตอร์ตั้งโต๊ะที่สิ้นสุดการใช้งานมีแนวโน้มที่จะเพิ่มจำนวนมากยิ่งขึ้นในประเทศไทย ทั้งนี้ย่อมสามารถส่งผลกระทบต่อสิ่งแวดล้อมได้ในอนาคต เนื่องจากมีสารอันตรายที่อยู่ภายอุปกรณ์ดังกล่าวหากไม่ได้รับการจัดการที่เหมาะสมจะปนเปื้อนต่อสิ่งแวดล้อมและส่งผลกระทบต่อสุขภาพอนามัยได้ งานวิจัยนี้มีเป้าหมายในการศึกษาผลกระทบทางสิ่งแวดล้อมที่เกิดจากการฝังกลบเปรียบเทียบกับการรีไซเคิลของอุปกรณ์คอมพิวเตอร์ที่สิ้นสุดการใช้งานโดยการประเมินวัฏจักรชีวิต (life cycle assessment) โดยวิเคราะห์ผลด้วยโปรแกรม SimaPro 7.3.3 และประมวลผลตามแนวทาง ReCiPe method 2008 งานวิจัยได้จำลองกรณีต่างๆในอนาคตและคาดการณ์ผลกระทบที่เกิดจากการจัดการขยะคอมพิวเตอร์ในช่วงปี พ.ศ. 2556-2564 (10 ปี) โดยคาดการณ์ผลกระทบจากสถานการณ์การจัดการที่แตกต่างกัน ประกอบด้วย (1) ฝังกลบทั้งหมด (2) รีไซเคิล 5% และฝังกลบ 95% (3) รีไซเคิล 20%และฝังกลบ 80% และในการวิจัยได้จัดทำแบบสอบถามความคิดเห็นของประชาชน สำหรับการวางแผนการจัดการที่เหมาะสมกับประเทศไทย ผลจากการศึกษาโดยรวมพบว่า อุปกรณ์คอมพิวเตอร์ในแต่ละชนิด มีองค์ประกอบของสารอันตรายและวัสดุที่สามารถรีไซเคิลในปริมาณที่แตกต่างกัน จึงส่งผลกระทบต่อสิ่งแวดล้อมจากการจัดการขยะที่แตกต่างกันออกไป ผลการประเมินผลกระทบต่อสุขภาพ ระบบนิเวศ และ ทรัพยากร พบว่าการฝังกลบ จอแบบ CRT ส่งผลกระทบมากที่สุด ผลกระทบลำดับรองลงมาคือคอมพิวเตอร์ตั้งโต๊ะ และ หน้าจอแบบ LCD ตามลำดับ ส่วนเทคโนโลยีการรีไซเคิลพบว่าสามารถทำให้ผลกระทบทางสิ่งแวดล้อมลดลงเนื่องจาก การรีไซเคิลได้ชดเชยผลกระทบที่เกิดจากกระบวนการผลิตโลหะและอโลหะในขั้นต้น การรีไซเคิลคอมพิวเตอร์ตั้งโต๊ะส่งผลดีกับสิ่งแวดล้อมมากที่สุดเทียบกับอุปกรณ์ จอคอมพิวเตอร์แบบ LCD และ CRT ตามลำดับ เมื่อวิเคราะห์ผลแบบ single score พบว่าการรีไซเคิลส่งผลดีกับสิ่งแวดล้อมโดยรวมเช่นกัน ผลการวิเคราะห์สถานการณ์จำลองของการจัดการขยะคอมพิวเตอร์ ผลที่ได้พบว่าในทุกอุปกรณ์หากมีการนำมารีไซเคิลเป็นสัดส่วน 20% ของขยะที่เกิดขึ้นจะสามารถส่งผลดีต่อสิ่งแวดล้อมมากที่สุด รองลงมาคือการนำมารีไซเคิล 5% โดยสถานการณ์ฝังกลบ 100% พบว่าส่งผลกระทบด้านลบต่อสิ่งแวดล้อม ดังนั้นงานวิจัยได้มีข้อเสนอแนะในการจัดการอุปกรณ์คอมพิวเตอร์ที่สิ้นสุดอายุการใช้อย่างเหมาะสม 4 ยุทธศาสตร์ ประกอบด้วย (1) การเพิ่มความตระหนักต่อ สถานการณ์และการมีส่วนร่วมรับผิดชอบในการจัดการขยะอย่างถูกต้อง (2) การจัดการขั้นต้นโดยการเพิ่มอายุการใช้งานของคอมพิวเตอร์ตั้งโต๊ะ ลดปริมาณขยะจากแหล่งกำเนิด (3) การส่งเสริมการจัดตั้งระบบจัดเก็บคอมพิวเตอร์ที่สิ้นสุดอายุการใช้งานอย่างเหมาะสมและสะดวกต่อประชาชน (4) จัดตั้งระบบการรีไซเคิลคอมพิวเตอร์ในประเทศที่เหมาะสมในประเทศไทย โดยการประสานงานและร่วมมือจากทุกภาคส่วนจึงจะสามารถทำให้การจัดการขยะคอมพิวเตอร์มีประสิทธิภาพและประสบความสำเร็จได้

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต..

ปีการศึกษา 2556 ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์หลัก...

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KEYWORDS : CRT /LCD/ Desktop PC / End of life management/ E-waste / Landfill/ Recycle / WEEE/ Waste management

TATTHAP VEERATAT: ENVIRONMENTAL ASSESSMENT OF END OF LIFE OF PERSONAL COMPUTER AND RECYCLING STRATEGIES DEVELOPMENT IN THAILAND. ADVISOR : ASST. PROF. CHANATHIP PHARINO, Ph.D., 176 pp.

The unused or broken desktop computers and equipment are accumulating significantly and also become the massive of waste in the near future. Particularly, computer wastes become concerning issues because of hazardous substances inside. Currently, there is a lack of proper treatment and management system for this type of wastes. Therefore, they can affect the environment quality and human health. To find the best approach to handle with these devices, the objectives of this research aim to evaluate the environmental impacts from proper landfilling and recycling approach. The LCA approach was applied in this study. The analysis used the SimaPro7.3.3 program under the ReCiPe 2008 assessment method. Furthermore, this research evaluated the potential future impact from the different management scheme including: (1) 100% landfilling , (2) 5% recycling and 95% landfilling, (3) 20% recycling and 80% landfilling. This research conducted the public survey to gather the information how to improve PC waste management. The research results revealed that different amount of embedded material types (toxic substances and recyclable material) can consequently provide the individual environmental performance in End of life management of each device. For the endpoint impact assessment, CRT landfilling could contribute highest negative burdens to the human health, ecosystem and resource depletion impact compared to recycling approach, following by desktop PC and LCD computer screen, respectively. Recycling approach can reduce the environmental burden due to the avoided of primary material production stages. Particularly, Desktop PC contributes the most environmental advantage from this scheme, following by the LCD and CRT computer screen, sequentially. The environmental single score results showed that recycling has lower single score than proper landfill. The scenario analysis results found that 20% of recycling scenario can achieve the most benefits following by recycling 5% scenario. However, the 100% landfilling yields negative environmental impact. This study developed 4 recommended strategies of desktop PC management improvement in Thailand including: (1) Increase people awareness and participation in desktop PC waste management, (2) Extended PC equipment lifespan by using proper upstream management, (3) Promoting creation of appropriate desktop PC waste collection center/scheme, and (4) Gradually changing the improper into proper recycling scheme. All strategies need corporation among all key sectors to implement waste management plan successfully and effectively.

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

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

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LIST OF ABBREVIATIONS

$	U.S Dollars unit
AEC	ASEAN Economics Community
ARF	Advance Recycling Fee
CCFL	Cold Cathode Fluorescent Lamps
CD/DVD-ROM	Compact Disc/Digital Video Disc Read-Only Memory
$CO_{2\ eq}$	Carbon Dioxide Equivalent
DALY	Disability adjusted life years
DOWA.	DOWA ECO-SYSTEM CO., LTD
EoL	End-of-Life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
E-Waste	Electronic Waste
FPD	Flat Panel Display
HDD	Hard Disk Drive
ISO	International Standard Organization
kg	Kilogram
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
LCIA	Life cycle impact assessment
NSO	National Statistical office
OEMs	Oil Equivalent
PWBA	Printed Wired Board Assembly
PCD	Pollution Control Department
PPM	parts per million
PC	Personal Computer
Pt.	point
S1	Scenario 1
S2	Scenario 2
S3	Scenario 3
THB	Thai baht unit
USB	Universal Serial Bus
WEEE	Waste electric and electronic equipment

CHAPTER I
Introduction

1.1 Rationale for study

In modern society, the using of electronic tools has proliferated in recent decades. The computer technology becomes a necessity for productivity in almost all sectors which number of usages have increased significantly from the past decades and still keep going on. For Thailand, Certain numbers of PCs users rapidly grow in recent decade and reached 19.1 million in 2010. Normally, the average lifespan of a PC is between 4–6 years but might be decrease to 2 years (Culver, 2005). In facts, this depends on many factors such as the rapid changes in computer technology today leads computer with old version cannot work compatible with rapid or online technology. Moreover, the computer manufacturer can cut the cost of computer producing which consequently reduce newer computer prices. Overall, these could possible to motivate people to buy a new computer and effect to increase the unused device before their certain lifetime.

According to this PC user mechanism, this is directly creating massive of disused equipment which also directly link to the future e-waste problems. This concerning issues began from hazardous material (Morf et al., 2007 and Robinson, 2009). For desktop PC, the hazardous substances are mainly embedded in printed wiring board and plastics material such as tin, lead, polychlorinated, mercury and brominated flame retardants. (Deng et al. 2007; Liu et al., 2008; Qu et al., 2007) In case of CRT computer screen, It significant also contains large amount of phosphor and lead oxide; Especially, 70% of lead oxide can be founded in overall glass tube (Socolof et al., 2005). For LCD screen, the variable compositions in liquid crystal assemblies and film sets also embedded heavy metals, dyes, and other coatings inside LCD module. Generally, black light is the well-known toxic source because LCD fluorescent lamp stored mercury trace elements.

Indeed, the waste management approach is the one factor to define the environmental and health quality from prevention of contamination. Landfilling is the one approach to manipulate the waste residues under the suitable processes. However, in reality, the old landfilling cannot prevent harmful elements from E-waste. There are many research founded toxic chemical exceed landfill leachate standards the contamination of them around that area (Noon et al., 2011). To avoid this problem, landfilling of this waste is banned in some country and recycling is considered as the state-of-art approaches which regarding to sustainability concept to solve this situation. The recycling of discarded PC is can help to minimize potential toxic leachate from improper landfill; not at all, it also provides re-valuable materials to utilize again. For desktop PC, this can create many profit because inside of this device contained various of recyclable element including 7% iron, 5% aluminum, 20% copper, 1.5% lead, 1% nickel, 3% tin and 25% organic compounds together with 250 ppm of gold, 1000 ppm of silver and 100 ppm of platinum (StEP, 2009).

However, this is obvious caveats in case of recycling without proper manner. The inappropriate tools and operating manner could pose a risk to the ecosystem and health from leaching from heavy metals and other elements. For example, this usually happened from recovering of copper wire by burning plastics, recovering precious metal from printed wired board using acid cyanide bath without safety procedure, disposal CRT leaded glass and LCD backlight residues without prevention. Interestingly, this problem of improper recycling is also intensified to large scale problem in many the developing countries and 80 percent of

total E-waste (including desktop PC device) was brought to manage by their backyard activities (Lundgren, 2012).Interestingly, many studied mostly founded contaminants in air, dust, bottom ash, soil, water, and around informal recycling site of all these countries. This consequently provides the risk of cancer and possibly effect to higher of death rate (Fang et al., 2005; Leung et al., 2008; Li et al., 2007; Sepúlveda et al., 2010; Tekwawa et al., 1997)
In Thailand Situation, there is a lot of improper E-waste collector which mainly gathered the waste before export to recycle in other countries. Nevertheless, it still has only small number recycling processors in Thailand when compare to the informal recycler. This is because the informal recycling approach does not involve high investment cost in operation, together with less restriction of pollution control enforcement.

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 plays an important in characterizing and evaluating of the environmental performance. Not at all, it also defines as the effective management supporting tool.(Hischier et al., 2010; Socolof et al., 2001 and Wittmaier et al., 2009). For LCA application in desktop PC relevant study, major of them generally showed that the disposal of desktop PC can distribute the wide spectrum of impact category except for upstream energy consumption(Atlantic Consulting, 1998; Socolof et al., 2005; Song, et al., 2013 and Williams, 2004). In case of CRT and LCD computer screen, landfilling approach possible contribute high level of burdens at of the final end of life stage(Socolof. et al., 2001). Despite to this strategy, recycling can avoid the burden from the primary materials extraction. These benefits were larger than the disposal environmental burden .This indicates that material recycling could decrease some of the end-of-life impact it possible to subtract around 75 to 80% of overall end of life phase (Socolof et al., 2005; Song et al., 2013).

As overall introduction contents, this type of waste could be the problem in Thailand if the less of understanding and studying in-depth to the environmental impact still persist. Therefore, this research aims to evaluate the environmental impacts of PCs at the end-of-life stage by comparing between two approaches. The evaluating approach in this study is considered to apply life cycle analysis (LCA) concept to generate total environmental profiles (ISO, 2006). In addition, this study also purposes to create the public opinion to identify appropriate strategies for promoting e-waste recycling implementation in Thailand by looking into the future projection.

1.2 Research Objectives

This study has three objectives:

1. To evaluate environmental impacts of selected desktop PC models at the end of life stages applying LCA approach

2. To forecast future impacts from End of Life of Obsolete PCs in Thailand regarding to the PC waste generation potential during 2012-2021

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

1.3 Hypotheses

1. The disposal of PC equipment into landfill can contribute higher degrees of environmental impacts compared to the proper recycling approach regarding to the release of toxic substances embedded in PC.

2. Increase recycling of discarded PC can reduces the levels of environmental impacts through overall life cycle management.

1.4 Expected outcomes

1. Identify the environmental impacts per unit of End-Of-Life of the selected PC model

2. Understand future impacts of discarded PC in Thailand in the future under different scenarios

3. Understand advantages and obstacles of PC recycle waste management and recommendation for better improving the computer waste management in Thailand

1.5 Scope of the study

The scope of this study is only aim to evaluate environmental burdens from desktop PC management including landfill, recycling, and other related activities related to end of life stage. Prior to suggestion of the proper waste management programs, scenario analysis was conducted at least for 10 year future projection.

Chapter II
Literature Reviews

2.1 Increasing of computer waste problems in the past decades

As the trend of globalization ,the information technology have been growth since the last decade(Teehan and Kandlikar, 2012). Computers are proliferated everywhere due to their basic intelligent in both data computing and storing; moreover, it also best as tool for connecting to each other. This tool began to the part of world business market and household user since 1980s and also more popular in the 21st century due to the internet booming .This lead to the computer market exponential growth. The observation at end of year 2010 showed that PC equipment growth around the world probably reached two billions machines in 2015 (Forrester, 2007). In facts, total desktop PC consumption also increase following the economic growth as showed in the Figure 2-1; the amount of this device is directly correlated with the country's GDP. The total number of computers increase faster in richer countries more than in poor countries (Robinson, 2009). Nevertheless, the new trend of economic growth in some developing countries such as Latin America and China will become new major E-waste producers in the future(Hischier et al. 2005).

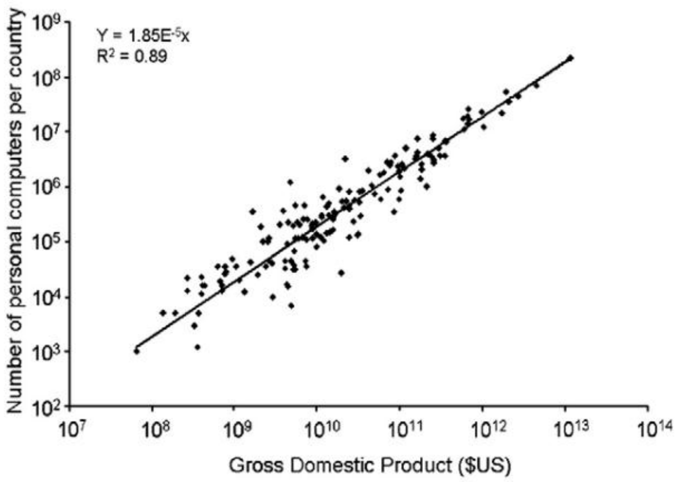
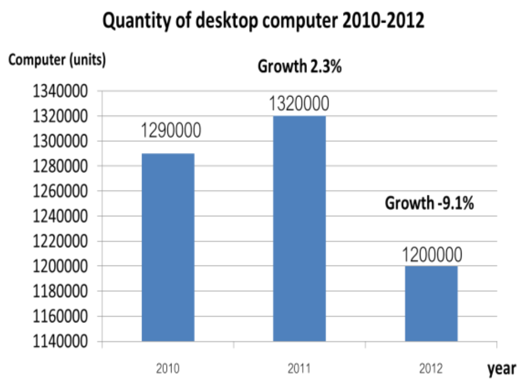
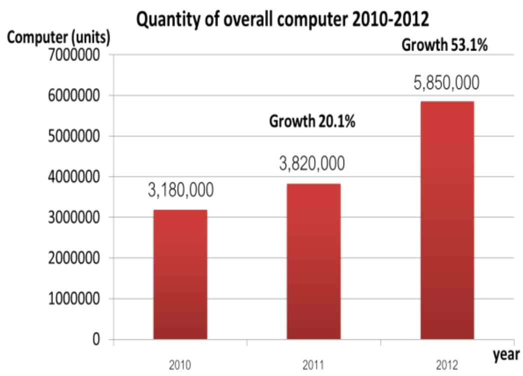


Figure 2-1: Number of personal computers per country as a function of GDP for 161 countries (Robinson, 2009)

For Thailand, computer products have been increase since 1990s and rapidly proliferated in this nowadays (PCD, 2010). The computer increasing in Thailand initially enhanced by the National IT Policy Framework for the year 2001-2010 according to the goals of knowledge-based economy and society by integrating information technology. Therefore, computers became fully utilized in many sectors and caused the computer market extended in as the world trend. Recently, Thailand's PC market bounced back strongly in the first quarter of 2012 after the great flood crisis except for desktop PC sales which were substituted by new type of notebook and tablet computer (Figure 2-2 (a), (b))





(a) (b)

Figure 2-2 (a): quantity of desktop PC in year 2010-2012, (b): quantity of overall computer product year 2010-2012

Computers are defined as the waste when the large amount of devices enter into the end of use stages because of several reasons; first, the operating system used to run the computer cannot compatible with the new model anymore. Second, the limitation of the memory capacity and low speed of old types cannot perform high efficiency for the firm because cannot synchronize with networks or online database. Third, the old equipment cannot respond to the new application software which require higher speed of computing process (Technology Recycling, 2003). Desktop PC device normally have an average lifespan of around three years but the truth is that people usually defines as obsolesces earlier than usual lifespan or breakdown. The certain data from USEPA show that approximately 29.9 million desktops and 12 million laptops were discarded in 2007 and still increase continuously (Electronics Take Back Coalition, 2007) As same as Thailand, the forecast number of waste production studied by EEI. It reveal that this type of waste still reach to high level during ten year (Figure 2-3)

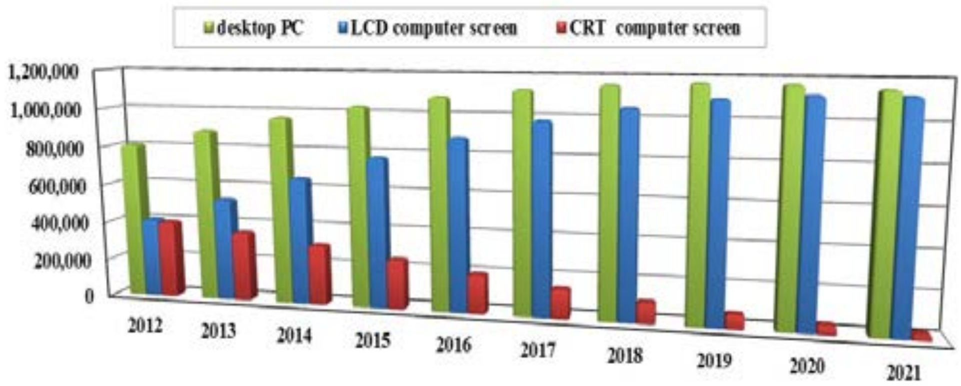


Figure 2-3: Desktop PC equipment forecasting year 2012-2021 (EEI, 2007)

2.2 The desktop PC equipment: Components and Substances

A computer is the great innovation which can mainly function serving user's purposes. This intelligent mechanism use the instruction program to analyze the information before reveal out to the user perception. In other words, the computer turn input data into useful information output through the program working instructions. To establish the computer function, hardware is the physical parts that constitute a computer system. Computer is necessary to have many logical electric, electronic and mechanical components cooperate with operation system for complete the loop of function. To emphasize on computer part,the different system of hardware already describes in figure 2-4. There are generally consisted of three main platforms including:

- **Input units:** There are the hardware components using to enter the data and instructions into a computer. The commonly known devices are keyboard, mouse, microphone, scanner, and Webcam

- **System units:** This is defines as important parts which control all of the operation in whole computer. This unit compute the operations through the basic arithmetical, logical, and input/output operations of the system by CPU unit. This system also requires the data storage unit and software operation in order to support CPU working. After that, this result from this step will be showed through the further output devices.

- **Output units**: Output units consist of hardware device which help to show the responded results to the users after passed through the input and processing operations. Generally, computer usually represents the output results back in graphics or vocal form.

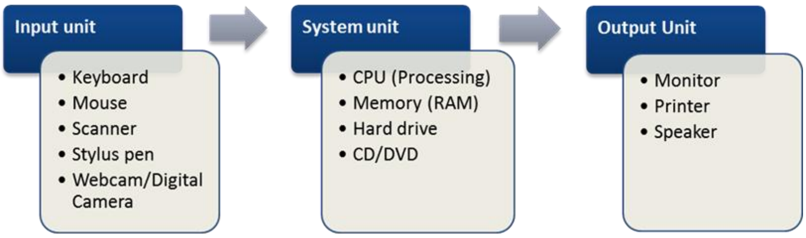


Figure 2-4: The computer operating components

2.2.1 The desktop computer components

According to the working framework, this hardware design for working together as a building block as described in Figure 2-5. These regular components are the component of ordinary-use computer. There are including cabinet, motherboards, Hard disk drive (HDD), Floppy disk drive (FDD), daughter boards (e.g. LAN card, sound card, graphic card) , power supply unit and other. When deliberated them into the several fraction, it can be classified into the major group of components which shows in the table 2-1.

Figure 2-5: The components in one desktop computer (Yindee, 2004)

Table 2-1: The lists of components in regular computer

Components	The Details of each components
A case cabinet	- It covers the key components of a computer and protect from dust or some physical damage.
Integrated Circuits	- Including both logical and computational functions. - Embedding in the Basic Input/output System (BIOS), Random Access Memory (RAM), and Read-Only Memory (ROM).
Central Processing Unit (CPU)	- This is also the one particular form of IC - The term CPU is the main processor for executing program instructions and mathematical calculations.
Printed Circuit Board (PCB)	- PWB is the based board contains computer's basic circuitry and components. (primarily copper, with gold-plated connectors) - This exist as the motherboard, daughter boards
Data Storage unit	- There includes fixed devices (e.g. magnetic "hard" drive) or removable devices (e.g. 3.5" magnetic disks, CD-ROM, USB drive, memory cards)
Power Supply unit	- The power supply takes mains power controller and send it to several parts
Battery	- A battery, either as a main source of power supply to enable basic functions.
Fans	- Using to sink heat from CPU, power supply and other heat-generating components.
Cables	- Cables to convey voltage to functional components (e.g. from the power supply to the motherboard) and data from one component to another (e.g. bus cables connecting the motherboard to storage devices).

Particularly, the regular desktop PCs contain a various amount of substances. There mainly founded some large quantities of Iron, non-ferrous metal, glass, plastics and electronic components in different proportion as shown in table 2-2 (UNEP, 2007).

Table 2-2: Average weight and composition of selected electrical and electronic appliances

Personal computer	% weight
Iron (Fe)	53.3
Non Ferrous metal	8.4
Glass	15
Plastics	23.3
Electronic components	17.3
Others	0.7

Source: UNEP (2007)

Normally, PC and other electronic device usually used plastic material in cabinet or covered material; it usually founded the different plastic types attached together at the same place such as PWBA, HDD, and other. Some types of plastic possibly include metals and other elemental additives. For example, PVC sheaths for cabling include cadmium and lead stabilizers. Focusing on the plastic fraction as shown in table 2-3, the quantity of desktop PC one regular PC has highest proportion of ABS plastic and following by PC/ABS, PPO and HIPS, respectively.

Table 2-3: Average percentage of plastic composition per one desktop computer (UNEP, 2007)

Plastic type	% Weight
Acrylonitrile Butadiene Styrene (ABS);	57
Polyphenylene Oxide (PPO);	5
High Impact Polystyrene (HIPS)	2
Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS)	36
Polyvinylchloride (PVC)	Trace

Source: UNEP (2007)

2.2.2 The computer screen components

The computer screen is necessary to perform the data output in visualization form. Nowadays, it can be separated roughly into both types of monitor including: (1) CRT (cathode ray tube) monitor and (2) flat panel display (FPD). In facts, both types can generate sharp images, but FPD monitors rather thinner and lighter than CRT monitor. For the more detailed, both items are described below.

2.2.2.1 CRT computer display unit

Cathode ray tube displays (CRTs) is the previous popular display technology. This electronic device comprised of high weight glass panel screen, a plastic casing, various connecting wires, magnetic and radiation shielding, and the cathode ray tube. Electron guns and deflection yoke coils is also the important which used to create an electron beam before react which phosphors on the back of the glass panel screen. In brief, the location of these components is shown in Figure 2-6. Moreover, there roughly conclude in the lists which elaborate this overall device in to group. This reveal just some of major elements (>5 wt. %) and the minor elements (<5 wt. %) which identified from the panel and funnel glass (14 inch Philips color monitors as showed in table 2-4)

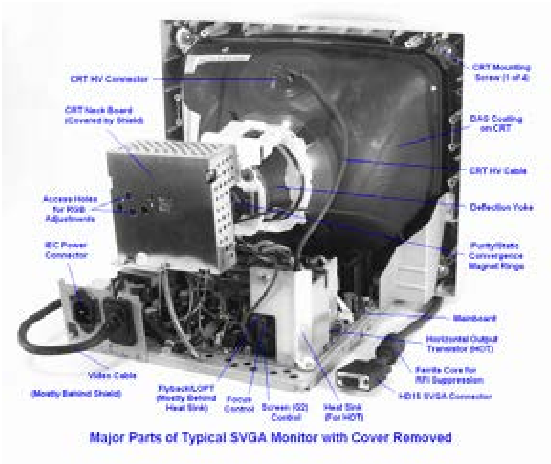


Figure 2-6: The components in one CRT computer screen
(Available from: http://www.repairfaq.org/sam/mon1rear.gif)

Table 2-4: Analysis of components in a 14 in. Philips color monitor

Item	Material	Weight (kg)	wt.%
Shell	Plastic	2.032	17.38
CRT explosion–protection unit	Iron	0.213	1.82
CRT unit		5.638	48.23
Shadow mask	Steel	0.455	3.89
Panel glass	Glass	3.356	28.71
Funnel glass	Glass	1.731	14.81
Gun	Steel, glass, copper, plastic	0.096	0.82
Yoke	Copper, plastic, iron	0.589	5.04
Metal parts	Iron	0.542	4.64
IC board	IC, resin, copper, iron	1.676	14.34
Wire	Copper, plastic	0.661	5.65
Rubber parts	Rubber	0.048	0.41
Plastic parts	Plastic	0.291	2.49
Total		11.690	100.00

Source: Lee et al. (2004)

The previous research by Huisman (2003) allocated the CRT product composition following table 2-5. Glass content composition distributed as the highest weight fraction. The valuable metals also founded in this type of screen .There are consisted of about 11 ppm for Silver, 0.7 ppm for gold and 0.25 ppm for palladium and other.

Table 2-5: Product composition of CRT monitors (Huisman, 2003)

Material	Weight (g)	Weight %
Aluminum	48.55	0.33 %
Copper	892.15	6.09%
Ferro	1324.08	9.04%
Glass	9392.50	64.1%
Plastics	2606.62	17.8%
Ag	0.16	11 ppm
Au	0.01	0.7 ppm
Pd	0.00	0.3 ppm
Other	385.22	2.63%

Source: Huisman (2003)

2.2.2.2 LCD computer screen

A liquid crystal display (LCD) is usually known as the flat panel display which contains the enormous color or monochrome pixels arraying in front of a light source or reflector. As shown in the Figure 2-7. The common LCD technology provided in computer monitors use separate and independent Thin Film Transistors (TFT) as a switch for each pixel. This type of screen demands the CCFL fluorescent lamps and a thin light diffuser to provide light so the screens may be seen in the dark. This part aligned as the layer inside a metal frame. Overall, main LCD display components are including: LC assembly, film set, backlight assembly, plastic housing/frames, power supply, and controller (Noon et al., 2011)

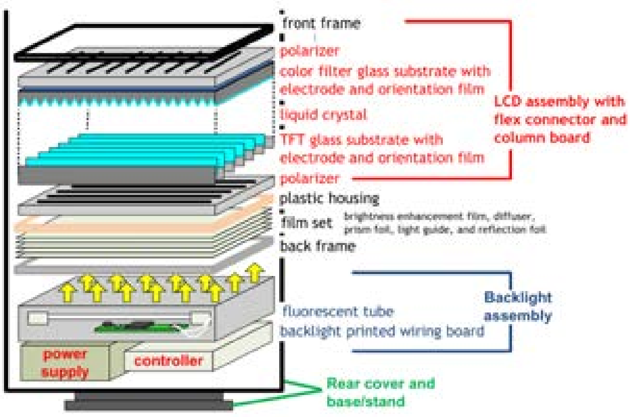


Figure 2-7 indicates the principal parts of an LCD Screen (Noon et al., 2011)

Focusing on the material component, it can be seen that LCD display consists of many type of materials. Figure 2-8 deliberated LCD display into several fractions, it showed that major component in LCD display made from the steel part. These came from the structural part and overall frame. Moreover, the other complex fraction is following by the plastics group contributing from light reflector unit. (Socolof et al., 2005)

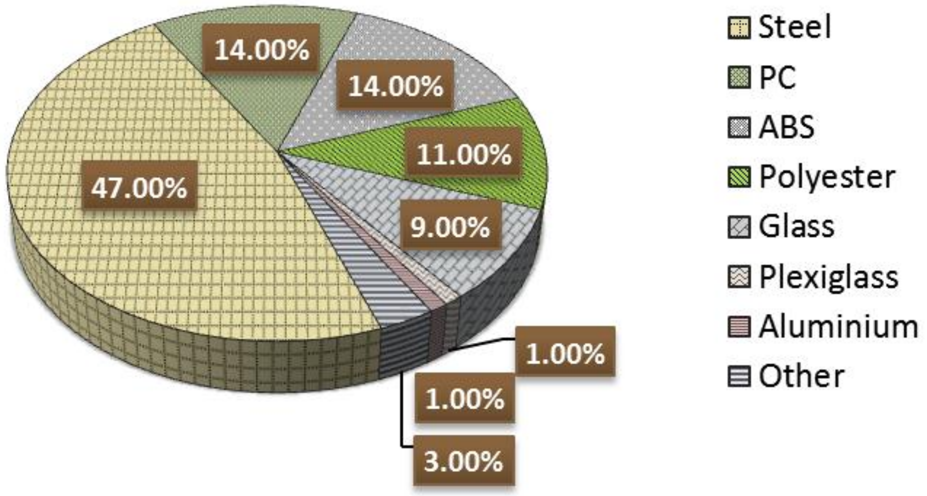


Figure 2-8: Material content of 15 inch LCD display (Socolof et al., 2005)

2.2.3 The toxic material and precious metal inside this components

Chemical elements in E-waste might widely contain over than 1,000 substances. Many of them usually founded as harmful, and create serious pollution(Grossman, 2006). The lists of toxic elements in table 2-6 partially showed some of risky substances which it might make the possible to make acute or chronic affect in living thing. this could reflect to the human exposure route which the improper management practices such as open-dumping or primitive recycling activities can cause substances leach out and transport with soil, water and air which become available to living organisms (Pirzada & Pirzada, 2006).

Table 2-6: Toxic substances composition in E-waste (Pirzada & Pirzada, 2006)

Material	Toxicity
Arsenic	skin diseases, lung cancer, decreased nerve conduction velocity
Barium	brain swelling, muscle weakness, damage to heart, liver and spleen
Beryllium	lung cancer , skin disease
BFRs	severe hormonal disorders
CFCs	skin cancer, deleterious to ozone layer
Chromium (VI)	irritating to eyes, skin and mucous membranes, DNA damage
Dioxins	impairment of the immune system
Lead	vomiting, diarrhea, convulsions, coma, even death
Mercury	brain and liver damage if ingested or inhaled
PVC	respiratory problems
Selenium	hair loss, nail brittleness, and neurological abnormalities

Source: Pirzada and Pirzada (2006)

2.2.3.1 CRT concerning Point about Toxic substances

Focusing on the CRT glass fractions, it completely defined that has high potential to be harmful due to the high-lead content. It is a one of prioritized toxic material and the subject of electronics industry efforts to reduce or eliminate its future use. Lead in CRT useful for radiation shielding during use stage. As represented in Table 2-7, lead is commonly founded in CRT glass parts at different level. Particularly, this table also showed that CRTs contain over 25 times more lead than LCDs. Interestingly, lead oxide is accounting for about eight percent of the overall composition of the CRT by weight. The potential impacts from lead were found in the following eight categories: non-renewable resources, hazardous waste landfill use, solid waste landfill use, radioactivity, chronic public health effects, chronic occupational health effects, aquatic toxicity, and terrestrial toxicity. (EPA, 2001)

Table 2-7: Computer display parts that contain lead

Part	Display type	Quantity (kg)[a]	% lead content of part (by weight)
Funnel	CRT	0.91	22-28% [b, c]
Front panel	CRT	0.18	0-4 [b, c]
Neck	CRT	0.012	26-32 [b, c]
Frit	CRT	0.026	70-80 [b, c, d]
Printed wiring boards (total)	CRT	0.051	NA
Printed wiring boards (total)	LCD	0.043	NA

Source: EPA (2001)

2.2.4 LCD concerning point about toxic substances

It is widely known that mercury is also harmful to the human health and animal by Bioaccumulation which humans could be exposed to the mercury in its many forms. The "mercury species" including: Hg^{0}, Hg^{1+} and Hg^{2+} exist within fluorescent lamps in both elemental and compound forms. In conventional CCFL operation, elemental mercury will be attracted to the coated on the electrode. Interestingly, it also has found in used lamps the mercury is absorbed by the existed phosphor coating. Nevertheless, this all type form is became addressed by the EU concerning in 2005. Basically, 90% of all current LCD equipment uses a backlight unit but different in the number and size as shown in Table 2-8.This related through the size which mercury trend to has high level in larger size. (McDonnell and Williams, 2010)

Table 2-8: Characterization of fluorescent lamps backlights in LCD

Type	Screen size	Average Lamp Length mm	Average Lamp Width mm	Average Lamp Weight kg	Number of Lamps	Mercury Content mg
LCD Monitor	15"	320	2	0.004	2	7
LCD Monitor	17"	350	2	0.006	4	14
LCD Monitor	19"	390	2.5	0.006	4	14
LCD Television	20"	430	2.5	0.009	6	21
LCD Television	26"	630	3	0.072	13	45.5
LCD Television	32-37"	805	4	0.115	16	56
LCD Television	42"	920	3	0.17	18	63

Source: WRAP (2010)

2.2.4 Precious metal in Printed wired board

Obsolete computers contain abundance amounts of recoverable materials which are the precious metals (gold, silver, and palladium) and special metals (indium, selenium, tellurium, tantalum, bismuth. the source of them are founded in printed wired board assembly. As the table 2-9, the average concentration of silver, gold, and palladium in PCBs from different types of equipment is usually much higher than the concentration of precious metals in mine ores (Chancerel et al., 2009).In general, the extraction of gold and palladium from ore usually yield less than 10 g/t (Hagelüken et al, 2005). This number is less than PCBA of personal computers. there revealed about 81-490 g/t of gold and of 3-100g/t of palladium (table 2-9), Therefore, the importance of recovering precious metals from electronics becomes obvious.

Table 2-9 Average concentration of precious metals in printed wired board assembly in computer and related equipment

References	Equipment type (Origin of the Printed circuit board)	Silver (g/t)	Gold (g/t)	Palladium (g/t)	Platinum (g/t)
Chancerel, Meskers, Hagelüken, et al. (2009)	**Personal computer**	**905**	**81**	**-**	**-**
Hageluken (2006)	**Personal computer**	**1000**	**250**	**110**	**-**
Huisman et al. (2008)	**Personal computer**	**1000**	**230**	**90**	**-**
Keller (2006)	**Personal computer**	**775**	**156**	**99**	**-**
Legarth et al. (1995)	**Personal computer**	**700**	**600**	**100**	**40**
Huisman et al. (2008)	**Computer CRT display**	**150**	**9**	**3**	**-**
Huisman et al. (2008)	**Computer LCD display**	**1300**	**490**	**99**	**-**

2.3 End-of-life of Desktop computer and other E-waste management

2.3.1 Dumping the Desktop PC into the landfill

Dumping the desktop PC waste into sanitary landfills can contributed ranges of potentially hazardous substances in desktop computer. The EPA revealed the results about CRT glass in computers are classified as hazardous waste as defined by EPA standards. TCLP tests have shown that circuit boards and CRT glass exceed EPA limits for lead leach ability (Williams et al., 2008). Moreover, there are many researches have founded that circumstance of leaching. For example, the research paper by Musson et al. (2006) emphasized on 13 different types of electronic devices, including CPUs, CRTs, and laptops, lead concentrations also exceeded the Federal TCLP limits for classification as hazardous waste. Jang and Townsend (2003) research by collected a representative sample from 11 Florida landfills. These samples were measured leaching properties using the TCLP approach. There conclude that PWBA and CRTs potential to leached the lead at average concentrations of 2.23 and 4.06 mg/L, respectively,

Beside the leaching occurrence, the heavy metals have a chance to go out from a landfill into the environment by advection flow out through the landfill gas. Heavy metals may also be released from landfills by solid-state diffusion, or less in diffusive flux of heavy metals (Williams et al., 2008). Nevertheless, the concentrations of heavy metals in landfill leachate and landfill gas are only part of the overall question of how well of sanitary landfills management in order to prevent these toxic materials.

2.3.2 Informal recycling activities

It usually found “backyard recycling processes” wide-spread in China, India, and Pakistan. For the example case Guiyu in China, it is the most well-known as the informal electronics recycle center contaminated with heavy metals, and cause undrinkable water and dioxin ash ,which have made worker and the 80% children suffered from lead poison (Huo et al., 2007; Pirzada and Pirzada, 2006) In addition, the level of Polybrominated Biphenyl Ether (PBDE) or Polybrominated Biphenyl (PBB) as the flame retardants at an e-waste combustion site was more 16,000 times than at a control level which overdosed in many villager blood level (Williams et al., 2008). Particularly, It has high toxicity level at the schoolyard and food market. Risk assessment predicted that Pb and Cu originating from circuit board recycling have the potential to pose a serious health risks to workers and local residents of Guiyu lead and Cu in road dust were 330 and 106, and 371 and 155 times higher, respectively non e-waste sites located 8 and 30 km away (Leung et al., 2008). However, long-term health studies of e-waste workers have yet to be conducted.

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 (The Basel Action Network, 2002). 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).

2.3.3 The various policies for end of life management: international regulation scheme

Many countries around the world have established many of policy frameworks to control E-waste. Typically, WEEE is quite different type of waste when compared to other type. The traditional waste type management cannot be applied in the case of the e-waste stream due to it characteristic of containing both highly toxic substances which pose a danger to health and environment, the table 2-10 below showed the example of regulations in various countries.

Table 2-10: WEEE regulation in some developed countries

Country	Legislation	Responsibility	In force since
Switzerland	Ordinance on the Return, Taking back and Disposal of Electrical and Electronic Equipment. (ORDEE)	Manufacturer/importer	July 1998
Denmark	Statutory Order from the Ministry of Environment and Energy No. 1067	Local Govt.	December 1999
Netherlands	Disposal of White and Brown Goods Decree	Manufacturer/importer	January 1999
Norway	Regulations regarding Scrapped Electrical and Electronic Products	Manufacturer/importer	July 1999
Belgium	Environmental Policy Agreements on the take back obligation for waste from electrical and electronic equipment	Manufacturer/importer	March 2001
Japan	Specified Home Appliances Recycling Law (SHAR)	Manufacturer/importer	April 2001
Sweden	The Producer Responsibility for Electrical and Electronic Products Ordinance (SFS 2000:208).	Manufacturer/importer	July 2001
Germany	Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment (ElektroG Act)	Manufacturer/importer	March 2005

Source: Khetriwal et al. (2009)

At the international level, the central framework for controlling international movements of hazardous substances is the Basel Convention the Convention. This regulation is mainly relates to trade measures and non-trade measures. It presents four main aims related to the waste hierarchy of prevention, reduction, recovery and final disposal. This regulation requires prior notification between signatories when trading hazardous wastes. Many categories of e-waste are classified as hazardous waste and thus are targeted for prior notification. (Lundgren, 2012)

Next, The Rotterdam Convention concern about responsibility between exporting and importing countries in protecting human health and the environment, and provides the exchange information about potentially harmful chemicals which could be exported and imported (Widmer et al., 2005).

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).

2.3.4 Current policies and relevant regulations of waste in Thailand

Today, Thailand still has no specific legal framework for controlling the WEEE disposal. The overall wastes activities are controlled under two bodies of legislation. Firstly, prior to provide 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. Secondly, the Factory Act, B.E. 2535 (A.D. 1992) attend to classification and regulation of industrial activities, recovery, treatment, and disposal of wastes under the sorting plants and landfill operators (Vassanadumrongdee, 2011). For example, industrial WEEE waste manifest system in the transportation of industrial wastes localities shall to manage under the regulation and requirement of this act.

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 National Integrated WEEE Management strategy Phase II: 2012-2016 which synchronizes various ministries for effective management. Unfortunately, a draft documents still considered for implementation

For economic incentive, the draft Act on Economic Instruments for Environmental Management, this is now being drafted by the Ministry of Finance (MOF) and will coordinate with the drafting royal decree as subordinate law from the Ministry of Natural Resources and Environment (MONRE). The principle of this framework are applied the fiscal instrument for motivate the organization to achieve the environmental outcomes such as performance bonds, tradable permits, and environmental subsidies (PCD, 2010).

2.3.4.1 The example of proper method to management end of life of WEEE

a) Extending the lifespan in upstream management

The style of this approach can be seen as usual in Thailand. This aim to reduce a large number of wastes by extends lifespan until meet the limited lifetime of machine in order to dispose less PCs to environment. Moreover, the extended of lifespan of the old personal computer device can lead to both energy saving, as well as energy expenditure relative to choosing a new one (Williams, 2008). There have much way to apply this scheme as showed below including:

- Repairing or Upgrading: This approach is referring to the replacement of same or new component in order to function as same or higher performance. In order to improve performance and lifespan, typically in CPU microprocessor, memory and hard disk drive. However, some of PC equipment (e.g. motherboard) cannot repair due to the incompatible with the new technology architecture. Nevertheless, upgrading might pay more than price of the new machine (Williams and Sasaki, 2003).Overall, Thailand has a large amount of PC equipment selling /installing shops prompting with high-skill technicians.

- Reselling or Donation: This approach is also the way to extend into second lifespan. Particularly, this is convenient in Thailand because there is a lot of open supporting in Bangkok or other provinces as well as internet 2nd shops. Despite of reselling, donation is fallen into the case of selling computer in zero prices. The special purpose of donation can be done by giving used PC equipment Schools, non-profits, and charitable association. This approach enhanced accessibility for people to main database which currently embedded all in website and online(Williams & and Sasaki, 2003).

- **Leasing:** This approach is also the choice in order to reduce the environment and cost-efficient for some sectors. Basically, this principle is that consumers lease the services from leasing provider those products, instead of buying the actual product. Thus, the equipment remains the property of vendor, which consumers have to return equipment back after running out of contact.

For Thailand, the donation is preferred by private companies and households which famous donating appliance center already known such as Wat Suankaew Foundation (SKF) and the mirror foundation. These foundations receive donations of durable used products to repair for reuse again.

b) Recycle of obsolete computer for environmental outcome sustainable resources

Although there are many strategies to prevent the waste generation, it cannot prevent the consequence that every desktop PC and other peripheral equipment will become infeasible to repair/reused anymore. Therefore, recycling scheme would be chosen as the first priority on the management of electronic equipment. These computer wastes recommended to entering the recycling center as the most preferable when there already malfunction due to their high percentage of precious metals contained in the waste components. In fact, The extraction of precious metals through mining is can cause the negative environmental impacts through significant emissions of greenhouse gases and energy, water, and land usage(Ayres, 1997) Therefore, the downstream recycling intends to decrease the environmental impact and also sustain the resource chain and is highly beneficial to E-waste management (Cui and Zhang, 2008). Recycling also perform the advantage from saving of energy more than virgin materials extraction as summarized in Table 2-11.

Table 2-11: Recycled material energy savings compared with virgin material extraction

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

Source: Nnorom and Osibanjo (2008)

❖ **The Recycling approach main processes**

The recycling process for e-waste consists of three main subsequent steps: collection, preprocessing and end-processing as described in figure 2-9. The first of all, all of obsolete machine will be collected from several methods, this step is known as crucial step of recycling which might be different depending on places and device properties(StEP, 2009). In fact, the collection rates depends on social and societal factors rather than on collection methods. In the environmental aspect, during the collection step there are no special measures necessary to avoid release of liquid form of hazardous substances to the environment except in the LCD monitors with mercury-containing backlights, there need special technic to prevent the contamination.

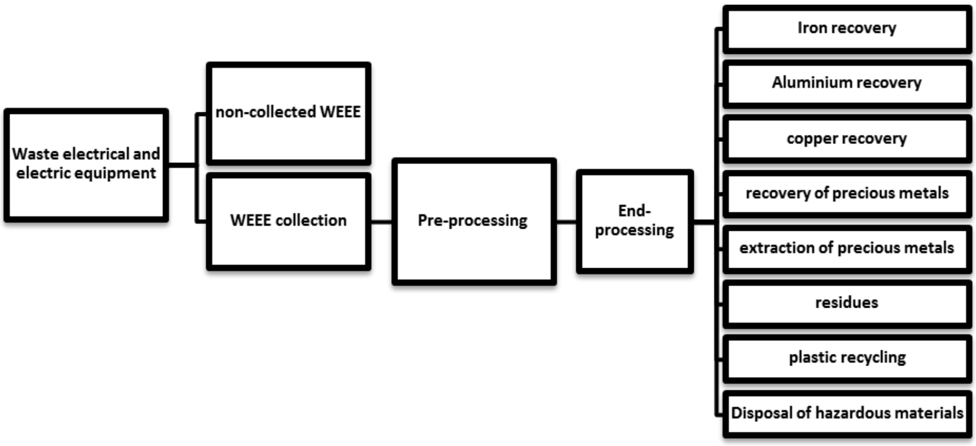


Figure 2-9: Recycling chain diagram (StEP, 2009)

❖ Preprocessing of desktop (E-waste)

Preprocessing is approach which applies physical techniques to liberate and upgrade desirable materials into relatively homogeneous streams which will be used as the input for end-processing. Generally, there have three major processes: (1) sorting, (2) selective disassembly or removing out hazardous and (3) upgrading, using mechanical/physical processing and/or metallurgical processing to prepare the materials for the final refining process (Cui and Forssberg, 2003). The most common in some country may use human labor or automatic machine, namely, magnetic separation separators, electric conductivity-based separation, and density-based separation by gravity separator or both.

The manual and semi-mechanical dismantling is suitable for disassembling the complex computer components because people can pay more attention in details and separate the usable part to reselling again or make suitable for next step (Figure 2-10). Focusing on Printed wiring board (PWB) serving as large proportion in computer devices, this is necessary to remove PWB from computer devices to avoid high losses of precious metals by manual dismantling, mechanical treatment or a combination of both (Chancerel et al., 2009)

For CRT preprocessing, the recycling chain for CRT containing appliances (monitors and TVs) starts with a collection phase where a critical environmental issue needs to be highlighted. The following dismantling activities aim at recovering valuable components or fractions like the electron gun (containing copper) or PWBs. The pre-processing activities primarily aim at separation of different types of glass used (the funnel contains lead and other metals and removal of coatings from the front panel. (StEP, 2009)

Figure 2-10: manual dismantling of hard disks (left) and dismantling table with pneumatic tools (right) (StEP, 2009)

❖ **The end processing of recycling desktop PC**

The end processing is the final recovery treatment from output fractions after preprocessing takes place at three main destinations. For example, ferrous fractions will be sent to steel as well as aluminum fraction send to smelters. Meanwhile, copper/lead fractions, circuit boards and other precious metals containing fractions are going integrated metal smelters, which recover precious metals, copper and other non-ferrous metals,(StEP, 2009). To conclude this, the state-of-the art in recovery of precious metals from electronic waste are including:

- **Pyro-metallurgy approach:** This approach use the high temperatures to chemically convert the feed materials and separate metals and impurities into different phases so valuable metals can be recovered. The high temperatures in the furnace or smelter are generated via the combustion of fuel or via electrical heating. For example, there are commonly known smelter such as lance smelters, converters, rotary furnaces, electric arc furnaces etc. (Cui & Zhang, 2008).

- **Hydrometallurgy:** This approach is to eliminate the impurities through the strong acidic or caustic watery solutions which pure fraction would dissolve and precipitate at the end. For example, technical processes for this activities including leaching approach, cementation approach, solvent extraction approach and other(Cui & Forssberg, 2003).

- **Electro-metallurgy,** which use electrical current to recover metals, e.g. electro-winning and electro-refining of copper, zinc etc.

As the recycling approach in Figure 2-11, this is the integrating processes which highly recovery of both copper and precious metals for treating complex material and recovering many different metals bases on a complex pyro-metallurgical approach. The process can be divided into the precious metals (PMO) and base metals operation (BMO). In a first step the input materials put into a smelter furnace, where air is injected and is applied as a reducing agent for metals. Using the gravimetric characteristics of the metals the copper fraction, carrying the precious metals, will separate from the lead slag, carrying most of the other metals. The copper will further be leach out and the residue, containing all the precious metals, will further be refined. The lead slag will run through many different, mainly refining processes to recover the base and special metals. Finally besides the precious metals (Ag, Au, Pt, Pd, Rh, Ir, Ru) also 10 base and special metals (Pb, Cu, Ni, Sb, Sn, Bi, Se, In, Te, As) are recovered. The slag is dominated by aluminum and ferrous metals, which are used especially for dyke constructions. The gases are cooled with energy recovery and cleaned using the best available technique (BAT). All the process water, cooling, rain and sprinkling water are treated within a BAT onsite wastewater treatment plant (WWTP). The slag of the WWTP, containing metals and other substances, is treated within the smelter furnace.

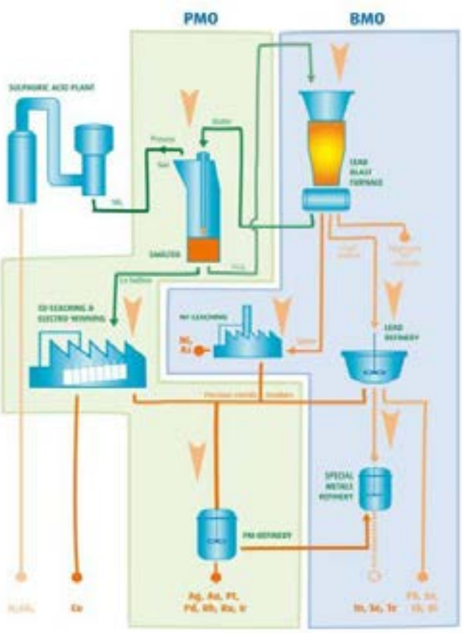


Figure 2-11: Precious metals and base metal operation (Hagelüken, 2005)

2.3.4.2 The current situation of recycling activities in Thailand

Thailand waste collection and recycling activities still has done by private waste dealers which Thailand pollution control department report in year 2003 that more than 3,000 waste dealers. They act as the middlemen in recycling processes by factories as selling metal and plastics scrap to recycling companies; however, their activities are still far from environmental protection and material conservation by doing without proper waste stream management. In addition, Thailand has registered two types of waste processor factories which deal with WEEE recycling including **factory type-105** which has authorized to separate or landfill wastes according to order of the Ministry of industrial and **factory type - 106** which authorized to recycle residual from industrial process or industrial waste (EEI, 2007). Although investments and technology are less required in collection and dismantling, mechanical pre-processing and metallurgical metals requires amount of capital in investments. In contrasts, recycling activities might not be worth investing in Thailand because of less material to reach breakeven point of investment. Therefore, many companies in Thailand prefer to ship their scraps for further metallurgic processes abroad

(Manomaivibool et al., 2009). However, Thailand has undertaken Industry Initiatives opening for management of electronic wastes; for instance, the DOWA ECO-SYSTEM Co., Ltd project. Moreover, Manomaivibool (2009) reported that the several investors express their interest in WEEE recycling in Thailand, but they are waiting to the clearer direction of Thai WEEE policies because it will support investment interest in the activity with enhancing the resources within the recycling program.

2.3.4.3 Evaluation method for estimated the environmental impact coming from disposal of computer

Environmental life-cycle assessment (LCA) is can be used as 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.(Cherubini, Bargigli, & Ulgiati, 2009) Therefore, the input and output from energy and material are useful for create life cycle inventory which helpful to evaluate the environmental aspect categories such the abiotic depletion (ADP), global warming (GWP), Eco-toxicity (ET), human toxicity (HT), acidification (Acid), depletion of the stratospheric zone (ODP), and eutrophication (Eut),then, interpret result from that depending on purposes in environmental goal(Andersen, Walnum, & Andrae, 2010).

The previous LCA studies of desktop computer by Choi et al. (2006) and Duan et al. (2008) investigated the overall of environmental impact categories. Obviously, Choi et al. (2006) investigated in-depth analysis and founded the pre-manufacturing stage of computer contributes to the overall environmental impact categories. Similarly, William (2004) also studied total energy and environmental burdens fallen to the production stage conducted 81%, than the usage, 19% of overall ecopoints. In the opposite, Duan et al. (2008) research shows the great environmental loads in the use stage because of the electricity consumption.

Not only in pre-manufacturing and production stage causing environmental impact, Duan et. al (2006) and William (2004) reported in the same direction that the end of life stage greatly contributed to the ecotoxicity as second rank under the pre-manufacturing stage ; in the other words, the improper way of landfill or incineration may be the most substantial factor leading to human toxicity.

The recycling end-of-life is the state-of-art to improve to reduce environmental impacts illustrated through The LCA of End of life of PC disposal in Choi et al. (2006) and Duan et. al (2006). Focusing on Choi et al. (2006) research, collection and material recovery environmental burdens in end of life stage were calculated from actual 46% Korea recycling rate compared with completely 100% idea recycling rate. The results showed that the environmental categories impact level decrease corresponding to the PC recycling rate (table 2-12) except for the ozone depletion and eco-toxicity. Interestingly, they found a linear relationship between environmental impacts and the recycling rate. The categories of environmental impact could be reduced by recycling at different rate as shown on the even point of recycling rate which contributes to sub-zero ranges level. For exception in eutrophication and human toxicity, the increasing the rate of recycling will not reduce the environmental burdens level unless still use actual recoveries methods. In brief, the recommended rate is at least 63% to reduction of environmental impact from computer and improve product recovery infrastructure for more environmental benefits. In conclusion, LCA perspective, it is clearly shown that the recycling of end-of-life PCs can improve the environmental performance of personal computer.

Table 2-12: Comparative LCA result of disposal stage with different recycling rates and their linear function of potentials of disposal stage depending on the recycling rate.

Impact category	current Recycling rate (46%)	100% recycling scenario	[b] F(x)=a + b*X	recycling rate Even point
Abiotic deletion	–0.00330	–0.00984	F(X)=0.00223+(–0.00012)* R	> 18.5%
Acidification	–0.32800	–8.41000	F(x)=6.55667+ (–0.14967) * R	> 43.5%
Global warming	66.70000	–170.000	F(x)=268.33333+(–4.38333) * R	> 61.2%
Ozone depletion	0.00047	0.00115	F(x)=-0.00010+1.25185E-05 * R	< 8.13%
Eutrophication	0.37900	0.32500	F(x)=0.42500 + (–0.00100) * R	425%
Photo-oxidant formation	0.04160	–0.32200	F(x)=0.35133+(–0.00673) * R	> 52.2%
Human toxicity	0.79800	0.15200	F(x)=1.34830+(–0.01196) * R	112%
Eco toxicity	0.00721	0.01360	F(x)=0.00177+0.00012 * R	< 14.9%
Total	**0.01028[a]**	**–0.02254[a]**	**F(x)=0.03823+(–0.00061) * R**	**> 62.9%**

[a] The figures were calculated by normalizing and weighting all the environmental parameters, using a method suggested by the Korea Accreditation Board ; [b] f (X) is environmental potentials as dependent variables , X: recycling rate of end-of-life PCs as the independent variable. The linear relationship ; Y = a + b * X , here Y represents the environmental potentials, and the coefficients could be derived ‚a' and 'b'. For instance, the coefficient 'b' of ADP was derived from the equation of (–0.00984 + 0.00310) / (100–46)

Source: Choi et al. (2006)

Song et al. (2012) identified the end of life stage environmental impact according to the Macau desktop PC waste situation. The actual impact in Macau came mainly from the incineration process of desktop PC. it also shown that the desktop owned the largest environmental impacts in the EoL phase, followed by the LCD screen. The impacts of incineration are relatively small, and some steel and electricity are recovered, but a large amount of resources (e.g., steel, plastic, copper, aluminum, and some others are wasted in the incineration process. Therefore, the recycling is one approach to waste management that can reduce the burden to the environment, such as reducing the landfill space. Recycling also reduces the consumption of refined material and energy used for new material extraction.

Moreover, the results from several sources of end-of-life assessment have ability to comparison between disposal options. The comparison between disposal options of LCD and CRT computer screen by Noon et al. (2011) . The result showed that recycling scenario (Credits) can reduce the adversely affect to the environment when compared with no recycling scheme (No Credits) as showed in table 2-13. For comparing between end of life of LCD and CRT monitor competing technologies, LCD monitor disposal had lower impacts than CRT monitor disposal in all impact categories except for the lead substance management.

Table 2-13: LCA results comparing LCD and CRT monitor disposal with (credits) and without (no credits) accounting for the avoidance of primary material production due to recycled materials.

Impact categories	Units	No credits		Credits	
		LCD	CRT	LCD	CRT
Global warming potential	kg CO_{2e}	8.5E−01	1.1E+01	−5.7E+02	−3.4E+01
Total energy consumption	BTU	8.6E+03	1.4E+05	−1.7E+06	−2.0E+06
Total fossil fuel consumption	BTU	8.1E+03	1.3E+05	−7.2E+05	−3.5E+05
Total select air pollutants	kg	5.3E+00	9.6E+01	−1.0E+03	−5.3E+02
Mercury (managed from monitor)	kg	3.0E−05	0.0E+00	3.0E−05	0.0E+00
Lead (managed from monitor)	kg	3.1E−03	2.0E−01	3.1E−03	2.0E−01

Source: Noon et al. (2011)

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 collecting data for developing and analyzing the thesis study, (II) steps in evaluating environmental impact using life cycle assessment approach, and (III) step of developing policy recommendation. Details of each step are as following;

3.1 Review and collecting relevant data

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

3.1.1 The substances in computer equipment

Many of literatures were investigated and discussed about various substances involving in disposed computers. The research reviewed existing environmental problem from managing computer wastes and valuable materials in computer.

3.1.2 The forecasting PC equipment number during 2012-2020 in Thailand

The secondary data of total amount of disposal computers in Thailand nowadays and in the future that were estimated by relevant governmental institution will be reviewed. The information will be used for evaluating overall environmental burdens recycled materials existing in computers will also be evaluated based on available information.

3.1.3 The life cycle assessment study related to this field of study

The previous studies using life cycle assessment method for evaluating environmental impacts to review and compare to select the assessment method which appropriate in this study and review more about interface software procedures relating in this research field.

3.1.4 Potential environmental impacts throughout LCA using SIMAPRO program

SimaPro program working procedure and other relating researches were reviewed. These materials useful for develop the life cycle assessment analysis in overall of E-waste treatment.

3.1.5 The 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 approach and understand situation before develop the recommendation that possible to apply in Thailand.

3.2 Environmental impact assessment using life cycle assessment approach

In this methodology part, environmental assessment has to establish planning and identify system following goal and scope step according to the international standards of the ISO 14040 series (ISO 14044, 2006).

3.2.1 SIMAPRO Program

In this study use Microsoft office excels 2010 and System for integrated environmental assessment of products program (SimaPro) versions 7.3.3 to develop LCA study. These tools aim to work together for analyzing the environmental impacts from end of life computer 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 PC equipment. Moreover, in order to understand the future projection of impacts through the different scenario analysis.

3.2.3 Functional units

Functional unit in this case of study are the desktop PC devices including desktop PC, CRT and LCD computer screen. All of each device compositions entered to the landfilling and recycling as the waste management alternatives. For the specification of PC waste, there are already described below;

3.2.3.1 Desktop PC computer

This study considered mainly the recent popular type of personal computer so-called desktop PC which is began to obsolescence technology and fallen into decrease of market share. To develop the study in order to reflect current situation in Thailand and near future projection, representative desktop PC in this study is referred to mainboard platform. Typically, all sub-components in desktop PC, must be connected to the motherboard and also the CPU processor which known as control unit of device. This equipment is so important criteria which can use to define and limit the functional unit in this study. Consequently, the computer based on ATX motherboard platform technology is selected as representative model (figure 3-1) because it can support objective to represent as recent technology study and support the mid-range computer which mainly used as regular specifications.

Figure 3-1: Desktop computer in this study
(Left: Front view, Center: Rear view, Right: Side view)

3.2.3.1 CRT and LCD Computer screens

The computer display is basic equipment that utilize as graphical interface between computer processing and human. Although CRT computer screen is fallen into unfashionable and defines as obsolescence technology, the transition of new types of computer screen such as LED or plasma screen is also the main factor to enhance people to discard LCD computer screen as same as replacing new type of computer which does not require separated display units (i.e. Notebook computer, Tablet PC). Consequently, the two technologies types of display are studied because LCD has large market shares and CRT is recent technology beginning to create enormous E-waste problem.

To perform following functional unit basis, this study have to provide screen specification following the previous study (Socolof et al., 2005) which normalized display is required for prediction the future. As presented on figure 3-2 and table 3-1, the CRT computer screen display size 17” CRT is equivalent to 15 ” LCD screen because when compare the diagonal viewing area (15.9” CRT and 15” LCD) of both equipment , there are no exactly produced the same size of viewing area as CRT screen; but almost of material contribution is almost equivalent. Moreover, the 17” CRT screen is reported that both of their size and weight does not change since 2004 (USEPA, 2008) which opposite to continuous changing in LCD screen.

Table 3-1: Computer screen functional unit specification

Specifications	**LCD Screen**	**CRT screen**
Display size	15 inches TFT LCD module	17 inches
Diagonal viewing area:	15 inches	15.9 inches
Resolution	XGA 1024 X 768 pixels	1280x1024 pixels @ 65 Hz
Dot Pitch	0.29 mm	0.20 mm

Figure 3-2: the computer screens obtained in this study
(Left: CRT computer screen, Right: LCD computer screen)

3.2.4 Scope and System boundaries

A consequential LCA was taken as approach focusing on the end of life phase. This was taken to investigate the environmental impact from relevant unit processes within the life cycle. The system boundaries decision is where the waste treatment and disposal end. For this case, overall LCI scope such as the resource and energy consumption, environmental released associated and recycled material would be scope within the treatment line. Typically, the main system of this study mainly contains two large approaches:

3.2.4.1 End of life management approach: Best practice landfilling

Due to lack of proper electronic wastes management system in Thailand, the overall process for landfilling this study was retrieved from Ecoinvent report No.13.(Doka G., 2007). Typically, 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. In brief, the landfill scheme in this study overall contribute burdens to environmental for three routes as shown on Figure 3-3 below: the landfill (A) wastewater treatment (B) and incineration (C). 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, 2007).Nevertheless, Thailand has various of landfill operation approach but mostly there still has inadequate prevention of leachate leaking and improper operation. Therefore, the selected landfill data in this research can be defined as best practice system landfilling which might reflect to the future proper landfilling in Thailand.

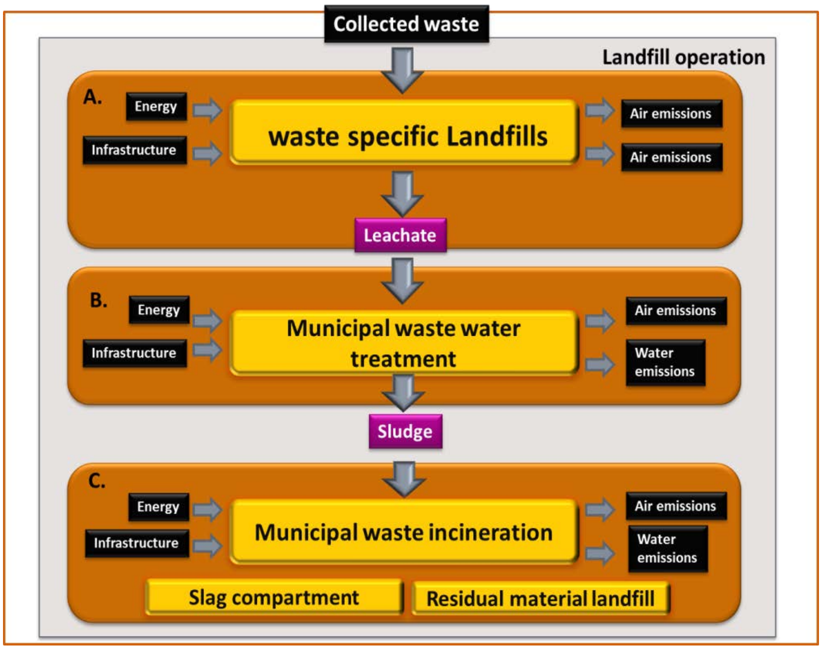


Figure 3-3: Process chain for landfilling

3.2.4.2 End of life management approach: Proper Recycling

The recycling approach can generate the co-product from their processes. This also affected the other processes outside. According to consequential LCA concept, the system expansion is the useful approach to avoid co-production allocation in other product. This concept means the system boundary is extended to cover alternative production of the exported function. In particular, the ISO 14044 and the guideline for recycling of metallic material in LCA, established by Centre for the environmental assessment of products and material systems, support that if the objective of LCA study is to compare the different between landfilling and recycling options, the system expansion is preferred as appropriate way. This method is effective to show the different environmental impacts and benefits between end of life treatment options (CPM, 2001; ISO-14044, 2006).

a) Recycling processes of PC equipment

The process boundary in this recycling scheme involved treatment until produce the new secondary product. As the overall processes described on figure 3-4, this study divided recycling system into two main stages of treatment processing divided into two: treatment level one and treatment level two.

i) Recycling treatment level one

Treatment level one is the operational units involving the physical treatment of electronic waste serving for level two treatment and depollution of hazardous substances before release through the environment. In particular, this system scope is conducted the waste storage section, manual preparation step and facilities of mechanical treatment. The physical treatment mechanical based on life Cycle Inventories of Electric and Electronic Equipment-Production; Use & Disposal in Ecoinvent report No. 18. (Hischier et al., 2007).This database surveyed from many recycling sites but there defines that can apply as global situation. However, this process does not include collected waste transportation.

ii) Recycling treatment level two process

To achieve the purpose of the recycling scheme, the mass fractions from previous treatment level one are imported to this level. This step has to purify the recyclable metals for using again by electrolytic process and smelting processes. The end product will perform as secondary metals. Due to the unavailable of the recycling of E-waste in Thailand, consequently, it has to retrieve dataset of secondary metal production from Life cycle inventories of metal embedded in Ecoinvent database report No.10 (Classen M., 2009). As the additional waste management details, there are explained in appendix A in order to more understand the comprehensive landfilling and recycling system.

Nevertheless, this study assumed that waste material enters the system boundaries without collection system which the life cycle burdens would be directly delivered from the compositions of waste management.

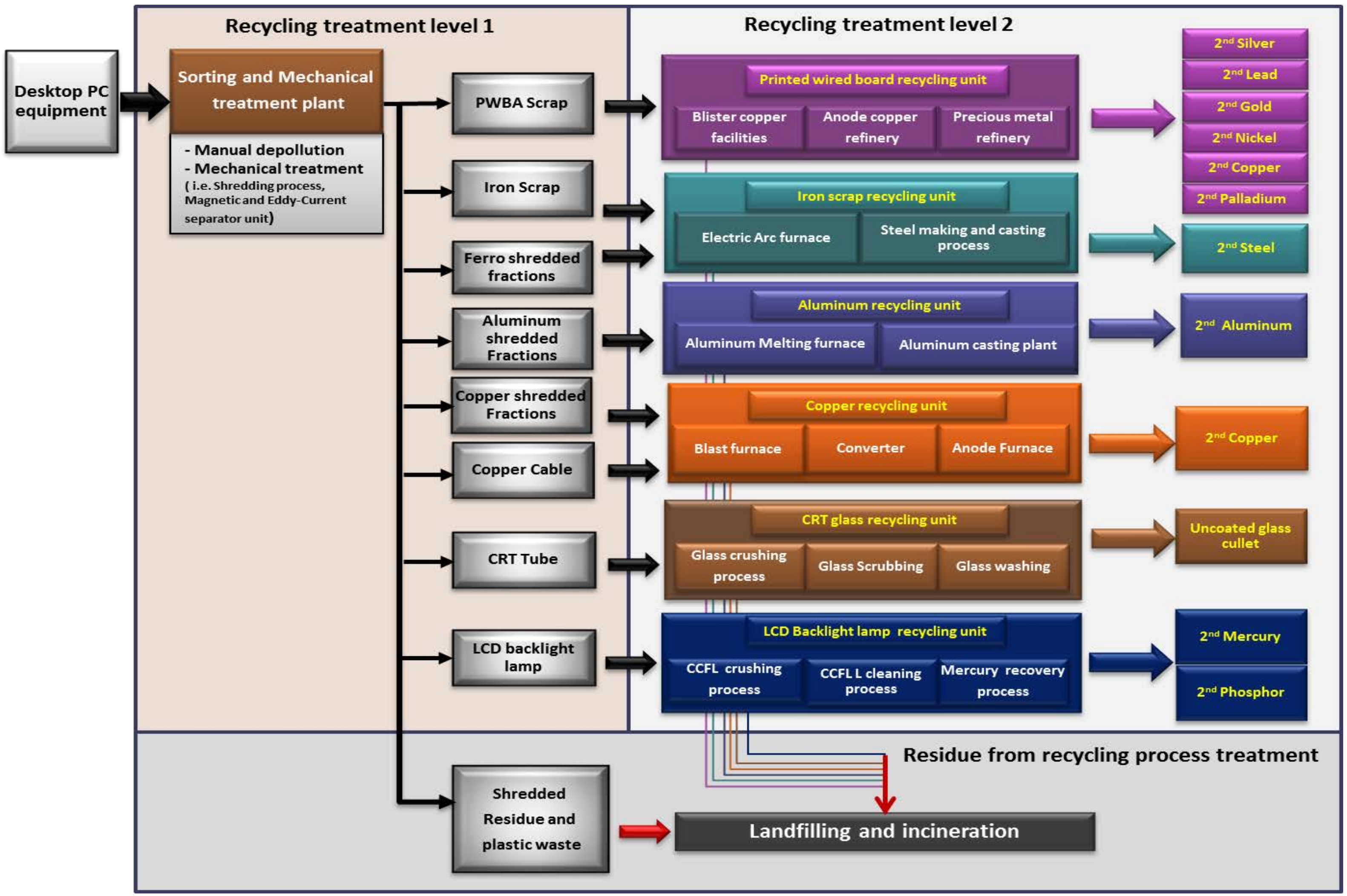


Figure 3-4: Recycling scheme in this study developed from Ecoinvent database

3.2.5 Life cycle inventories analysis

In order to generate landfilling and recycling process inventories, the disassembly analysis is acquired to characterize the waste type before input useful data to management scheme. For more understanding, the characterized waste type from previous assembly analysis step will be subsequently used to identify the landfill type or recycle processes according to Ecoinvent database waste-specific burden. Meanwhile, the waste-mass qualitative data will be calculated and turning to operating profile (inputs and outputs substances of processing system) in each of landfilling or recycling pathways. Nevertheless, this process will be run automatically after define landfill type and waste mass into SimaPro calculation module. To elaborate all of this step, there were described below for more in details

3.2.5.1 PC waste Disassembly analysis : The defining of specific process in waste management

Environmental performance of the waste management depends on waste type and weight input to the specific treatment which embedded in landfill and recycling scheme. Therefore, knowing the substances are required which implement through the material characterizes and weighting approach. Due to the limitation to directly acquire the primary data from PC equipment manufacturer restriction of company, the self-disassembly of computer model is necessary for creating waste input to landfilling and recycling scheme. In order to meet validity and completeness, lists of materials modified from several LCA and other literatures as shown on appendix A.

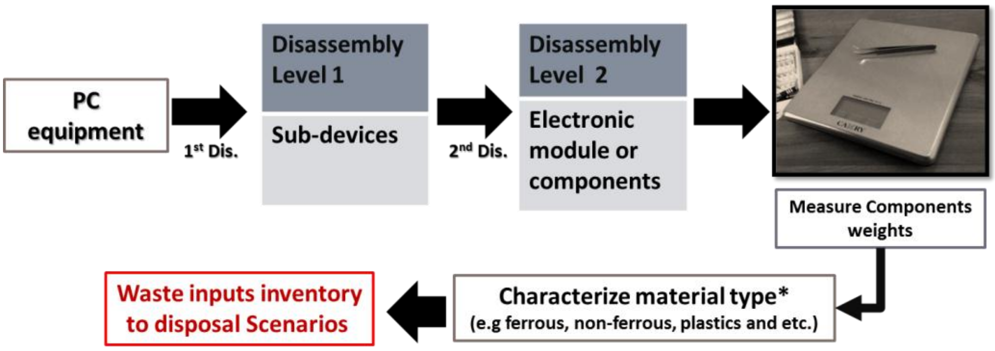


Figure 3-5: Disassembly analysis of PC equipment

As shown on Figure 3-5, Disassembly process of PC equipment is done by screwing disassembly until reach the limitation at component unit as showed on disassembly level 2 (i.e. PWBA, propeller fans, liquid crystal unit, and large capacitor) .Then, there would be measure the weight of each component and recorded their weight before use this multiply with qualitative trace element dataset in electronic equipment obtained in Ecoinvent report NO.18 (Hischier et al., 2007). Overall, the result of these steps would be showed as the list of waste types including both of qualitative and quantitative data before entering to both management processes

3.2.5.2 Life cycle inventory of landfill analysis

In this study used quasi-process information of landfill approach from Ecoinvent database obtained in SimaPro 7.3.3 software which inside necessarily contain landfill process input (resource, material, energy) as well as output (water, air and soil). Overall, table 3-2 presents the selected landfill type assumption for this study.

Table 3-2: Landfill assumption according to waste-specific burden

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) - Other Inorganic compounds

Source: Doka (2007)

3.2.5.3 Life cycle inventory of recycling analysis

This research purposed to apply the comprehensive recycling system for supporting all area of desktop PC recycling. Therefore, there is involved the reliable data of full-scale recycling system came from the Ecoinvent database which already obtained entire processes from Europe. This can divide into two main stages.

a) Recycling approach LCI : Treatment level I

Treatment level one is defined following the Ecoinvent database as physical approach of E-waste management including manual depollution, separation, shredding and fraction separation. For additional information is included in the appendix a). Typically, the treatment level one LCI result depends on the waste inputs following disassembly analysis. The pathway of each specific waste input are defines in table 3-3, which 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 report in Ecoinvent database except for plastic waste and residue releasing from process will be disposed. For the processes LCI, these normally involve the material input, energy and pollutant emission.

Table 3-3: Treatment level one processes

Treatment level one	Inputs	Processes	LCI dataset embedded in Ecoinvent database
i. Depollution process	PC,CRT and LCD computer screen	Manual separation between the hazardous and useful substance	- Manual treatment plant, WEEE scrap/GLO/I U
ii. Shredding and Separation steps	PC,CRT and LCD computer 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, desktop computer, in MSWI/CH U
iii. Plastics fraction	PC 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

Source: Hischier et al. (2007)

b) Recycling approach LCI : Treatment level II

The recycling processes in this stage conduct the separated LCI dataset individually from each metal recovery process (table3-4). Therefore, this system might perform as the single integrated system of recycling approach. The wastes inputs also reflect to LCI of this stage of management which input are retrieved from previous treatment level I. 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 be utilized again as same properties of primary products.

Table 3-4: The treatment level two considered recovery system in this study

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
4. Precious metal recycling	Printed wired board assembly (i.e. PC 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

Source: (Classen et al., 2007)

In order to compare between PC waste management options, this necessary to examine the net impact of recycling by considering the inventory datasets of recycling activities and also subtract the primary material process as avoided process (because recycling generate the recovered material). Therefore, this study also require the LCI of primary metal from Ecoinvent database No. 10 for impact subtraction which the table 3-5 below shown the secondary production and their avoided processes.

Table 3-5: The avoided production processes due to recycling process subsidy

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

3.2.5.4 The scenario analysis defining LCI results

To forecast future potential impact of computer wastes in Thailand, the study applied the predicted number of PC equipment during year 2012-2021 in Thailand retrieving from Electrical and Electronics Institute report as show in figure 3-6 (EEI, 2007). This study projected only total 10 year time duration which based on trend of PC waste growth. Typically, the calculation of computer equipment number performed regarding to the many factors including equipment lifespan, historical sales, world population growth during study time and market inflation rate. During 2012-2021, total PC equipment was calculated to accumulate and begin to decline. However, the amounts of discarded equipment are 10,564,652 units for desktop PC; 1,931,163 unit for CRT computer screen and 8,633,489 for LCD computer screen, respectively.

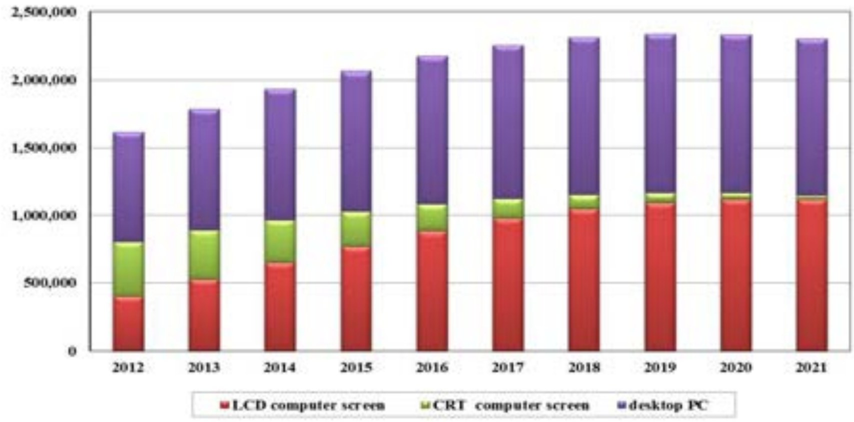


Figure 3-6: The prediction number of PC equipment (PCD, 2010)

Consequently, to evaluate all possible effects and forecast the future environmental impact of end of life of computer, comprehensive scope of assessment was done. Therefore, the prediction number from this part would be multiply with material composition embed in disassembly analysis and then used as waste inputs to management scheme in different disposal options. The quantity mass in any scenario are defined already in different recycling collection rate and landfilling dumping rate (table3-6). In this study, scenario 1 performs environmental impact when applying the proper landfilling scheme in Thailand also used this 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 .This rate number referred to the initiate plans of national strategy of E-waste collection strategy goal. Scenario 3 aims to show the environmental performance due to the high rate of E-waste recycling (20% recycling collection rate).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 3-6: 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)

3.2.6 Life cycle impact assessment and interpretation

3.2.6.1 Impact assessment approach : ReCiPe 2008 method

The end of the environmental mechanism called the endpoint impact was used to compare impacts from different management scenarios. Therefore, the recent method suitable for this study is fallen to the ReCiPe 2008 Endpoint (H) V1.07, World ReCiPe H/A. In depth, this method developed by Goedkoop et al. 2009 which fully aggregate between CML midpoint impact Eco-indicator 99 endpoint methodologies in a consistent way. Therefore, the results were performed following this method. The mechanism of this methodology and LCI data is describe in Figure 3-7 below, the various environmental impacts examined within this method are summed in this picture. SimaPro program was used for analysis through this step. Firstly, the LCI results were converted to midpoint indicator unit. Then, these results are subsequently converted to the endpoint impact following ISO terminology. 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.

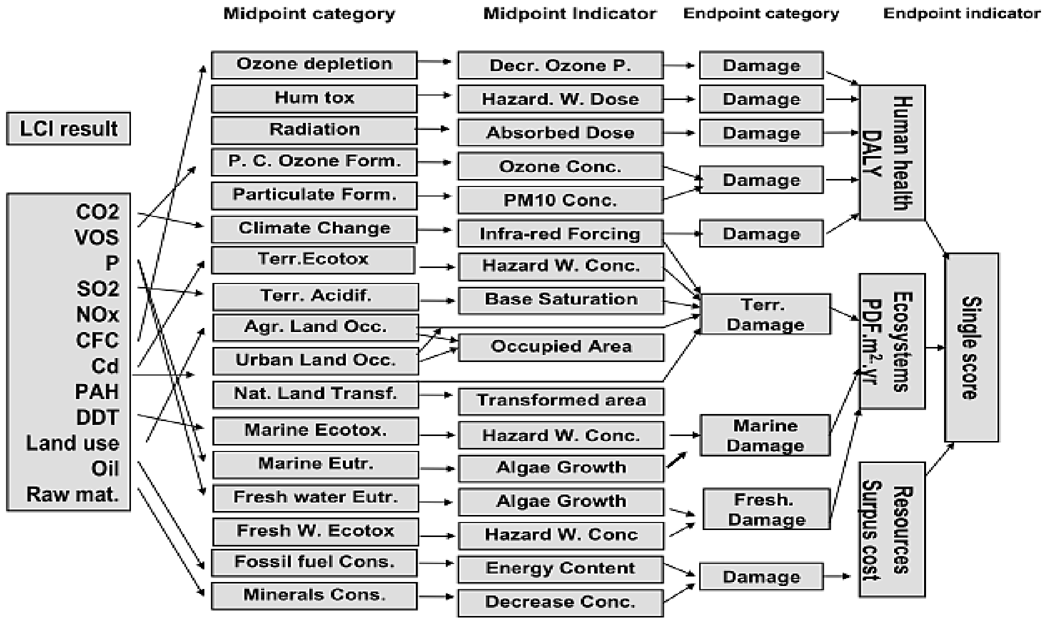


Figure 3-7: Impact categories and pathways covered by the ReCiPe methodology

As the "World ReCiPe H/A", 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. In other words, this calculation factor support this issue 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).

3.2.6.2 Sensitivity analysis

This step aims to evaluate the properties of result including the consistency and completeness. In addition, the sensitivity analysis is also need, and in this study set up the initially a target for variation occurrence in study result for ± 5% and ±10% mass weights error.

3.3 Establishing the recommendation of computer waste management in Thailand

3.3.1 Questionnaire methods

To develop recommendations for improving desktop PC 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 first part is the results on current manner of obsolescence PC management. The second part is the results on the feasibility management plan coping with waste collection to recycling system. The numbers of respondents in this study established need to include at least 400 people to reach the criteria that result have to at least for a 95% confidence level or 5% chance of your sample results differing from the true population average.(Yamane, 1973)

This questionnaire was used in order to survey through the two pathways involving the online survey (200 persons) and paper survey (200 persons)

3.3.2 The recommendation of PC equipment for Thailand

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

CHAPTER IV
LIFE CYCLE INVENTORY DEVELOPMENT

4.1 Life cycle inventory of desktop PC waste management processes

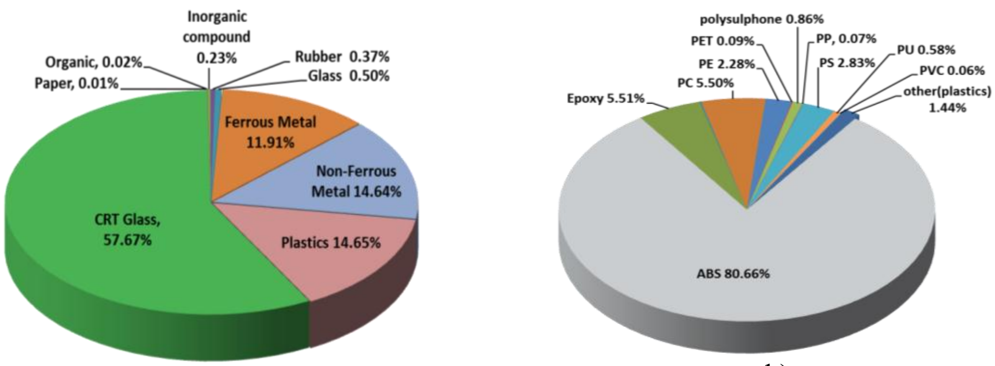
The life cycle inventory was developed through many steps. The results are shown in the system inputs and outputs table. In facts, the most demanding task is data collection and modeling the system. There are two processes subsequently presented below.

4.1.1 Creating of desktop PC waste inputs into SimaPro 7.3.3 program

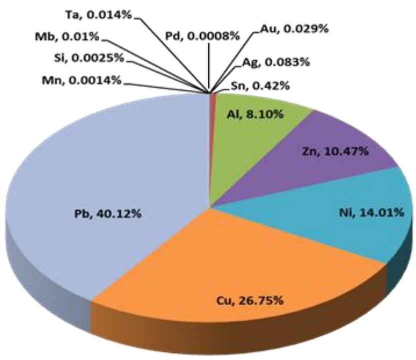
Although background data already embedded in SimaPro 7.3.3 including generic materials, energy, transport and basic waste management systems, it also needed to foreground data which used for modeling the end of life of desktop PC system. Therefore, to generate lists of residue inputs to the landfill and recycling inventory, a selected model of desktop PC equipment were disassembled into components parts and constructed substance lists as the foreground data before entered into calculation module of inside of SimaPro 7.3.3 program. Overall equipment profiles are including:

4.1.1.1 CRT computer screen material composition

This type of screen was disassembled and thoroughly analyzed until reach to residue type as showed in Figure 4-1 (a). In facts, the entire one of CRT computer screen weight was about 14.88 kg. The bulk of weights data in different part for CRT computer screen were classified in the appendix 1 section. In brief, the CRT glass contributed approximately 57.67% of total weight which existed as the CRT tube basic building block. Apart from this, plastic composition overly consisted about 14.65%, which ABS plastic has highest proportion because it is the main structural parts (Figure 4-1b). Epoxy substances are also high because it is the main component in printed wiring bare board, which CRT computer screen has occupied from several PWBA including: switch board, controller board and power supply board. Moreover, polycarbonate plastic (PC) contributed similar amount to epoxy. This material founded more in brackets, joint, and fly-back transformer. Nevertheless, other types of plastic also came from several parts in several functions.



a) b)



c)

Figure 4-1: The classified residues consisted in CRT computer screen described as: (a) the entire material categories in CRT computer screen (b) particular proportion of plastics (c) the particular non-ferrous proportion substances

For relevant concerning point as shown in Figure 4-1c, the largest proportion of toxic lead contained about 40.12% of total non-ferrous metal part (8.50 % of total equipment weight) by utilizing as the lead oxide coating substance on CRT tube. In facts, this number showed similarly with previous studies which leaded-glass in funnel and faceplate assembly and frit (solder glass) contained approximately 8.2 % of lead total CRT tube (EIA, 2001). For 14.01 % of nickel substances, this is the proxy from nickel alloy (invar) sub-assembly in CRT face plate. Importantly, in process of accelerate electrons into light. Phosphor is the substances convert the kinetic energy of the electrons beam into red blue green color on screen and this high amount were showed through the high percentage of zinc and nickel. Nevertheless, the useful copper resource is contained approximately 26.75% from cable utilizing as the signal transfer, grid line and deflection yoke coil.

4.1.1.2 LCD computer screen material composition

Apart from the CRT display, LCD computer screen type weight was approximately 5.6 kg. Focusing on overall material categories (Figure 4-a), the ferrous metal of monitor base steel is accounted for 46.61% of total weight, subsequently followed by existed plastics about 36.41 % of total weight. Particularly, a Figure 4-2 (b) helps to describe overview of plastic compartment. This ABS plastic is contributed as the highest fraction of overall plastics (47.19%) which utilized as structural material. Moreover, PMMA plastics are fallen into second rank of plastic which this is the light guide panels used in LCD backlight reflection. In facts, around 85 % of all TVs produced worldwide are LED edge lit or backlit TFT - LCD TVs and consist of Light Guide Panels made from optical grade PMMA(Extrusion of Clear PMMA Sheets used in LED - LCD TVs, Monitors, Laptops). Furthermore, PVC is contributed as the third came from cable covered substances.

Non-ferrous metal showed the highest amount of this category came from copper fraction (45.52% of non-ferrous metal fraction) which commonly founded as the signal/grid line. Next, the chromium substances was embedded about 37.17% of entire non-Ferro metal fraction, this is the result of the alloy steel which composed of iron and chromium. This type of material founded in back pane cover of LCD computer screen. To emphasize on the mercury hazardous substances, it represented approximately 3.96E-07% of total weight or 2.22E-06 kg. However, this amount is less than previous study which it represents about 3.95E-6 kg. of mercury (Socolof. et al., 2001) Nevertheless, this increasing of mercury amount is relied on the number of CCFL lamps. The number and size of CCFLs in each unit varies with the size and type of LCD screen. Therefore, this possible contain range 4-10 milligrams (mg) of mercury (Socolof et al., 2005; WRAP, 2010)

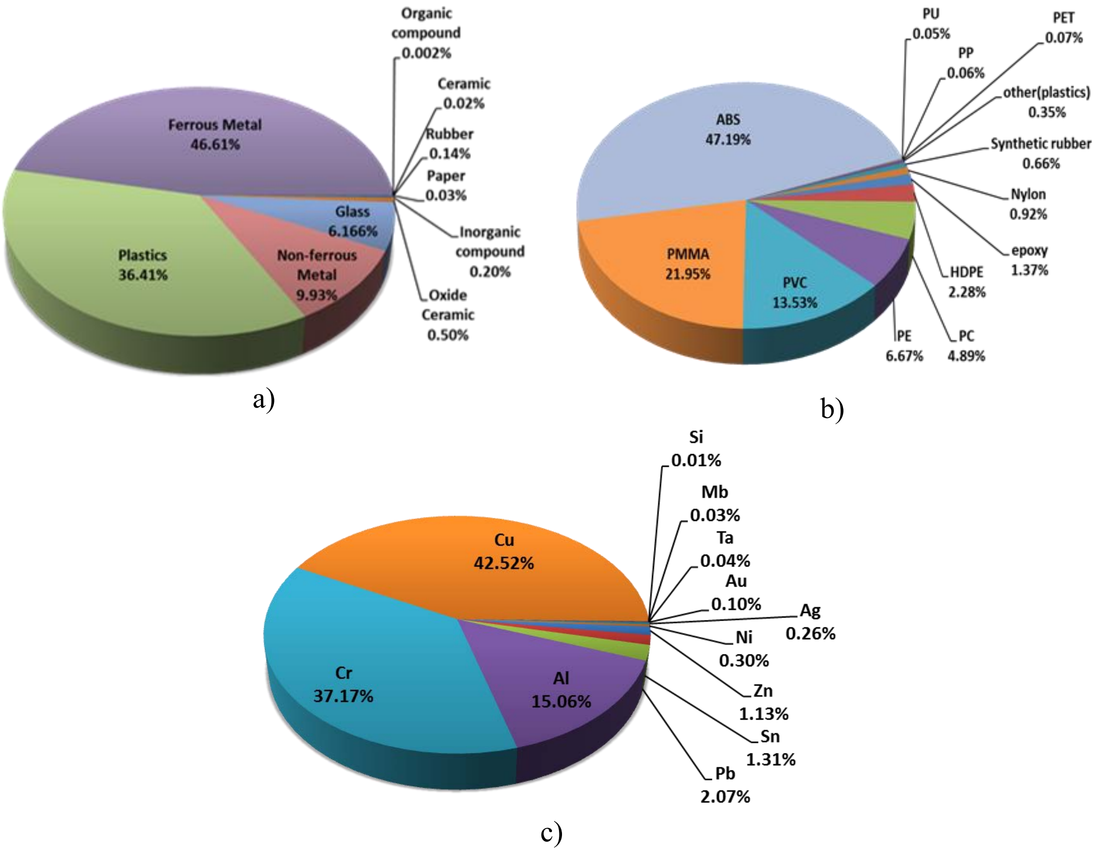


Figure 4-2: The classified residues consisted in LCD computer screen described as: (a) the entire material categories in LCD computer screen (b) the particular plastic compartment substances (c) particular proportion of non-ferrous metal compartment

4.1.1.3 Desktop computer material compositions

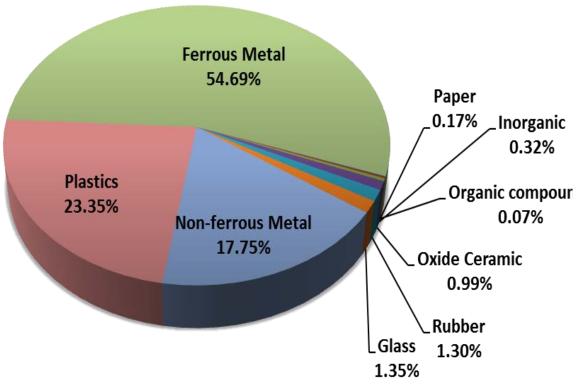
The entire total weight of one Desktop PCs is 9.67 kilograms were dissembled and classified into compartment bandwidth as shown in figure 4-3a. The results performed that one regular desktop PC component about 54.69% made from ferrous metal, 23.35% from plastics, 17.75% from nonferrous-metal and 4.42% from others. This results is also similarly shown on the research by Chatterjee and Krishna (2009)

Normally, the ferrous metal is contributed from iron structural part such as desktop PC cabinet, Slide-in module case and some cascade holder inside the cabinet. For plastic compartment as shown in Figure 4-3b, HDPE plastic is the main compound in desktop PC sub compartment such as subassembly main frame, ventilation fan, and ribbon cable. Moreover, PVC as the second rank of plastic embedded in capacitors and covering of ribbon cable in mainboard connection. Thirdly, ABS plastic is comprised a high amount in CD-ROM, HDD and desktop cabinet as strengthen plastic frame.

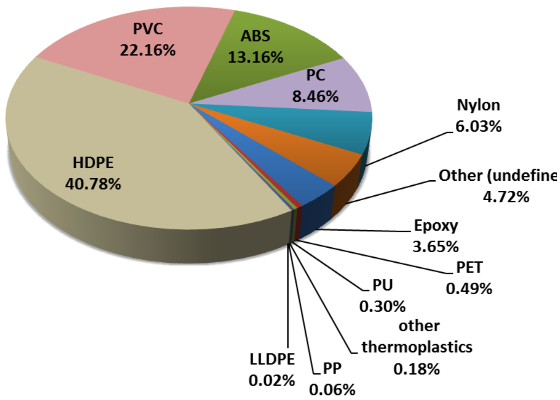
Non-ferrous compartment are presented in Figure 4-3c, aluminum compounds is established in almost every sub-part of this devices such as a fan-cooled heat sink, PWBA board and especially highest in hard disk drive which particularly founded in frame of cover, and HDD disk platters. In next descending, copper fraction in these devices was founded highly in cable grid line, internal peripherals subpart and high grades of PWBA (using as conductive pathways onto a non-conductive substrate).

For toxic substances which scoping in this study represent that one desktop PC contains lead about 2.77E-02 kg and chromium steel around 3.90E-02 kg.

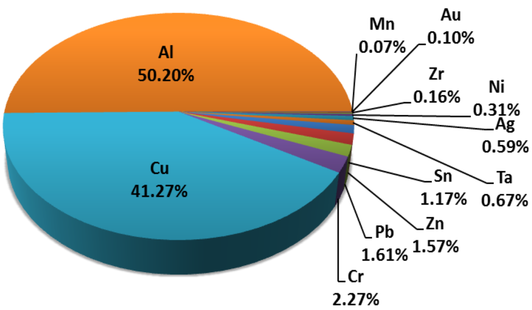
Focusing on precious metal, gold components in this comprised about 0.10% in overall nonferrous or 0.02 % in total computer device. This is mainly from PWBA mainboard and main CPU microchip (IC logic types). Moreover, Palladium is also contained less amount approximately 2.00479E-05 % in non-ferrous metal fraction.



a)



b)



c)

Figure 4-3: The classified residues consisted in PC desktop computer described as: a) the entire material categories in desktop PC computer b) the particular plastic compartment substances c) particular proportion of non-ferrous metal compartment

Overall, the results of PC equipment showed that the several of material categories as represent in various spectrum of pie charts. PWBA are a major part of e-products, containing the most ECs, such as resistors, relays, capacitors, and IC chips. The previous study represented the PWBA components in desktop computer and other by weight (Tohka A. & Lehto, 2005). There is made up of semiconductor components (wt. 33%), followed by capacitors (24%), unpopulated circuit boards (23%), resistances (12%), switches and other materials (8%) For in-depth analysis , Takanori et al. (2009) reports that PWBA trace element is included approximately one-third of metallic material such as Cu and Fe, one-fourth of organic resin materials containing elements such as C and H, and one-third of glass materials used as resin reinforcing fibers. In terms of the metal composition, the highest content was Cu, which is used in the circuitry, followed by Sn, Fe, and Pb, which were used in the soldering and lead frames. In terms of the precious metal composition, Au, Ag, and Pd were found in ICs, as contact materials or as plating layers due to their high conductivity and chemical stability (Hino et al., 2009; Jung and Bartel, 1999)

4.1.2 Entering the desktop PC equipment compartment into modeled processes regarding to SimaPro program

Due to using the SimaPro program procedure, this is necessary to declare the type of waste and amount of them to the particular waste treatment processes. After that, 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. Entirely, the entered amount of several types of material to the landfilling and recycling approaches are shown in section below.

4.1.2.1 Landfilling approach

In real manner, the materials sent to landfill are not split but dumped in bulky form. However, for modeling it in SimaPro is have to model landfill in separating fraction which splits into waste type according to waste-specific burdens. Overall, The table 4-1, 4-2, 4-3 presented the total disposal pathways in each waste types which amount different were relied on their substance compositions. Nevertheless, in case of unavailable for some waste type (e.g. PC, Epoxy plastic wastes), this solved by implemented other processes which suitable to use as proxy.

Table 4-1: The CRT computer screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	CRT tube (kg)	Anode connection (kg)	Chassis (kg)	Deflection Yoke(kg)	De-magnetic coil (kg)	Electron Gun (kg)	PWBA (kg)	Other (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	**8.54E+00**	-	-	-	-	-	**7.41E-02**	-	**8.61E+00**
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	**1.74E-01**	**4.44E-03**	**9.37E-01**	**3.38E-01**	-	**7.30E-02**	**1.29E-01**	**1.03E-01**	**1.76E+00**
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	**3.03E-01**	**2.40E-02**	-	**2.81E-01**	**9.54E-02**	**7.82E-04**	**3.61E-01**	**1.90E-02**	**1.08E+00**
4. Oxide ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	-	-	-	**3.42E-02**	-	**8.57E+00**
5. Epoxy	Disposal, paint, 0% water, to inert material landfill/CH U	-	-	-	-	-	-	**1.20E-01**	-	**1.20E-01**
6. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	-	-	-	-	-	-	**4.93E-02**	-	**4.93E-02**
7. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	-	**2.04E-02**	**9.95E-02**	-	**1.20E-01**
8. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	**1.26E-02**	-	**8.22E-06**	-	**1.26E-02**
9. PET plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	-	-	-	**1.92E-03**	-	**1.92E-03**
10. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	-	-	-	**4.04E-05**	-	**4.04E-05**
11. Poly-sulphone	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	**1.87E-02**	-	-	-	-	**1.87E-02**
12. PP	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U	-	-	-	-	-	-	**1.57E-03**	-	**1.57E-03**
13. PVC	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	-	-	-	-	-	-	**1.30E-03**	-	**1.30E-03**
14. ABS plastic	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	-	-	**1.76E+00**	-	-	-	-	-	**1.76E+00**

Table 4-1(continued): The CRT computer screen fraction entering to modeled specific landfill in SimaPro program

categories	Ecoinvent library : (based on waste specific burdens)	CRT tube (kg)	Anode connection (kg)	Chassis (kg)	Deflection Yoke(kg)	De-magnetic coil (kg)	Electron Gun (kg)	PWBA (kg)	Other (kg)	Total (kg)
15. Other plastic	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	-	-	2.83E-03	3.13E-02	-	9.67E-02
16. Chemical organic compound	Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	-	-	-	-	-	-	3.08E-03	-	3.08E-03
17. Paper	Disposal, paper, 11.2% water, to sanitary landfill/CH U	-	-	-	-	-	-	2.06E-03	-	2.06E-03
18. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	1.06E-02	-	1.37E-02	-	-	8.03E-04	3.00E-02	5.51E-02
19. CRT coating substances	Disposal, coatings in CRT screens, to municipal waste incineration/CH U	1.11E+00	-	-	-	-	-	-	-	1.11E+00
20. Other Inorganic compounds	Disposal, waste, silicon wafer production, 0% water, to underground deposit/DE U		-	-	-	-	-	1.34E-02	-	1.34E-02
21. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	-	-	-	-	-	-	1.35E-02	-	1.35E-02

Table 4-2: The LCD computer screen fraction entering to modeled specific landfill in SimaPro program

Material categories	Ecoinvent landfills (based on waste specific burdens)	Liquid crystal (kg)	Backlight (kg)	Cabinet (kg)	Controller (kg)	Inverter (kg)	Power Supply (kg)	Power Switch (kg)	PWBA (kg)	Cable and other (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	2.67E-01	2.30E-02	-	-	-	-	-	5.59E-02	-	3.46E-01
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	-	9.90E-02	2.25E+0	-	7.91E-04	2.02E-01	-	1.99E-02	4.30E-02	2.61E+00
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	4.13E-03	3.00E-04	-	6.01E-03	-	2.70E-0	-	1.87E-01	1.13E-01	3.37E-01
4. Oxide ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	1.99E-03	-	-	-	-	-	-	2.58E-02	-	2.78E-02
5. Ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	-	-	-	-	-	-	-	1.04E-03	-	1.04E-03
6. Epoxy	Disposal, paint, 0% water, to inert material landfill/CH U	1.35E-03	-	-	-	-	-	-	2.66E-02	-	2.80E-02
7. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	4.90E-02	-	-	-	-	-	5.078E-02	-	9.98E-02
8. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	-	-	-	2.07E-04	-	-	-	6.20E-06	7.99E-04	1.01E-03

Table 4-2(continued): The LCD computer screen fraction entering to modeled specific landfill in SimaPro program

Material categories	Ecoinvent landfills (based on waste specific burdens)	Liquid crystal cell (kg)	Backlight (kg)	Cabinet (kg)	Controller (kg)	Inverter (kg)	Power Supply (kg)	Power Switch (kg)	PWBA (kg)	Cable &other (kg)	Total (kg)
9. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	-	8.30E-02	-	-	3.43E-03	1.60E-02	-	3.715E-02	4.18E-2	1.81E-01
10. PET plastic	Disposal, polyethylene terephthalate, 0.2% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	1.444E-03	-	1.44E-03
11. PP plastic	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	1.19E-03	-	1.19E-03
12. PVC plastic	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	-	2.95E-04	-	1.03E-02	7.75E-04	-	-	9.77E-04	2.64E-1	2.76E-01
13. ABS	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	-	-	9.340E-01	-	-	-	2.90E-02	-	-	9.63E-01
14. Nylon	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	2.41E-03	-	-	-	-	-	-	1.64E-02	-	1.88E-02
15. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	4.48E-01	-	-	-	-	-	3.05E-05	-	4.48E-01
16. Other(plastics)	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	7.23E-03	-	7.23E-03
17. Paper	Disposal, paper, 11.2% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	1.55E-03	-	1.55E-03
18. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	3.64E-03	-	-	3.49E-03	-	-	-	6.06E-04	1.35E-2	2.12E-02
19. Chemical organic compound	Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	-	-	-	-	-	-	-	1.17E-04	-	1.17E-04
20. LCD backlight coating	Disposal, spent activated carbon with mercury, 0% water, to underground deposit/DE U	-	1.08E-03	-	-	-	-	-	-	-	1.08E-03
21. Inorganic compounds	Disposal, waste, silicon wafer production, 0% water, to underground deposit/DE U	-	-	-	-	-	-	-	1.13E-02	-	1.13E-02
22. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	-	-	-	-	-	1.34E-02	-	2.04E-01		2.17E-01

Table 4-3: The desktop PC fraction entering to modeled specific landfill in SimaPro program

Material categories	Ecoinvent landfills	FDD (kg)	ATX-mother Board (kg)	CD/DVD rom (kg)	Cooling body for CPU (kg)	Cooling body for GPU (kg)	CPU (kg)	Cabinet (kg)	GPU Card (kg)	HDD (kg)	LAN Card (kg)	Power supply (kg)	RAM (kg)	Total (kg)
1. Glass	Disposal, glass, 0% water, to inert material landfill/CH U	3.19E-03	5.32E-02	7.51E-03	4.17E-03	4.44E-04	-	3.63E-03	1.18E-02	3.07E-03	5.40E-03	1.09E-02	2.76E-02	1.31E-01
2. Ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	1.93E-01	1.10E-02	5.44E-01	4.07E-03	4.33E-04	4.19E-03	4.05E+0	4.19E-03	4.91E-02	1.92E-03	4.30E-01	1.72E-04	5.29E+00
3. Non-ferrous metal	Disposal, steel, 0% water, to inert material landfill/CH U	1.88E-01	2.85E-01	4.69E-02	1.59E-01	4.95E-03	-	4.86E-02	3.88E-02	3.91E-01	1.77E-02	3.93E-01	7.83E-02	1.65E+00
4. Oxide ceramic	Disposal, glass, 0% water, to inert material landfill/CH U	1.62E-03	3.57E-02	3.81E-03	3.71E-03	3.95E-04	5.13E-03	2.72E-03	5.43E-03	1.55E-03	2.49E-03	2.42E-02	8.98E-03	9.57E-02
5. Epoxy	Disposal, paint, 0%water, to inert material landfill/CH U	1.36E-03	3.38E-02	3.21E-03	3.39E-03	3.61E-04	3.47E-03	2.43E-03	4.82E-03	1.31E-03	2.21E-03	2.12E-02	5.01E-03	8.26E-02
6. PC plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	2.90E-03	4.24E-03	5.18E-02	1.05E-02	1.12E-03	-	6.98E-03	1.07E-02	2.79E-03	4.91E-03	9.50E-02	-	1.91E-01
7. PU plastic	Disposal, polyurethane, 0.2% water, to inert material landfill/CH U	3.54E-07	4.04E-04	8.33E-07	1.28E-06	1.37E-07	-	8.52E-07	1.31E-06	3.40E-07	5.98E-07	6.30E-03	3.14E-05	6.74E-03
8. ABS plastic	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U	-	-	1.50E-02	-	-	-	2.80E-01	-	2.00E-03	-	-	-	2.97E-01

Table 4-3 (continued): The desktop PC fraction entering to modeled specific landfill in SimaPro program

Material categories	Ecoinvent landfills	FDD (kg)	ATX-mother Board (kg)	CD/DVD rom (kg)	Cooling body for CPU (kg)	Cooling body for GPU (kg)	CPU (kg)	Cabinet (kg)	GPU Card (kg)	HDD (kg)	LAN Card (kg)	Power supply (kg)	RAM (kg)	Total (kg)
9. PE plastic	Disposal, polyethylene, 0.4% water, to sanitary landfill/CHU	**9.02E-03**	**-**	**2.00E-01**	**2.51E-01**	**2.67E-02**	**-**	**2.23E-01**	**5.63E-05**	**1.47E-05**	**2.58E-05**	**2.12E-01**	**-**	**9.22E-01**
10. PET plastic	Disposal, polyethylene terephthalate, 0.2% water, to sanitary landfill/CH U	**8.24E-05**	**5.30E-03**	**1.94E-04**	**2.99E-04**	**3.18E-05**	**-**	**1.98E-04**	**3.04E-04**	**7.93E-05**	**1.40E-04**	**4.43E-03**	**-**	**1.11E-02**
11. PMMA	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	**1.74E-06**	**4.51E-05**	**4.09E-06**	**-**	**-**	**-**	**7.36E-07**	**6.42E-06**	**1.67E-06**	**2.94E-06**	**-**	**2.35E-05**	**8.62E-05**
12. PP plastic	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U	**6.77E-05**	**-**	**1.59E-04**	**2.45E-04**	**2.61E-05**	**-**	**1.63E-04**	**2.50E-04**	**6.51E-05**	**1.15E-04**	**3.02E-04**	**-**	**1.39E-03**
13. PVC	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U	**5.58E-05**	**2.69E-02**	**1.31E-04**	**2.02E-04**	**2.15E-05**	**-**	**1.93E-02**	**2.06E-04**	**5.36E-05**	**9.44E-05**	**4.52E-01**	**1.56E-03**	**5.01E-01**
14. Nylon	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	**9.34E-04**	**1.10E-01**	**2.20E-03**	**3.62E-04**	**3.86E-05**	**6.21E-03**	**5.94E-04**	**3.45E-03**	**8.98E-04**	**1.58E-03**	**5.41E-04**	**8.88E-03**	**1.36E-01**
15. Other plastics	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	**2.54E-03**	**4.72E-02**	**5.96E-03**	**2.97E-03**	**3.16E-04**	**-**	**2.70E-03**	**9.38E-03**	**2.44E-03**	**4.30E-03**	**9.32E-03**	**2.33E-02**	**1.10E-01**
16. Chemical organic	Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	**1.35E-04**	**2.12E-03**	**3.18E-04**	**1.97E-04**	**2.10E-05**	**-**	**1.65E-04**	**1.30E-03**	**1.30E-04**	**5.94E-04**	**6.83E-04**	**1.09E-03**	**6.75E-03**

Table 4-3(continued): The desktop PC fraction entering to modeled specific landfill in SimaPro program

Material categories	Ecoinvent landfills	FDD (kg)	ATX-mother Board (kg)	CD/DVD rom (kg)	Cooling body for CPU (kg)	Cooling body for GPU (kg)	CPU (kg)	Cabinet (kg)	GPU Card (kg)	HDD (kg)	LAN Card (kg)	Power supply (kg)	RAM (kg)	Total (kg)
17. Rubber	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	3.46E-05	1.32E-02	8.14E-05	1.25E-04	1.33E-05	-	8.33E-05	1.28E-04	3.33E-05	5.85E-05	1.11E-01	5.29E-04	1.25E-01
18. Paper	Disposal, paper, 11.2% water, to sanitary landfill/CH U	-	8.08E-03	2.09E-04	3.21E-04	3.42E-05	-	2.13E-04	3.27E-04	8.52E-05	1.50E-04	6.93E-03	-	1.63E-02
19. Inorganic compounds	Disposal, waste, silicon wafer production, 0% water, to underground deposit/DE U	7.50E-04	1.16E-02	1.77E-03	8.63E-04	9.18E-05	-	7.89E-04	2.77E-03	7.21E-04	1.27E-03	5.65E-03	4.32E-03	3.06E-02
20. Other toxic substance	Disposal, hazardous waste, 0% water, to underground deposit/DE U	4.58E-03	4.13E-03	9.36E-03	1.77E-03	1.88E-04	7.25E-04	2.22E-02	2.14E-03	6.56E-03	9.80E-04	1.29E-02	1.18E-03	6.67E-02

4.1.2.2 Recycling approach

Apart from landfilling approach, the recycling mass inputs in this study considered following transfer coefficient in the mechanical treatment of WEEE obtained from Ecoinvent report No. 18. Basically, desktop PC equipment mass had defined and separated flow direction and then transferred into sequential treatment level 2. There are presented each of PC device mass flow in sections below.

a) Treatment level I : the relevant processes and their mass flow

The dismantled desktop PC devices are separated and sorted in this step. 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 as shown in table 4-4, 4-5, and 4-6. This result is useful for sequentially defined total input amount and recovering processes in treatment level 2.

- **CRT computer screen treatment level one**

Table 4-4 showed the disintegrated fraction of device separating into five fractions. One of them is sent to proper incineration following working instruction. Regarding to this approach, the CRT computer screen components was entered to 2nd treatment including: 68.09% CRT glass treatment unit, 20.66% to shredding process, 5.91% to incineration, 3.18% to PWBA and metal scrap recycling 2.18%,respectively.

Table 4-4: Treatment level I – the CRT computer screen mass flow according to mechanical treatment scheme transfer coefficiency calculation

Depollution components		Input to further treatment processes treatment (Kg)				
Sub-assembly	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shreddin g process (kg)**	**Metal Scrap for 2nd recycling (kg)**	**CRT glass treatment (kg)**	**Incine ration (kg)**
1. CRT tube	CRT tube, without gun	-	-	-	1.01E+01	-
2. Anode connection	metal parts, inside	-	2.84E-02	-	-	-
	plastic parts, inside	-	1.06E-02	-	-	-
3. Chassis	metal parts, inside	-	2.88E-01	-	-	-
	metal parts, outside	-	3.24E-01	3.24E-01	-	-
	plastic parts, outside	-	8.80E-01	-	-	8.79E-01
4. Deflection Yoke	CRT, deflection yoke	-	7.13E-01	-	-	-
5. De-magnetic coil	metal parts, inside	-	9.54E-02	-	-	-
	plastic parts, inside	-	1.26E-02	-	-	-
6. Electron Gun	CRT, electron gun	-	9.70E-02	-	-	-

Table 4-4 (continued): Treatment level I – the CRT computer screen mass flow according to mechanical treatment scheme transfer coefficiency calculation

Depollution components		Input to further treatment processes treatment (Kg)				
Sub-assembly	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shredding process (kg)**	**Metal Scrap for 2nd recycling (kg)**	**CRT glass treatment (kg)**	**Incine ration (kg)**
7. Miscellaneous	metal parts, inside	-	1.22E-01	-	-	-
	plastic parts, inside	-	3.00E-02	-	-	-
8. PWBA*	high quality, mounted	4.73E-01	4.73E-01	-	-	-
Total input of materials		**4.73E-01**	**3.07E+00**	**3.24E-01**	**1.01E+01**	**8.79E-01**

Furthermore, CRT computer screen shredding fraction had inputted as illustrated in previous table was calculated with transfer coefficients of WEEE shredder. Then, the summation of ended fraction is outputted in different amount including: 37.8 % of Ferro-fraction, 18.08% of copper fraction, 4.05 aluminum fraction and 40.05% of other residue. As this separation, this would be taken as the input to treatment level 2.

Table 4-5: The fraction classification in shredding fraction of CRT computer screen

Input substances	Amount (kg)	Output to 2nd recycling system			
		Ferro fraction (kg)	**Aluminum fraction (kg)**	**Copper fraction (kg)**	**Residue (kg)**
aluminum	9.81E-02	4.93E-04	8.12E-02	4.82E-03	1.18E-02
Copper	4.95E-01	4.64E-03	2.48E-02	3.87E-01	7.87E-02
Ferro	1.20E+00	1.14E+00	1.19E-02	1.19E-02	3.60E-02
Glass	5.42E-02	3.01E-04	3.01E-04	5.42E-03	4.81E-02
Plastics	1.14E+00	1.38E-02	5.71E-03	1.14E-01	1.01E+00
Ag	9.03E-04	8.95E-06	8.95E-06	7.68E-04	1.18E-04
Au	3.16E-04	3.12E-06	3.12E-06	2.52E-04	5.68E-05
Pb	6.72E-03	7.87E-05	7.87E-05	5.38E-03	1.18E-03
others	7.41E-02	5.09E-04	4.99E-04	2.61E-02	4.70E-02
Total	**3.07E+00**	**1.16E+00**	**1.25E-01**	**5.56E-01**	**1.23E+00**

- **LCD computer screen treatment level one**

As the same manner, table 4-6 showed number of LCD device fractions separating into six fractions. According to the mass flow calculation, the LCD computer screen components was considered to enter further treatment processes including : 46.85% shredding process treatment, 24.16% to metal scrap , 6.28% cable scrap recycling, 4.13% to PWBA recycling and 18.20% to incineration, respectively.

Table 4-6: Treatment level I – the LCD computer screen mass flow according to mechanical treatment scheme transfer co-efficiency calculation

Depollution components		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**	**incine-ration**
1. Backlight Unit	Backlight lamp	-	-	-	-	2.60E-02	-
	Metal parts, outside	-	1.28E-01	1.28E-01	-	-	-
	Plastic parts, inside	-	4.90E-02	-	-	-	-
	Plastic parts, outside	-	2.65E-01	-	-	-	2.65E-01
2. Base/Stand Assembly	Metal parts, outside	-	6.58E-01	6.58E-01	-	-	-
3. Inverter	Plastic parts, outside	-	1.94E-01	-	-	-	1.94E-01
	Cable (power, w/o plugs)	-	5.00E-03	-	-	-	-
	Metal parts, inside	-	5.00E-02	-	-	-	-
4. Power Supply Assembly	Metal parts, inside	-	2.70E-02	-	-	-	-
	Metal parts, outside	-	1.01E-01	1.01E-01	-	-	-
	Plastic parts, inside	-	1.60E-02	-	-	-	-
5. Outer frame	Plastic parts, outside	-	9.90E-02	-	-		9.90E-02
6. Power Switch	Plastic parts, outside	-	1.45E-02	-	-		1.45E-02
7. Printed wiring boards	PWB, high quality, mounted	2.28E-01	2.28E-01	-	-		-
8. Rear Cover Assembly	Metal parts, outside		4.66E-01	4.66E-01	-		-
	Plastic parts, outside	-	1.74E-01	-	-		1.74E-01
Total		**2.31E-01**	**2.63E+00**	**1.35E+00**	**3.52E-01**	**2.60E-02**	**1.02E+0**

The shredding fraction of LCD computer screen also calculated into sub-fractions with transfer coefficients of shredder (table 4-7). As this matter, the different amount of this processing is including: 51.79 % of Ferro-fraction, 7.96 % of copper fraction, 2.64 % aluminum fraction and 37.66 % of other residue. These several fractions would be taken as inputs to appropriate treatment level 2.

Table 4-7: The fraction classification in shredding fraction of LCD computer screen

Input substances In this study	Amount (kg)	Output to 2nd recycling system			
		Ferro fraction	Aluminum fraction	Copper fraction	Residue
Aluminum	5.399E-02	2.72E-04	4.47E-02	2.66E-03	6.48E-03
Copper	1.024E-01	9.59E-04	5.13E-03	8.01E-02	1.63E-02
Ferro	1.413E+00	1.34E+00	1.41E-02	1.41E-02	4.23E-02
Glass	4.183E-02	2.33E-04	2.33E-04	4.18E-03	3.72E-02
Plastics	9.970E-01	1.21E-02	4.98E-03	9.97E-02	8.79E-01
Ag	7.101E-04	7.04E-06	7.04E-06	6.04E-04	9.30E-05
Au	2.790E-04	2.76E-06	2.76E-06	2.23E-04	5.02E-05
Pb	5.211E-03	6.10E-05	6.10E-05	4.17E-03	9.17E-04
others	1.078E-02	7.41E-05	7.26E-05	3.80E-03	6.84E-03
Total	**2.626E+00**	**1.36E+00**	**6.93E-02**	**2.09E-01**	**9.89E-01**

- **Desktop PC computer treatment level one**

In case of desktop PC, table 4-8 represented whole desktop PC fractions after calculated mass flow pathway. The further treatment processes had modeled from different desktop PC fractions including: 58.54% shredding process treatment, 21.13% to metal scrap, 8.34% cable scrap recycling, 9.84% to PWBA recycling and 2.16% to incineration, respectively.

Table 4-8: Treatment level I – the desktop PC mass flow according to mechanical treatment scheme transfer co-efficiency calculation

Depollution components			Depolluted equipment Input to further treatment (Kg)				
Main components	**Sub assembly**	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shredding process Treatment (kg)**	**Metal scrap recycling (kg)**	**Cable scrap recycling (kg)**	**Plastics incineration (kg)**
1. **CPU Microchip**	IC logic type	PWB, high quality, mounted	9.50E-03	9.50E-03	-	-	-
2. **Cooling body for CPU**	ventilation fan	metal parts, inside	-	2.66E-02	-	-	-
		plastic parts, inside	-	2.51E-01	-	-	-
	PWBA	PWB, high quality, mounted	2.57E-02	2.57E-02	-	-	-

Table 4-8 (continued): Treatment level I – the desktop PC mass flow according to mechanical treatment scheme transfer co-efficiency calculation

Depollution components			Depolluted equipment Input to further treatment (Kg)				
Main components	**Sub assembly**	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shredding process Treatment (kg)**	**Metal scrap recycling (kg)**	**Cable scrap recycling (kg)**	**Plastics incineration (kg)**
2. Cooling body for CPU	CPU heat sink	metal parts, inside	-	1.14E-01	-	-	-
3. ATX motherboard	PWBA	PWB, high quality, mounted	3.24E-01	3.24E-01	-	-	-
4. RAM	PWBA	PWB, high quality, mounted	7.99E-02	7.99E-02	-	-	-
5. GPU card	PWBA	PWB, high quality, mounted	4.80E-02	4.80E-02	-	-	-
6. Local Area Network card	PWBA	PWB, high quality, mounted	2.20E-02	2.20E-02	-	-	-
7. GPU card (Cooling unit)	ventilation fan	PWB, high quality, mounted	2.30E-03	2.30E-03	-	-	-
		metal parts, inside	-	3.69E-03	-	-	-
		plastic parts, inside	-	2.67E-02	-	-	-
8. Hard disk drive (HDD)	Pointer assembly frame	Slide-in Modules	-	4.80E-02	-	-	-
	HDD platter	Slide-in Modules	-	2.30E-02	-	-	-
	Main back frame	Slide-in Modules	-	2.28E-01	-	-	-
	Plastic parts	Slide-in Modules	-	2.00E-03	-	-	-
	Pointer assembly	Slide-in Modules	-	5.00E-03	-	-	-
	PWBA	Slide-in Modules	-	2.50E-02	-	-	-
8. Hard disk drive (HDD)	Top cover	Slide-in Modules	-	1.25E-01	-	-	-
	Screws	Slide-in Modules	-	6.00E-03	-	-	-
9. Power Supply	Cable	cable (power, w/o plugs)	-	-	-	1.96E-01	-
	Capacitor	high quality, mounted	3.65E-02	3.65E-02	-	-	-

Table 4-8 (continued): Treatment level I – the desktop PC mass flow according to mechanical treatment scheme transfer co-efficiency calculation

Depollution components			Depolluted equipment Input to further treatment (Kg)				
Main components	**Sub assembly**	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shredding process Treatment (kg)**	**Metal scrap recycling (kg)**	**Cable scrap Recycling (kg)**	**Plastics incineration (kg)**
9. Hard disk drive (HDD)	Top cover	Slide-in Modules	-	1.25E-01	-	-	-
	Screws	Slide-in Modules	-	6.00E-03	-	-	-
10. Power Supply	Cable	cable (power, w/o plugs)	-	-	-	1.96E-01	-
	Capacitor	high quality, mounted	3.65E-02	3.65E-02	-	-	-
	Computer cable	cable (power, w/o plugs)	-	-	-	6.10E-01	-
	Ventilation fan	PWB, high quality, mounted	5.53E-03	5.53E-03	-	-	-
		metal parts, inside	-	8.86E-03	-	-	-
		plastic parts, inside	-	6.41E-02	-	-	-
	Housing material	Metal parts, inside	-	3.45E-01	-	-	-
	Inductor	PWB, high quality, mounted	4.55E-02	4.55E-02	-	-	-
	Plugs (inlet &outlet)	Plugs (power cable)	1.49E-01	-	-	-	-
	PWBA	PWB, high quality, mounted	7.15E-02	7.15E-02	-	-	-
	Transformer	PWB, high quality, mounted	5.25E-02	5.25E-02	-	-	-
11. CD/DVD Rom	Bottom cover	Slide-in Modules	-	5.42E-01	-	-	-
	Disk tray	Slide-in Modules	-	4.50E-02	-	-	-
	Front cover	Slide-in Modules	-	1.50E-02	-	-	-
	Plastic frame	Slide-in Modules	-	1.99E-01	-	-	-
	Main PWB	Slide-in Modules	-	6.12E-02	-	-	-
	Optical driving motor assembly	Slide-in Modules	-	2.21E-02	-	-	-
	Screws	Slide-in Modules	-	8.00E-03	-	-	-

Table 4-8 (continued): Treatment level I – the desktop PC mass flow according to mechanical treatment scheme transfer co-efficiency calculation

Depollution components			Depolluted equipment Input to further treatment (Kg)				
Main components	**Sub-assembly**	**Components in Ecoinvent reference**	**PWBA for 2nd metal recycling (kg)**	**Shredding process Treatment (kg)**	**Metal scrap recycling (kg)**	**Cable scrap Recycling (kg)**	**Plastics incineration (kg)**
12. 3½" floppy drive	Driving motor	Slide-in Modules	-	7.80E-02	-	-	-
	Headset assembly	Slide-in Modules	-	1.92E-01	-	-	-
	Metal casing	Slide-in Modules	-	1.00E-01	-	-	-
	Plastic part	Slide-in Modules	-	9.00E-03	-	-	-
	PWBA	Slide-in Modules	-	2.60E-02	-	-	-
	Screws/ spring	Slide-in Modules	-	4.00E-03	-	-	-
13. Desktop cabinet	Plastic front cover	plastic parts, outside	-	1.40E-01	-	-	1.40E-01
	PWBA switch board	PWB, high quality, mounted	5.50E-03	5.50E-03	-	-	-
	Ventilation fan	PWB, high quality, mounted	1.19E-02	1.19E-02	-	-	-
		metal parts, outside	-	9.49E-03	9.49E-03	-	-
		plastic parts, outside	-	6.86E-02	-	-	6.86E-02
	Screws	metal parts, outside	-	1.05E-02	1.05E-02	-	-
	Side cover plate	metal parts, outside	-	8.81E-01	8.81E-01	-	-
	Steel housing	metal parts, outside	-	1.14E+00	1.14E+0	-	-
	Cable inner cover steel	PWB, high quality, mounted high quality, mounted	6.20E-02	6.20E-02	-	-	-
Total (Kg)			**9.514E-01**	**5.66E+00**	**2.043E+00**	**8.06E-01**	**2.087E-01**

The shredding process of desktop PC can divided into useful sub-fractions based on transfer coefficients of shredder (table 4-9). Finally, the different output amount from this processing is including: 34.74 % of Ferro-fraction, 15.87 % aluminum fraction, 12.87 % of copper fraction, and 37.66 % of other residue. After that, this sorted fraction would be taken as inputs to further treatment level 2, respectively.

Table 4-9: The fraction classification in shredding fraction of desktop PC

Substances	Output to 2nd recycling system				
	Input substances	Ferro fraction	Aluminum fraction	Copper fraction	Residue
Aluminum	7.90E-01	3.98E-03	6.54E-01	3.88E-02	9.48E-02
Copper	2.85E-01	2.67E-03	1.43E-02	2.23E-01	4.52E-02
Ferro	3.22E+00	3.06E+00	3.21E-02	3.21E-02	9.64E-02
Glass	1.23E-01	6.85E-04	6.85E-04	1.23E-02	1.10E-01
Plastics	1.16E+00	1.40E-02	5.80E-03	1.16E-01	1.02E+00
Ag	3.39E-03	3.36E-05	3.36E-05	2.88E-03	4.45E-04
Au	9.28E-04	9.17E-06	9.17E-06	7.43E-04	1.67E-04
Pb	2.50E-02	2.93E-04	2.93E-04	2.00E-02	4.40E-03
others	4.65E-02	3.20E-04	3.13E-04	1.64E-02	2.95E-02
Total	**5.66E+00**	**1.97E+00**	**9.00E-01**	**7.30E-01**	**2.07E+00**

b) Treatment level II: the relevant processes and their mass flow

In this final stage, the previous residues is admitted to detoxify and refine processing by chemical, thermal and metallurgical processes to produce secondary metal and to eliminate final residues. Overall, results was showed in table 4-10, 4-11, 4-12 included the amount of recycled material and potential revenue profits (Market value of primary materials in appendix B multiplying the recycled mass). The outcome has elaborated in this section below.

- **Recycled material outcome from CRT computer screen**

This recycled outcome performed as shown in table 4-10. The recycling one of CRT device could provide secondary Ferro and nonferrous metal about 0.95 kg from 2.64 kg. Interestingly, these metal outcome possibly provide from list in table, which are; 2^{nd} steel production (66.82% of non-Ferro and Ferro recycled amount), 2^{nd} copper (26.29%), 2^{nd} aluminum (4.14 %), 2^{nd} nickel (1.66%), 2^{nd} lead (0.79%), 2^{nd} silver (0.28%), 2^{nd} palladium (0.015%), and 2^{nd} gold (0.0085%). However, glass cullet from this recycling scheme is also generated from this at highest weight or 90.04% of total recycled material but less in value. As potential recovering revenue, the total value of monetary benefits is account for 385.53 Thai baht. Gold is precious element perfectly bought to the highest revenue (32.68%) in just few amount as similar as palladium (26.52%). Nevertheless, the other recycled can also indicate to the benefits as well.

Table 4-10: The mass flow of CRT computer screen fraction during the treatment level II management step

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2nd Steel recovery	Metal scrap	3.245E-01	**2nd Steel**	**2.937E-01**	**5.848E+00**
2. 2nd Precious metal recovery from PWBA fraction	PWBA scrap	4.730E-01	**2nd Lead**	**7.558E-03**	**5.048E-01**
			2nd Nickel	**1.577E-02**	**7.794E+00**
			2nd Copper	**1.121E-01**	**2.557E+01**
			2nd Gold	**8.080E-05**	**1.232E+02**
			2nd Palladium	**1.470E-04**	**1.000E+02**
			2nd Silver	**2.668E-03**	**7.350E+01**
1. Shredding fraction Scrap metals recycling	Iron fraction recovery	1.16E+00	**2nd Steel**	**3.421E-01**	**6.812E+00**
	Aluminum fraction recovery	1.25E-01	**2nd Aluminum**	**3.936E-02**	**2.314E+00**
	Copper fraction recovery	5.560E-01	**2nd Copper**	**1.380E-01**	**3.148E+01**
2. CRT Glass sorting	Mixed glass, culets	1.008E+00	**Glass cullet**	**8.957E+00**	**8.509E+00**
	Panel glass, culets	5.977E+00			
	Funnel glass, culets	3.085E+00			
3. Disposal treatment	CRT coatings	5.693E-02	-	-	-
	Shredding residue	4.004E-01	-	-	-
	Plastics waste	8.790E-01	-	-	-
Total input material		**1.488E+01**	**Total output 2nd treatment**	**9.908E+00**	**3.86E+02**

- **Recycled material outcome from LCD computer screen**

The total outcome according to LCD computer screen recycling is presented in table 4-11. The overall scrap 3.6 kg can recycle into new secondary metal which contributed yield about 2.95 kg (82% recovered from total scrap). As these results, these total secondary resources can be classified including: these outcome possibly provide from list in table, which are; 2nd steel production (83.2%) , (26.29%) 2nd copper, (13.29%) 2nd aluminum, (2.28%) glass cullet, (0.78 %) 2nd nickel (0.26%), 2nd lead (0.13%), 2nd palladium , 2nd silver (0.044%) , 2nd mercury (0.0044%), 2nd palladium (0.0024%) and 2nd gold (0.0013%), respectively

For the potential recovering revenue, this scheme can totally provide 332.1 Thai baht. Especially, this majority of benefits came from 2nd copper which contributed about 30.65% of total revenue, following by 2nd gold about 20.67%, 2nd palladium about 16.79%

and etc. However, gold and palladium have higher price than other trace elements and potential to make high potential benefit.

Table 4-11: The mass flow of LCD computer screen fraction during the treatment level II management step

Treatment Processes	Input Material	Scrap input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2nd steel recovery	Metal scrap	1.354E+00	2nd Steel	1.225E+00	2.439E+01
2. 2nd precious metal recovery	Printed wired board assembly scrap	2.314E-01	2nd Lead	3.697E-03	2.469E-01
			2nd Nickel	7.713E-03	3.812E+00
			2nd Copper	5.486E-02	1.252E+01
			2nd Gold	3.955E-05	6.029E+01
			2nd Palladium	7.198E-05	4.897E+01
			2nd Silver	1.305E-03	3.595E+01
3. Shredded fraction Scrap metals recycling	Iron fraction recovery	1.356E+00	2nd Steel	1.228E+00	2.445E+01
	Aluminum fraction recovery	6.929E-02	2nd Aluminum	6.728E-02	3.955E+00
	Copper fraction recovery	2.095E-01	2nd Copper	1.598E-01	3.646E+01
4. Cable recycling treatment	Copper fraction recovery	3.518E-01	2nd Copper	1.772E-01	4.043E+01
5. Fluorescent lamp recycling unit **(mercury recovery , glass cullet, non-specific 2nd metal , phosphor recovery units)**	CCFL lamp in LCD screens.	2.600E-02	2nd Mercury	1.300E-04	4.043E+01
			Glass cullet	2.314E-02	1.963E-01
			2nd metal (No-specific type)	2.080E-03	2.198E-02
			2nd phosphor (assumed as ZnS)	3.900E-04	-
6. Disposal proportion	LCD module, to incineration	2.704E-01	-	-	-
	Shredding residue	9.894E-01	-	-	-
	Plastics waste	7.470E-01	-	-	-
	Phosphor waste (backlight lamp)	2.600E-04	-	-	
Total input material		**5.61E+00**	**Total output 2nd treatment**	**2.95E+00**	**3.321E+02**

- **Recycled material outcome from desktop PC**

Regarding to the desktop PC recycling, the overall outputs from refinery processes is presented in table 4-12. In facts, the entire recycling efficiency expressed that they can turn 7.4 kg of inputs to new secondary metal about 5.75 kg (approximately 77.7 % of treatment level II inputs). Turning to the recovered fraction, these total recycled metals were classified including: 2nd steel (63.28%), 2nd copper (20.64%), 2nd aluminum (15.16%), 2nd nickel (0.56%), 2nd lead (0.26%), 2nd silver (0.087%) , 2nd palladium (0.0051%) and 2nd gold (0.0028%), respectively.

For the potential recovering revenue, this obsolete desktop PC recycled materials can probably made profits around 997.4 Thai baht. A significant material contributing to revenue came from broad recycled traces; especially, from 2nd copper about 24.76% of total revenue, 27.14% from 2nd gold and 20.19 from 2nd palladium.

Table 4-12: The mass flow of desktop PC fraction during the treatment level II management step

Treatment Processes	Input Material	Input Amount (kg)	Output Material	Recovered amounts (kg)	Potential Recovering value (THB)
1. 2nd steel recovery	Metal scrap	2.043E+00	2nd Steel	1.849E+00	3.682E+01
2. 2nd precious metal recovery	Printed wired board assembly scrap	9.510E-01	2nd Lead	1.500E-02	1.002E+00
			2nd Nickel	3.200E-02	1.581E+01
			2nd Copper	2.250E-01	5.133E+01
			2nd Gold	1.620E-04	2.470E+02
			2nd Palladium	2.960E-04	2.014E+02
			2nd Silver	5.000E-03	1.378E+02
3. Shredded fraction Scrap metals recycling	Iron fraction recovery	1.971E+00	2nd Steel	1.790E+00	3.564E+01
	Aluminum fraction recovery	8.980E-01	2nd Aluminum	8.720E-01	5.126E+01
	Copper fraction recovery	7.280E-01	2nd Copper	5.560E-01	1.268E+02
4. Cable recycling treatment	Copper fraction recovery	8.060E-01	2nd Copper	4.060E-01	9.262E+01
5. Disposal proportion	Shredding residue	2.061E+00	-	-	
	Plastics waste	7.470E-01	-	-	
Total		**9.667E+00**	**Total output 2nd treatment**	**4.998E+00**	**9.974E+02**

c) Entering the desktop PC equipment compartment into recycling scheme

In this mass flow investigation, the aim was to assess type and amount of recycled materials in order to declare the avoided process following the expanded system in LCA modeling. The table 4-13 was described the quantity level and types of primary processes which would be avoided. In facts, these occurred differently depending on amount of recycled matters in each of equipment. Ultimately, these flow will be calculated with background data and released into recycling inventory for further step in environmental impact assessment

Table 4-13: 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)	Desktop PC (kg)
2nd Aluminum	Aluminum, primary, at plant/RER U	3.94E-02	6.73E-02	8.72E-01
2nd Steel	Steel, low-alloyed, at plant/RER U	6.36E-01	2.45E+00	3.64E+00
2nd Copper	Copper, primary, at refinery/GLO U	2.50E-01	3.92E-01	1.19E+00
2nd Lead	Lead, primary, at plant/GLO U	7.56E-03	3.70E-03	1.50E-02
2nd Nickel	Nickel, 99.5%, at plant/GLO U	1.58E-02	7.71E-03	3.20E-02
2nd Silver	Silver, at regional storage/RER U	2.67E-03	1.31E-03	5.00E-03
2nd Gold	Gold, primary, at refinery/GLO U	8.08E-05	3.96E-05	1.62E-04
2nd Palladium	Palladium, primary, at refinery/ZA U	1.47E-04	7.20E-05	2.96E-04
2nd Mercury	Mercury, liquid, at plant/GLO U	-	1.30E-04	-
2nd unspecific metal	Steel, low-alloyed, at plant/RER U	-	2.08E-03	-
2nd phosphor	Zinc sulphide, ZnS, at plant/RER U (proxy assumption	-	3.90E-04	-
Glass cullet	Glass cullet, sorted, at sorting plant/RER U	8.96E+00	2.31E-02	-
Total		**9.91E+00**	**2.95E+00**	**5.75E+00**

d) The scenario analysis : the total amount of recycled material output

Not at all, the scenario analysis also explored situation during 2012-2021 through three scenarios. two of them are modeling to apply appropriate recycling approach in Thailand included either 5% or 20% collecting to recycling processes and another one for do nothing situation. The results were reflected the potential recovered amount and potential revenues.

Referring to the secondary metal resources profiles showed in Table 4-14, 4-15, 4-16. Both of 20% and 5% recycling collection scenario (S3) are provide high amount of recycling outputs as well as their potential revenue. However, this largest profit is truly attributed from 20% recycling scenario. In-depth, desktop PC provided the largest contributor to net recycled material and following by LCD and CRT computer screen, respectively. Desktop PC and LCD computer waste generation have been gradually increased in every year during 2012-2021.The average waste generation rate is about 123.05% for desktop PC and 67.25% for LCD flat screen. This is reasonable to contribute the bulk amount of waste support into the recycling for desktop PC and LCD scheme. In despite of CRTs, there have largely been superseded by newer display technologies which presented amount of waste in 2012 only about 398,863.58 units cumulated with -55.80 generation rate. Although 20% recycling collection rate is high, recycled material from CRT screen is still low because lowering input of this screen scrap. In despite of recycling scheme, the landfill approach could imply to the unsustainability of resources by expressed as non-recycled outcome; in other words, this showed the loss of opportunity in sustaining the resource.

Table 4-14: the amount of recycled materials according to the end of life managing scenario in CRT computer screen for 10 years timeframe

CRT computer 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	6.14E+04	1,222,426.25	2.46E+05	4,889,704.99
2nd Aluminum	3.80E+03	223,435.57	1.52E+04	893,742.29
2nd Copper	2.41E+04	5,508,642.76	9.66E+04	22,034,571.05
2nd Gold	7.80E+00	11,895,964.74	3.12E+01	47,583,858.96
2nd Lead	7.30E+02	48,742.56	2.92E+03	194,970.23
2nd Nickel	1.52E+03	752,574.26	6.09E+03	3,010,297.05
2nd Palladium	1.42E+01	9,655,815.54	5.68E+01	38,623,262.14
2nd Silver	2.58E+02	7,097,024.42	1.03E+03	28,388,097.67
Glass cullet	8.65E+05	821,613.34	3.46E+06	3,286,453.38
total	**9.57E+05**	**37,226,239.44**	**3.83E+06**	**148,904,957.75**

Table 4-15: the amount of recycled materials according to the end of life managing scenario in LCD computer screen for 10 years timeframe

LCD computer 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	1.06E+06	21,084,109.88	4.24E+06	84,336,439.52
2nd Aluminum	2.90E+04	1,707,201.12	1.16E+05	6,828,804.49
2nd Copper	1.69E+05	38,589,992.86	6.77E+05	154,359,971.45
2nd Gold	1.71E+01	26,026,122.33	6.83E+01	104,104,489.32
2nd Lead	1.60E+03	106,586.92	6.38E+03	426,347.68
2nd Nickel	3.33E+03	1,645,484.58	1.33E+04	6,581,938.31
2nd Palladium	3.11E+01	21,139,957.53	1.24E+02	84,559,830.11
2nd Silver	5.63E+02	15,519,936.09	2.25E+03	62,079,744.37
Glass cullet	9.99E+03	9,489.50	4.00E+04	37,958.00
Total	**1.27E+06**	**125,913,602.36**	**5.09E+06**	**503,654,409.46**

Table 4-16: the amount of recycled materials according to the end of life managing scenario in desktop PC for 10 years timeframe

Desktop PC recovered fractions	S2: recycling 5%		S3: recycling 20%	
	recycled amount (kg)	potential revenue per unit (THB)	Recycled mass amount (kg)	potential revenue per unit (THB)
2nd Steel	1.92E+06	38,275,735.69	7.69E+06	153,102,942.77
2nd Aluminum	4.61E+05	27,077,204.13	1.84E+06	108,308,816.54
2nd Copper	6.27E+05	143,018,982.04	2.51E+06	572,075,928.17
2nd Gold	8.56E+01	130,473,457.30	3.42E+02	521,893,829.20
2nd Lead	7.92E+03	529,289.09	3.17E+04	2,117,156.34
2nd Nickel	1.69E+04	8,351,357.73	6.76E+04	33,405,430.93
2nd Palladium	1.56E+02	106,386,049.80	6.25E+02	425,544,199.20
2nd Silver	2.64E+03	72,790,455.13	1.06E+04	291,161,820.50
Total	**3.04E+06**	**526,902,530.91**	**1.22E+07**	**2,107,610,123.65**

As the study assumption, the results are significant in at least major two respects: (1) this study does not involve taking obsolete PC equipment back processes; consequently, the whole number of desktop PC equipment forecasting in Thailand is directly dedicated to recycling step without material loss. (2) The potential revenue from this recycling does not take into account the operational cost and other relevant aspect is necessary to consider when compared recycling scheme with landfill.

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 impact from the desktop PC equipment landfilling and recycling following the assumptions. Overall, this study reported endpoint impact score based on the three environmental impact including human health, ecosystem quality and resource availability. Then, those three impact would be aggregated via through weighting calculation into one single score (non-metric unit) which helpful to comparison between managing approach.

5.1.1 The Human health endpoint category

The human health impact results calculated by Recipe 2008a 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. In other words, these midpoints were aggregated into DALY or disability-adjusted life year unit through the multiplying with the endpoint characterization factor. The overall results have different level of environmental impact depending on each waste specific burden of components. This study only showed some of midpoint impact indicator which contributed as highest first four ranks of environmental burdens or benefits to the human health endpoint impacts. Overall, the results are described below.

5.1.1.1 The landfilling burdens contributing to human health impact

a) CRT computer screen landfilling

For CRT computer screen in proper landfilling, there properly affected to human health by showing the endpoint score about 1.67E-05 DALY. In particularly, the highest four midpoint impact are performed as the main proportion contributed to endpoint impact (as shown in Figure 5-1) including the human toxicity impact, climate change in human health impact , particulate matter and ionizing radiation impact.

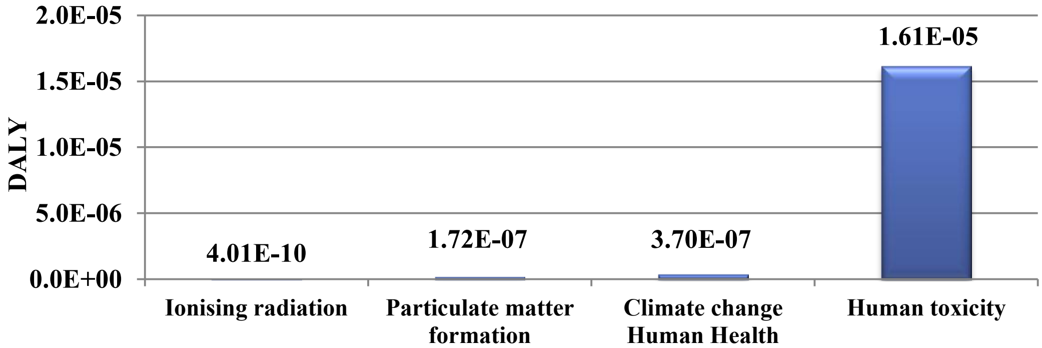


Figure 5-1: The characterized of human health impact according to CRT computer screen landfilling management

The human toxicity impact displayed as the highest midpoint which attributed to the human health endpoint burdens about 96.75% of overall human health impact category. (1.61E-5 DALY) The result showed that the disposal of coatings CRT screens which contains toxic substance inside to the municipal waste incineration contributed almost 98% of all human toxicity. When focusing on the substances contribution showing in SimaPro program , this landfilling approach can defect human health through the waterborne emission including 81.3% from zinc ion, 9.01% from silver ion and from 8.05 % barium

For climate change human health category, this environmental impact contributed only 2.22% (3.70E-07 DALY) of total human health categories. This climate change impact for human impact generated from 23.1% of disposed CRT glass, 26% of disposed plastics and 16.9% of disposed CRT coating. For process contribution, transportation in operation and diesel burning in building machine are the main factor to this impact by largely emitted out the carbon dioxide (about 73.5% of this impact) and methane (25.1%), respectively.

Particulate matter formation generated about 1.03 % of total human health impact. This impact mainly came from the incineration of CRT coating substances (32.07% of this impact), which causing harmful to human health following by landfilling of CRT glass (26.83%) and other toxic substances (11.25%).Above of all, the landfilling processes cannot avoid the emission of pollutants such as nitrogen oxide and other particulate matter which contributed to this impact.

For the least contributor to the human health impact, the ionizing radiation impacts are contributes less in this category (2.40E-05% or 4.01E-10 DALY). These are come from electricity producing which emission some of carbon-14 and radon which mainly distributed from nonferrous metal (27.5%) and CRT glass landfill (22.9%).

b) LCD computer screen landfilling

Disposal of LCD computer screen in landfilling affected to human health as revealing endpoint score about 9.04E-07 DALY .The four midpoint impact are performed as the main proportion contributed to endpoint impact (as shown in Figure 5-2) including the human toxicity impact, climate change in human health impact , particulate matter and ionizing radiation impact, respectively.

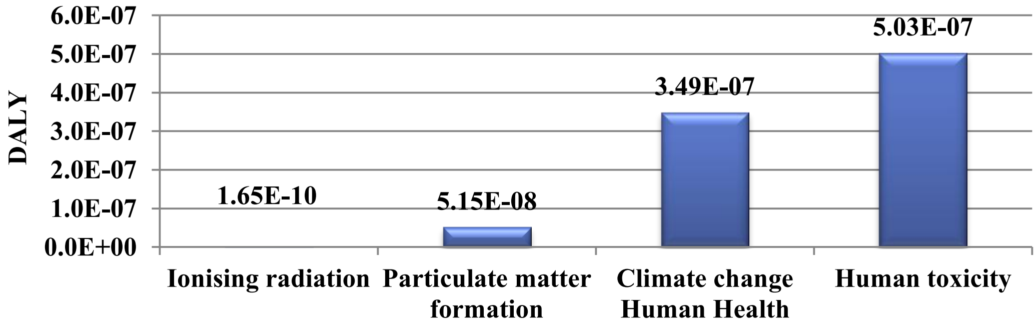


Figure 5-2: The characterized of human health impact according to LCD computer screen landfilling management

The human toxicity category displayed as the highest midpoint attributed to endpoint human health burdens about 55.67% of overall human health impact category. Disposal of Plastics parts to landfilling could generate tremendous of human toxicity than other parts (about 93.6 % of total burdens). Especially, the ABS plastics inside LCD screen provided largest impact than other plastics (33.2% of overall human health burdens). Focusing on the affected from substances, There highly came from waterborne emission including lead (26.17%), barium (21.47%) and manganese (14.84%). The roots of all substances came from operation of landfill.

The climate change affected to the human health category by contributed burdens for 38.61% (3.49E-07 DALY) of total human health categories. It can be seen that this category generated from plastics of LCD landfilling approximately 83.16% of entire climate change impact. In facts, the disposal of ABS plastics is contributed high proportion of this impact (about 40.89% of entire level) and following by other waste types. In facts, the main contributors of this impact according to fossil fuel utilization are from 59.28% methane and 39.84% carbon dioxide.

The particulate matter was contributed to human health for 5.7 % (5.15E-08 DALY) This problem occurred during operating of machine and lorry transportation .Specifically, the substances causing particulate matter happened in landfill activities was highly from nitrogen oxides (51.34% of impacts), particulate matter (38%) and sulfur oxide (10.29%) respectively. The severity of particulate matter formation impact are different relied on types of waste in which 37.1% of impact from plastics, 27.4 % from ferrous metal and 22.1 % from other toxic substances.

As the least contribution of human health impact, the less ionizing radiation impact came from the electricity generation relied on Ecoinvent database which emitted majority of radon-222 (65.92%) and carbon-14 (33.68%) .There are mainly distributed from LCD plastics burdens for 54.4% of this entire sub impacts

c) Desktop computer landfilling

In the desktop PC landfilling, this human health impact is distributed about 1.39E-06 DALY. The overall results are performed as shown in Figure 5-3. This are aggregated from all relevant midpoint impact of human health impact; however the major proportion of human health impact (DALY unit) was specifically generated from highest four impact including human toxicity, climate change in human health, particulate matter and ionizing radiation. Consequently, these impacts are exactly need to specialize as man human health endpoint contributor.

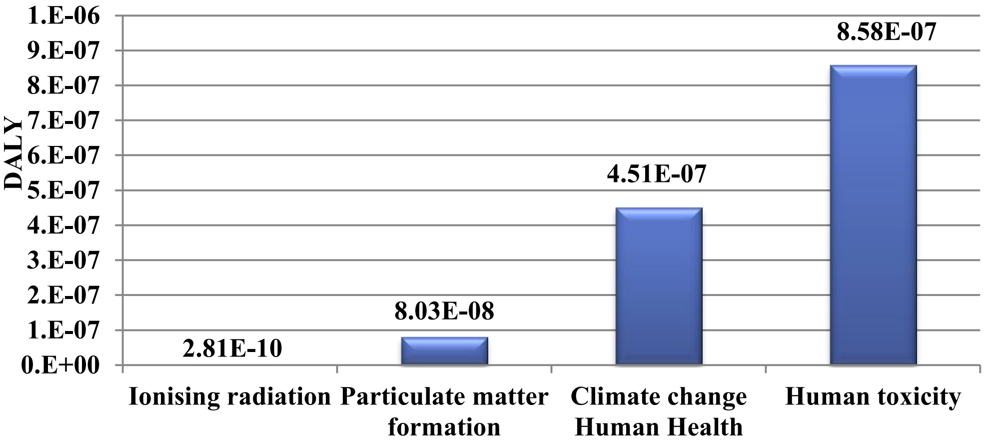


Figure 5-3: The characterized of human health impact according to desktop PC landfilling management

The human toxicity displayed as the highest midpoint contributed to the human health endpoint burdens which contributed 61.76 % (8.58E-7 DALY) to this endpoint category. The result showed that the facility operation and transportation are the main factor contributing to the human toxicity. Particularly, the disposal of plastics and non-ferrous to sanitary landfilling can provide human toxicity as high level which plastic landfilling contributed for 83.3% (PE and Epoxy plastics as main impact contributor) and 12.8% for nonferrous landfill. Focusing on the substances, it can be seen the main substances that affect to human toxicity are lead (21.57%), vanadium (16.07%), and barium (8.34 %).

For climate change human health category, this environmental impact contributed for 32.44 % (4.51E-07 DALY) of total human health categories. The plastics parts from disposed desktop PC provided the high numbers of burdens which contributed from diesel burned in processes during operated the landfill. In facts, plastics landfill burdens are amount to 68.6 % of climate change affecting to human health; especially, in PE and ABS plastic landfilling. Apart from this, the disposed of ferrous contributed to human health climate change for 11.7 % and 10.2 % for nonferrous metal. The methane emissions contributed for 70.84 % and carbon dioxide for 29.04 % of overall human climate change impact. This emission is connected with the landfilling operation which involved mainly in energy demand and land use (i.e., process specific burdens in sanitary and inert landfill, transportation).

The particulate matter formation results represented as significant impact which contributed for 5.78% of entire human health impact (8.03E-08 DALY). In depth, the particulate matter information was generated for 35.5 % from PC ferrous metal, 31.8 % from nonferrous and 26.5 % from plastics landfilling, subsequently. The main landfilling processes that contributed to this occurrence are normally included the process specific for inert and sanitary landfilling including lorry transportation and building machine during operation. This adversely affect came from the nitrogen oxide responding to 55.67% and particulates (> 2.5 um, < 10um < 2.5 um, Particulates) which contribute to 44.64 % of this impact category.

The ionizing radiation impact is the last of four highest human health impacts which contribute for 0.02 % (2.81E-10 DALY). These also came from electricity producing which emission some of carbon-14 and radon. The examined result reveals that mainly distributed from nonferrous approximately 37 % as well as plastic landfill.

According to the landfilling approach, these all equipment showed the same kinds of mid-impact distributed to the endpoint. When compared the human health impact between three devices (Figure 5-4), the CRT computer screen has highest potential to impact human health. The study founded that CRT computer screen contributed human health impact for 12.03 times higher than LCD screen as well as 18.48 times of desktop PC.

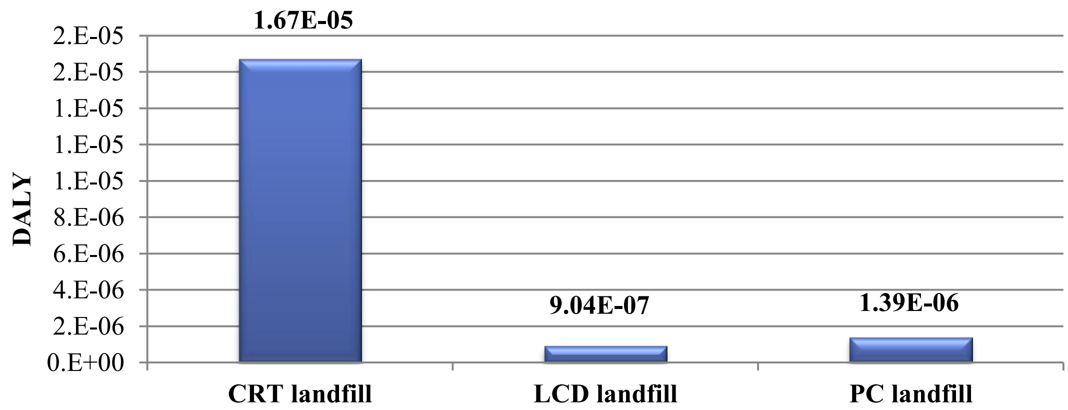


Figure 5-4: The human health comparison between desktop PC equipment contributing from landfilling approach

5.1.1.2 The Recycling approach burden contributing to human health impact

a) The recycling of CRT computer screen

In opposite to the landfilling approach, the CRT recycling scheme can avoid overall impacts on human health. The negative impact DALY contributed from different fractions of midpoint impact when applied recycling scheme about -2.72E-04 DALY as shown in the Figure 5-5.

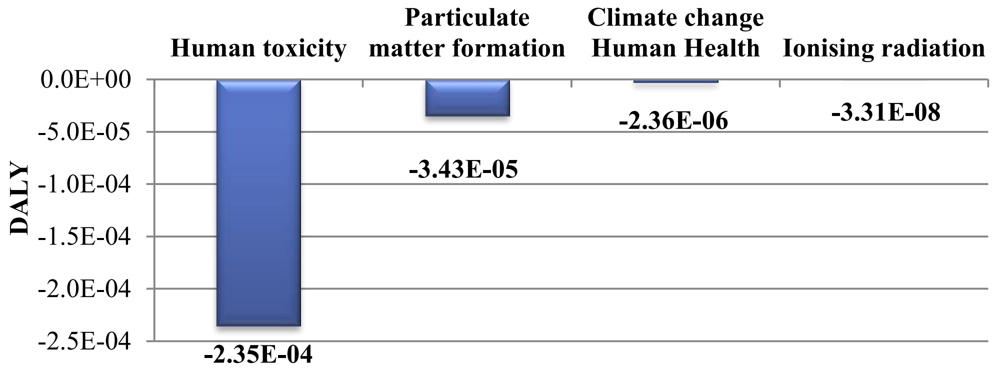


Figure 5-5: The avoided of human health impact according to CRT computer screen recycling approach

The recycling processes can subtract almost 86.49% (-2.35E-04 DALY) of human health impact through the midpoint human toxicity impact. The majority of this subtraction came from the elimination of landfilling of sulfidic tailing producing in mining which avoided about 77.24 % of this impact. Furthermore, when focused on substance contribution to this impact, recycling can avoided the impact mainly 54.48% from manganese waterborne 15.50% from arsenic waterborne 13.15 % from arsenic airborne emission and 7.47 % from lead substances, respectively.

Particulate matter formation would not be generated 12.62% (-3.43E-05 DALY) of human health problem when apply recycling scheme. In facts, this advantage provided about 70% (-2.4E-5 DALY) from CRT shredded fraction recycling (mainly from subtraction of copper production) and 30.5% (-1.05E-5 DALY) from PWBA recycling (mainly form subtraction of palladium). In facts these two main processes are avoided impact from blasting substances emission mainly including sulfur dioxides (52.03%), particulate matter (37.2%).

The subtraction of climate change midpoint impacts on human health category can consequently avoided about 0.87% (-2.36E-06 DALY) of entire human health endpoint impact. When focusing on the impact contribution, it can be seen that recovering of the precious metal from PWBA can omit this impact approximately 46.1%, and avoided about 54.75% from recovering the shredded fraction (recycling of steel, aluminum and copper). In facts, this eliminated processes from building machine, industrial furnace and some power generator by mainly depleted both of carbon dioxide emission for 51.32% and methane for 21.7% of entire climate change impacts.

Due to recycling scheme, the midpoint ionizing radiation impact subtraction can help to make the benefit only about 0.01% (-3.31E-08 DALY) of overall avoided endpoint impact. In facts, recycling scheme can avoid the radon-122 emission (67.9%) due to the electricity producing in Europe system which mainly founded in palladium production.

b) The recycling of LCD computer screen

The result of LCD recycling scheme showed the human health benefits for human health as shown in the Figure 5-6. In facts, this LCD screen recycling can avoid this kind of impact
about -1.98E-04 DALY. Overall, this avoided human health impact was described through the summation of benefits through the different categories.

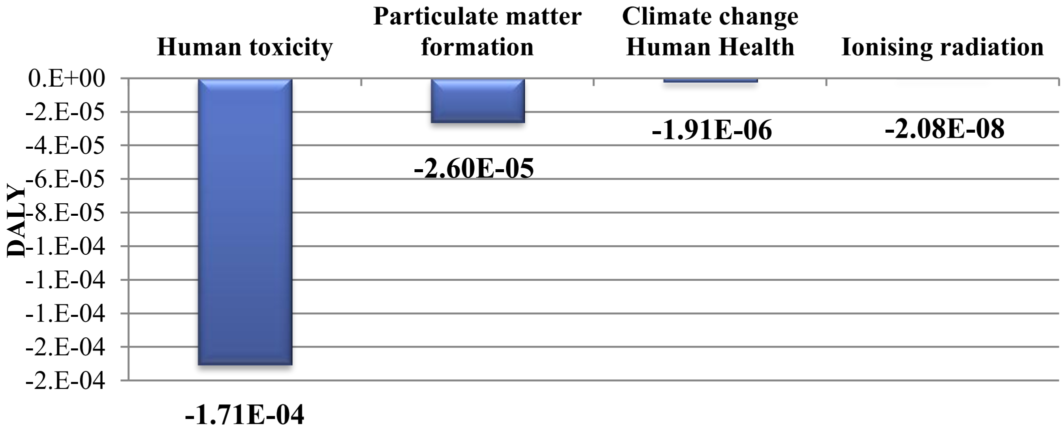


Figure 5-6: The avoided of human health impact according to LCD computer screen recycling approach

The largest contribution of the advantages to human health in LCD computer screen recycling came from avoided the impact of human toxicity. Particularly, this avoided provided the benefits about 85.93% of human health impact (-1.71E-04 DALY). Focusing on the evaluating results, this analysis showed that recovery of copper from PWBA, shredded fraction and cable can avoid 75.2% of this impact. As these results, this is because recycling scheme eliminated the pollution emitted from disposal of tailing from mining processes (mainly avoided the manganese and arsenic substances)

Next, the avoided of particulate matter formation also showed the 13.10% (-2.60E-5 DALY) of avoided human health endpoint impact. Overall, recycling avoided the formation of particulate matter about 49 % from sulfur dioxide, 40.3 % from particulate matter (PM, >2.5 um, <2.5 um, < 10 um) and other which these usually came from non-ferrous smelter.

The recycling of LCD screen can subtract a few amounts or 0.96% of human health impact from avoided the climate change human health impact. Interestingly, recycling of steel from LCD ferrous scrap and shredder fraction can take a benefit about 47.8% (-4.46E-06 DALY) and other 26.79% from PWBA precious metal recovery. This is because recycling can eliminate carbon dioxide and methane emission.

For the last of top four avoided impact, there is the ionizing radiation this may be said that recycling can be provided good benefits around 0.01% (-2.08E-08 DALY) which came from avoided of some radiation in electricity producing which hazard to human health through the uranium tailing.

c) The recycling of PC recycling scheme

In opposite to the landfilling approach, PC recycling scheme can avoid overall impacts on human health as the results shown in the figure 5-7. 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 -1.35E-03 which particularly came from different significant impacts.

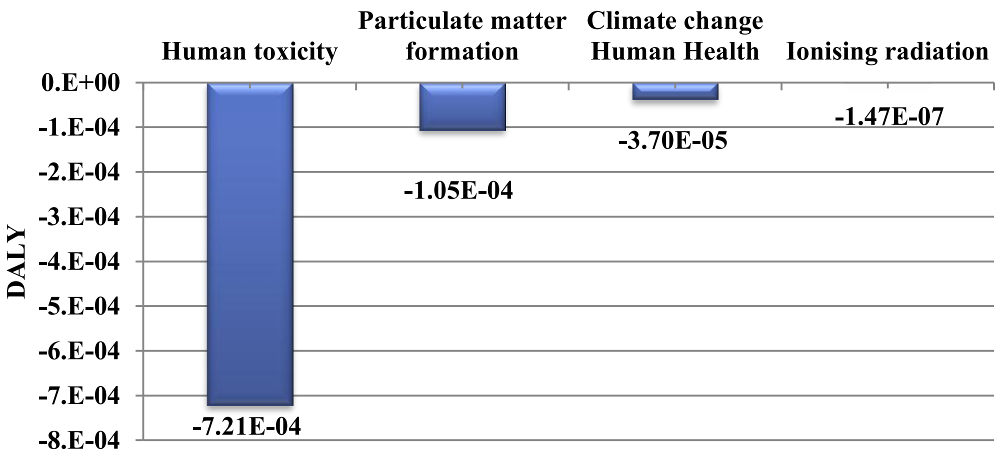


Figure 5-7: The avoided of human health impact according to desktop computer recycling management

It is apparent that human toxicity would be enormously reduced by recycling which is totally sink the negative impact about 83.49% (-7.21E-04 DALY) of that total human health endpoint impact. Eventually, the avoided of human toxicity impact significantly performed through 47.4 % of PWBA recycling(take benefits mainly from primary gold production), 27.5% of cable recycling (mainly benefits from copper production) and 25.6% of shredded fraction recycling (mainly benefits copper production), respectively. As this matter, recycling can avoided negative effect from many substances (55 % from manganese, 27% from arsenics substances) which contributed from sulfidic tailing disposal.

For particulate matter formation impact, it distributed to human health impact for 12.21% (-1.05E-04 DALY).There are also the same trend that recycling can avoid this impact mostly through the recycling of PWBA (43%), cable (25.4%) and shredded fraction (29.7 %). Focusing on processes, recycling can avoid 59% of the particulate matter impact causing from copper production following by 9.21% from palladium production and other processes. Because of the avoided substances in recycling scheme, this can reduce coagulation of particulate matter from sulfur dioxide 50.7 % as well as 36.7% of particulate matter of total impact contribution.

The climate change human health burden which potential affected to human health category contributed around 4.28% (-3.70E-05DALY) of human health impact category. Recycling can subtract the burning processes which 60.4% came from precious metal recovery in PWBA and 45.8% from shredded fraction recycling. In-depth analysis result showed that the highest avoided impact processes are including aluminum production, burned gas in industrial furnaces and burned diesel. Overall, 85.6% of carbon dioxide emission impact and 10.72% methane impact were exterminated from recycling scheme as well.

The recycling can avoided impact from ionizing radiation in the process of primary metal production for 0.01% (-1.47E-07 DALY) of total human health impact. There are basically generate less ionizing radiation matter in electricity generation due to the data from Europe (Eco invent database).Thus, applying the recycling scheme was also avoided the impact from releasing of radon (67.98 %) and carbon-14 (31.66 %).

According to the overall result, the human health endpoint impact mainly distributed from the same types of mid-impacts. As shown in Figure 5-8, Recycling of desktop computer has highest potential to avoid the human health impact, following by CRT recycling and LCD recycling. It is interesting that recycling PC equipment produced benefits to human more than CRT for 3.17 times and LCD for 4.35 times. This is because of different recyclable material existed in each equipment would define the end amount of recovered material per weight.

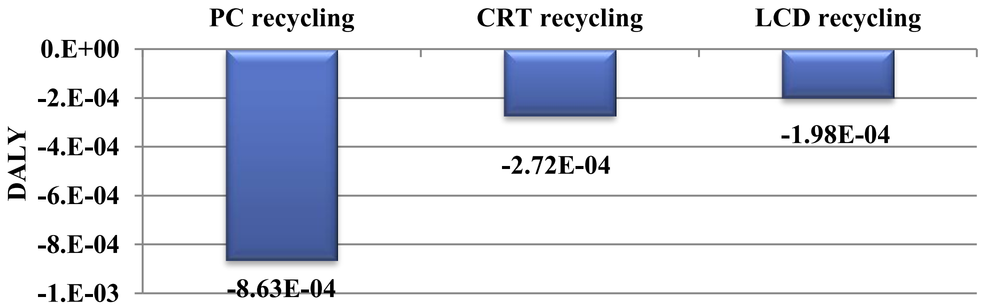


Figure 5-8: Comparison between avoided human health impacts contributing from recycling approach

5.1.2 The Ecosystem endpoint 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." desktop impacts regarding to Recipe 2008 method assumption. This study only showed some of midpoint-impact indicator which contributed as highest first four ranks of environmental burdens or benefits to the ecosystem endpoint impacts. Overall, the results are described below.

5.1.2.1 The landfilling burdens contributing to ecosystem impact

a) CRT computer screen landfilling

The results of landfilling impact to the ecosystem are showed in the Figure 5-9. There are revealed the loss of diversity in ecosystem entirely contributed about 7.47E-09 species*yr. For this endpoint impact score matter, there was distributed from significant midpoint impact categories.

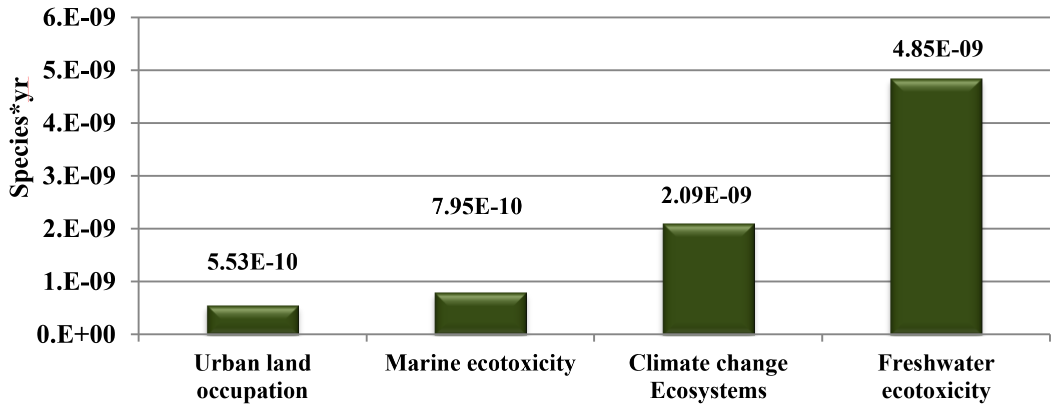


Figure 5-9: The characterized of ecosystem impact according to CRT computer screen landfilling management

The freshwater toxicity displayed as the highest midpoint impact which distributed to endpoint ecosystem problem .In other words, 64.91% (4.85E-09 species*yr.) of ecosystem category came from this impact. Apparently, the disposal of CRT coating in landfilling made the harmful to this fresh water toxicity approximately 99.3 % because these chain processes had emitted the pollution from both of waste-specific of incineration (water emission) and dumped of their slag to residual landfilling. Overall, these mainly affected from high amount of zinc ion 69.26% and silver ion 30%

For climate change ecosystem category, this environmental impact contributed to 28.05% (2.09E-09 species* yr.) of this total ecosystem impact category. The plastics parts from disposed CRT provided negatively impact to the climate about 26% (especially in ABS and PU plastics), following by 23 % of CRT glass, 16.88% of CRT coating. The transportation during the operation of landfilling, burning in building machine and other combustion processes were usually affected to this impact which impact came from carbon dioxide (73.48% of this impact) and methane (25.06% of this impact),respectively.

As the marine eco-toxicity, this impact contributed 10.65% (7.95E-10 species*yr.) to ecosystem quality deterioration. The majority of impact was come from managing of CRT glass coating substances management 99.45% of this impact. The substances that affected to marine species are mainly from zinc ion (69.14%) and silver ion (30.15%) as same as fresh water toxicity impact, traffic area, and road network

It can be seen that urban land occupation category distributed 7.41 % (5.53E-10 species*yr.) to overall ecosystem impact. The occupying and transforming of urban land provided to this impact which mainly came from 44.01 % of dump-site occupation impact as same amounts of impact from traffic occupation. These all distributed from 32.1% from CRT Glass landfilling, 28.64% for ferrous metal landfilling and 19.07% from CRT glass coating management.

b) LCD computer screen landfilling

In attention to ecosystem impact according to the LCD landfilling, the results expressed through the loss of species diversity about 2.08E-09 species* yr. (figure 5-10). As this matter, there was distributed from essential four midpoint impact categories as described below

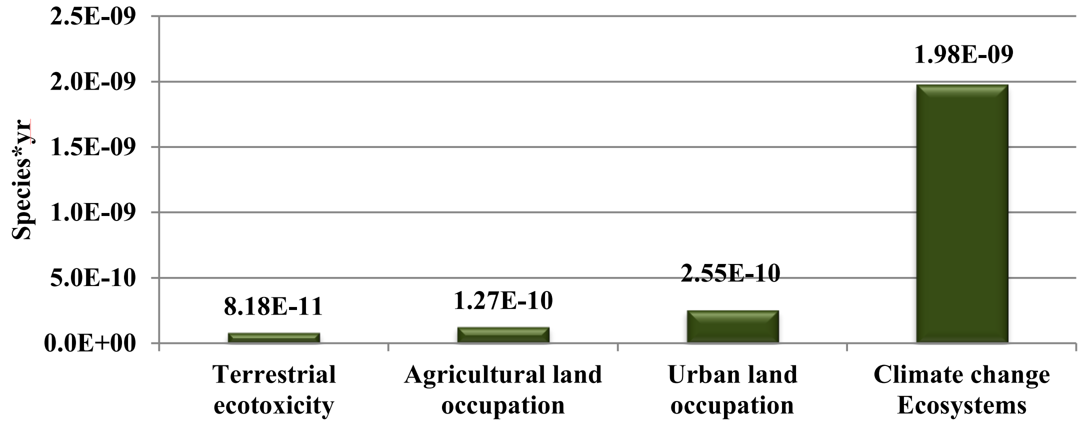


Figure 5-10: The characterized of ecosystem impact according to LCD computer screen landfilling management

LCD landfilling approach created the highest level of climate change impact which this burdens also consequently distributed almost 95.10% (1.98E-09 species*yr.) to endpoint ecosystem. The landfilling of plastics contributed the highest amount of climate change impact (83.15% of this impact). Especially, there are highest contributed from ABS plastic (40.8%) following by PE and other plastic wastes, respectively. For the substances contribution to this impact, it showed that combustion occurred during landfill operation generated impact came from 59.25% of methane and 39.87% of carbon dioxide emission.

The urban land occupation (in this case is the LCD landfilling) was affected to ecosystem quality about 12.26% (2.55E-10 species*yr.) Almost 62% of this impact came from plastic landfilling following by 21.1% from ferrous metal and 12.24% from ferrous metal, respectively. For this result, it direct linked to landfilling operation which became from burdens from occupation dumpsite (40%) and traffic area (49%).

As the agricultural land occupation, this midpoint impact was contributed to ecosystem impact about 6.10% (1.27E-10 species*yr.) of total ecosystem impact, mainly from LCD toxic substances landfilling (76.78% of this entire impact) which this type of landfilling disturbed the forest occupation.

The last of top four contribution impact came from terrestrial eco toxicity about 3.94 % (8.18E-11 species*yr.) Which totally aggregated from 99.23% of plastic landfilling (highest proportion from ABS plastics) particularly, bromine, phosphorus and mercury are the key factors that contributed to this impact to terrestrial burdens.

c) Desktop PC computer landfilling

As shown in the Figure, the PC landfilling can generate negatively affected to ecosystem which reflected as the loss of species about 2.50E-09 species* yr. (Figure 5-11). There are contributed from main relevant midpoint impact as described below

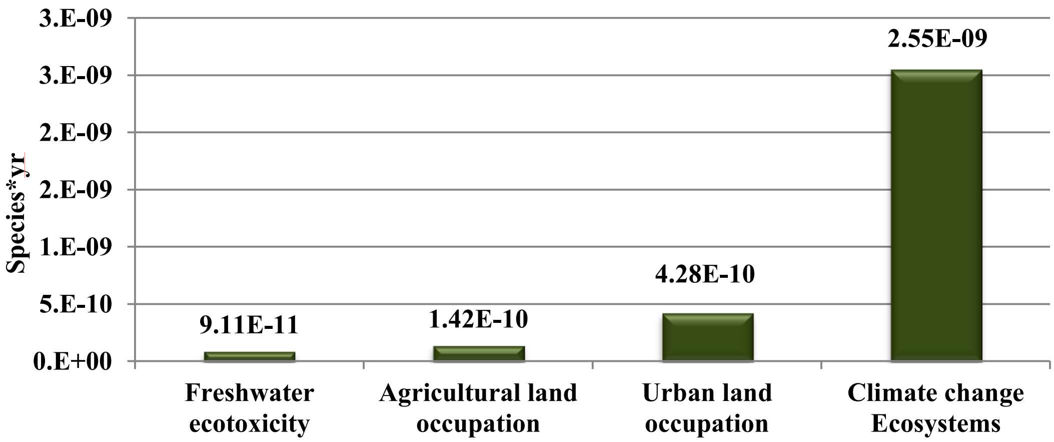


Figure 5-11: The characterized of ecosystem impact according to desktop PC landfilling management

For Climate change ecosystem impact, this midpoint impact distributed to the overall ecosystem deterioration about 78.15 % (2.55E-09 Species* yr.) of ecosystem quality. Dumping the plastics waste to landfill is possible to impact about 68.6 % to the climate change category, following by ferrous metal (about 11.7%) and nonferrous metal (about 10.2%). Process contribution to this climate change ecosystem impact is combustion in landfill machine .Therefore, all these process related to emission mainly included methane (contributed to 51.55 % of this impact) and carbon dioxide (contributed to 43.35%).

For the urban land occupation category, this impact distributed 13.10 % (4.28E-10 species* yr.) to the ecosystem for endpoint impact .the plastics landfilling are contributed higher level or 40.9% of this impact category. Apart from this, there are also contributed 29.7 % in nonferrous landfill, 25.5 % for ferrous metal and other. The process contribution explained that the potential occupational activities mainly contributed impact to ecosystem. In facts, It approximately 48.56 % of total occupational impact contributed from traffic area and road network during operation of landfilling process. Similarly, the operation of landfilling or are also contributed about 41.173% of this total impact

Interestingly, the impact from agriculture land occupation is contributed about 4.35 % (1.42E-10 species* yr.) of ecosystem impact. This impact contributed largely from PC nonferrous metal fraction landfilling (about 67.1%), ferrous metal landfilling (for 13.9 %) and inorganic landfilling (10.9%). The results are apparently showed that landfilling approach contributed the impacts by changing land occupation from the natural state of forest and shrub land to landfill.

For fresh water Eco toxicity, this impact distributed few amount of impact in ecosystem category for 2.79 % (9.11E-11 species* yr.) of total ecosystem category. The results showed that Plastics waste also contribute approximately 89.6 % of overall impact, following by nonferrous for 8.11 %, respectively. For the substances contribution, this impact are generate by potential substances includes vanadium (for 63.34%) from sewer grid system, bromine (for 11.08%) and zinc ion (8.73%) as landfill facilities maintenances respectively.

According to the landfilling approach, these all equipment showed the different kinds of mid-impact distributed to the endpoint. The CRT computer screen has highest potential to impact ecosystem following by PC landfilling and LCD landfilling. As a result, CRT computer landfilling can pollute the ecosystem at highest level because of its weight as well as their toxic substance in CRT coating which affected to landfilling management.

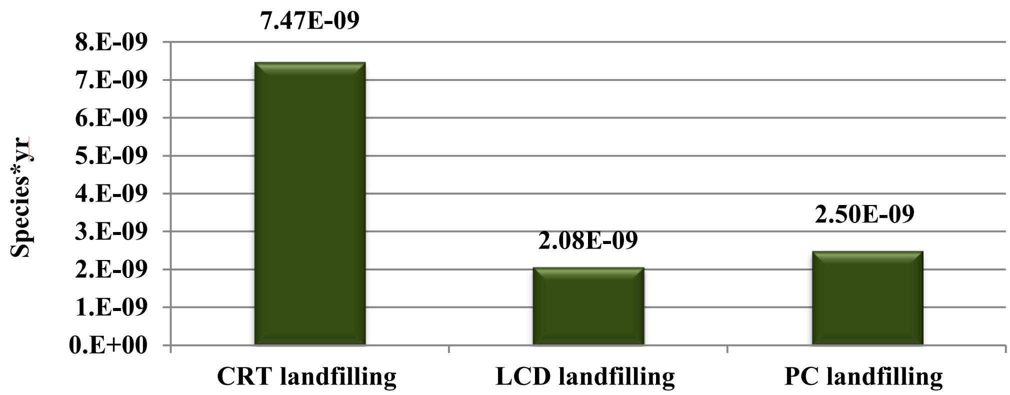


Figure 5-12: The Ecosystem impact comparison between desktop PC equipment contributing from landfilling approach

5.1.2.2 The Recycling approach burden contributing to ecosystem impact

a) The recycling of CRT computer screen

In opposite to the landfilling approach, the recycling scheme can avoid the entire impacts on human ecosystem due to the avoided primary material acquisition (Figure 5-13). The negative point of species*yr. is about -3.74E-08 which it reflected reduction of losing species during a year. These benefits came from different avoided burdens that overall results are described as shown below.

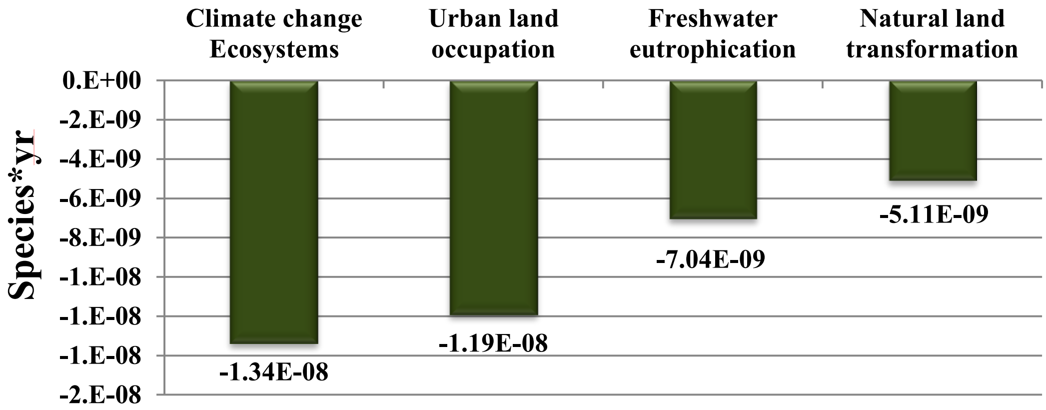


Figure 5-13: The avoided of ecosystem impact according to CRT computer screen recycling management

The highest avoided score came from avoided of the climate change ecosystem impact which contributed to the benefit about 28.81% (-1.34E-08 species*yr.) of entire ecosystem impact. The recycling can reduce this impact; especially, from recovered gold and palladium at higher level which existed in PWBA and following by other shredding fraction recycling including steel, aluminum and copper. When eliminated these entire primary production, climate change from burned in building machine, blasting furnaces pig iron production and other all would be avoided. Consequently, It was able to reduce almost 51.3% from carbon dioxide as well as 21.68% from methane emission.

For the urban land occupation impact, the CRT recycling bought about 25.66% (-1.19E-08 species*yr.) to the ecosystem benefits. As the result shown, this total benefits came from avoided the loss of biodiversity according to the elimination of the urban land occupation .When focused into recycling processes, this founded that can significantly avoided urban land occupation impact from palladium (5.5%) ,Gold (33.3%) and copper (57.7%). In facts, this contribution happened from avoided requiring of dumpsite area land use and mineral extraction site.

For the freshwater eutrophication, recycling can avoiding this impact and consequently reduce entirely ecosystem endpoint impact about 15.17% (-7.04E-09 species* yr.). As this result, the disposal of sulfidic tailing can be avoided from recycling and also brought about 97.57% to fresh water eutrophication. In other words, recycling scheme can deplete phosphate the eutrophication substance at highest level.

The disturbed of the natural land transformation impact was avoided through the recycling scheme .Typically, this category was provided 11.00% (-5.11E-09 species*yr) of ecosystem benefits. The sulfidic tailing from mining was the source of problem and can be reduced 49.7% from recycling of PWBA and 54% from copper fraction.

b) The recycling of LCD computer screen

In facts, this LCD screen recycling avoided this kind of impact affected to the ecosystem quality by preventing of loss about -3.47E-08 species*yr. The result of LCD recycling scheme showed the ecosystem benefits which distributed from main avoided four factor impacts as shown in the Figure 5-14.

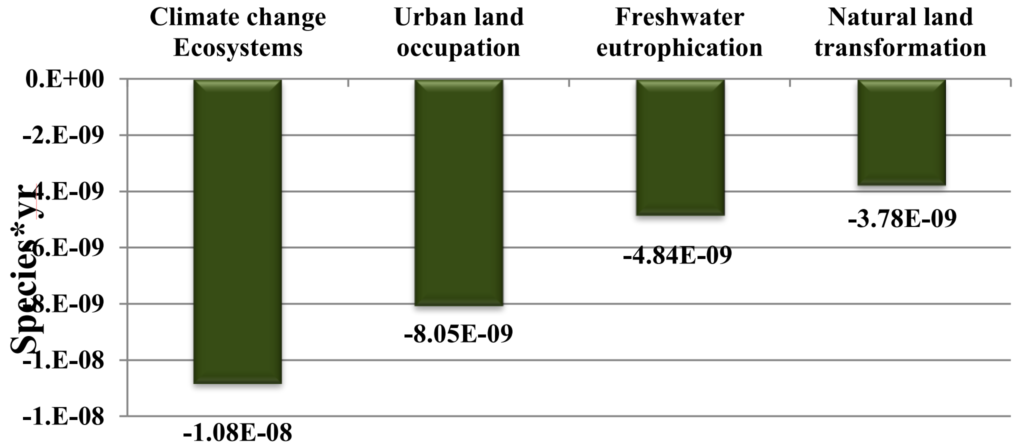


Figure 5-14: The avoided of ecosystem impact according to LCD computer screen recycling management

The avoided highest level of climate change impact according to the LCD recycling can avoid approximately 31.15% (-1.08E-08 species* yr.) of total endpoint ecosystem impact. The recycling of shredded fraction, especially from steel, can avoid 44.3% of climate change as well as 26 % from recycling of precious metals. 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. Therefore, it truly that substance causing the climate change were also avoided including 51.62% of carbon dioxide, 28.3% methane and other, respectively.

As the urban land occupation impact, the LCD recycling shown 23.22% (-8.05E-09species*yr.) of benefit through the avoiding of ecosystem impact. Typically, PWBA recycling can avoided 37.1% of this impact, following by 31.1% from LCD shredded fraction recycling, and 29.3 % from cable recycling. In other words, this management scheme can subtract dumpsite and mineral extraction site land use.

The freshwater eutrophication, LCD computer screen recycling can avoiding this impact and consequently reduce entirely ecosystem endpoint impact about 13.97% (-4.84E-09 species* yr.) The avoided of this impact mainly distributed from copper recycling (37.1%), and gold recycling from PWBA (29.7%). These is because can avoid impact from phosphate emission due to disposal of mining tailing.

The natural land transformation impact was avoided through the recycling scheme which particularly provided about 10.91% (-3.78E-09 species*yr.) of avoided ecosystem impact.

As this fact, recycling can totally prevent the impact from land transformation during the primary metal extraction including 38% from sulfidic tailing impact and other 27.8% from transforming the land to exploration and production site.

c) The recycling of Desktop PC

As the PC recycling scheme results, the overall are benefits for ecosystem as shown in the figure 5-15. The ecosystem endpoint category overall can subtract ecosystem impact about -3.26E-07 species*yr. The total benefits of ecosystem impact were aggregated from avoided of several midpoint; however, this consisted of four main impacts which were described below.

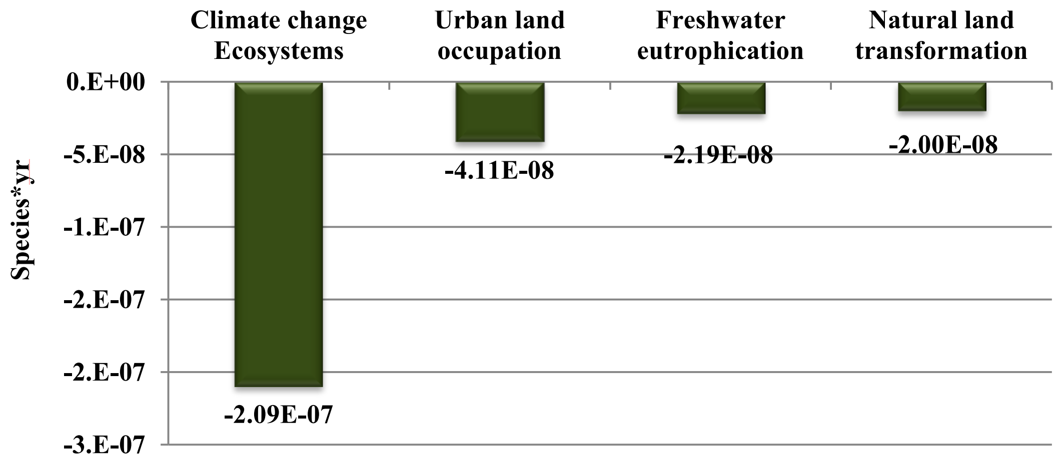


Figure 5-15: The avoided of ecosystem impact according to desktop PC recycling management

The results indicates that recycling scheme can subtract the climate change ecosystem about 64.19% (-2.09E-07 species*yr.). Interestingly, the half of total impact was avoided according to PWBA recovery which is especially in avoided the impact from gold and palladium production. Not at all, the recycling of shredded fraction (copper, aluminum, steel) can also avoid this climate change impact about 38.8%. For the processes and substances contribution, recycling can lead to the benefits according to the avoiding 85.6% of climate change from carbon dioxide and other which emitted from combustion processes.

For urban land occupation impact subtraction, recycling approach can avoid about 12.62% (-4.11E-08 species* yr.). This recycling approach generated the positive ecosystem quality which mainly came from recovering gold (41.9 %), copper (37.3%), silver (3.03%) and other via the PWBA, cable and shredded fraction recycling. For the processes contribution, the dumpsite occupational impact can be 59% avoided as well as 30.9% avoided the mineral extraction site occupational impact.

For the freshwater eutrophication, desktop PC recycling can avoid this impact and consequently reduce entirely ecosystem endpoint impact about 6.73% (-2.19E-08 species* yr.) The avoided of this impact mainly distributed from PWBA recycling (33.8 %), and copper recycling (65.2%). Overall, this benefits came from the avoided of phosphate emission causing due to disposal of mining tailing.

For the natural land transformation impact, the resulted showed that recycling can avoid 6.12% (-2.00E-08 species*yr.) of ecosystem impact. As this fact, recycling can totally prevent the impact from land transformation during the primary metal extraction including 33.27% from transforming the natural land to the well for exploration and production and 32.89% from disposal of sulfidic tailing.

According to the recycling of all desktop PC equipment, the ecosystem endpoint score was avoided which largely contributed from subtraction of climate change ecosystem impact. It can be seen that recycling of desktop computer can bright about the profits to ecosystem more than LCD and CRT screen (Figure 5-16). In facts, recycling of desktop PC would gather the ecosystem benefit more than CRT computer screen for 7.02 times and also 9.41 times than LCD computer screen. This is because the amount of recyclable material existing in desktop PC than other two equipment.

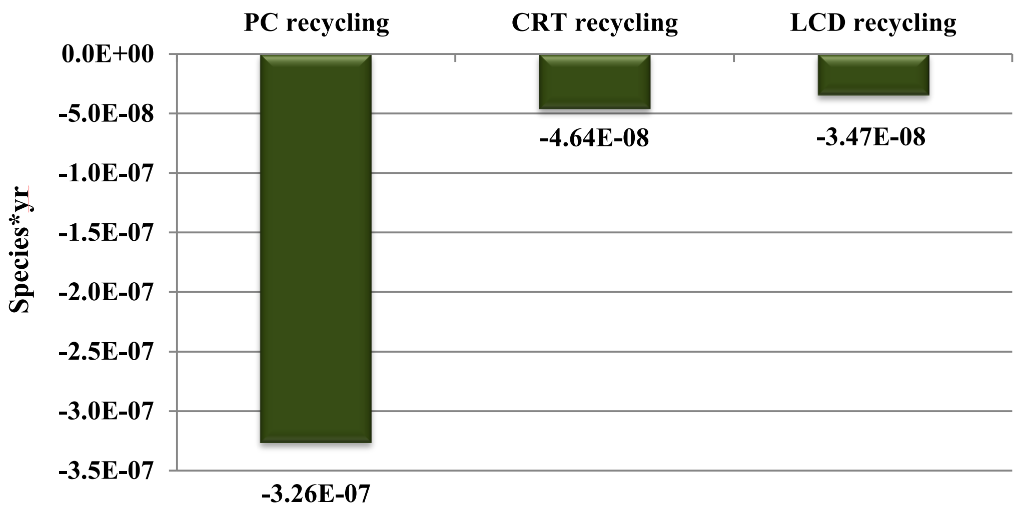


Figure 5-16: The Ecosystem impact comparison between desktop PC equipment contributing from recycling approach

5.1.3 The Resource depletion endpoint impact category

The resource depletion impact category was represented 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.

5.1.3.1 The landfilling burdens contributing to resource depletion impact

a) CRT computer screen landfilling

The result of this study indicate that CRT computer screen landfilling can impact to the resource which brought about to the surplus cost about 1.86E-02 $ (as shown on table 5-1) which came from the depletion fossil and metal resource.

Table 5-1: The contribution of resource depletion impact due to CRT screen landfilling

Resources depletion impact	CRT landfilling ($)	% contribution
Fossil depletion($)	1.61E-02	86.48%
Metal depletion ($)	2.51E-03	13.52%
Total($)	1.86E-02	100%

This can be seen that 86.48% (1.61E-02 $) of total resource depletion impact contributed from fossil depletion. When focusing on the waste type management, the result also deeply showed that fossil resources was utilized in CRT glass landfilling , following by CRT glass coating , nonferrous metal landfilling and etc. It truly that the landfilling approach is always lead to cause the fossil depletion which evaluating result founded that fossil depletion contribute from 75.93% of oil depletion and 11.69 % of natural gas depletion.

Moreover, the metal depletion from CRT computer screen landfilling also contributed to the overall resource depletion about 13.52% (2.51E-03 $). As this result, a large proportion of metal depletion impact came from landfilling of CRT toxic substance; CRT glass coating and CRT glass, respectively. When focusing on substances, these landfilling of each waste type can cause the metal depletion impact which contributed mainly from iron (80.22%) % and Nickel (11.55%).

b) LCD computer screen landfilling

During this operation of LCD landfilling scheme, it can affect to overall resource depletion through the marginal surplus cost of resource extraction about 6.51E-03 $ (as shown on table 5-2) which affected from two types of midpoint impacts including fossil depletion and metal depletion.

Table 5-2: The contribution of resource depletion impact due to LCD screen landfilling

Resources impact	LCD landfilling approach	% contribution
Fossil depletion($)	5.60E-03	86.00
Metal depletion ($)	9.12E-04	14.00
Total($)	6.51E-03	100.00

Firstly, the fossil depletion impact according to the LCD landfilling can provide 86 % (5.60E-03$) of overall resource impact. Importantly, the result revealed that LCD screen management can significantly lead to fossil resource depletion which mainly contributed from plastics, ferrous metal and toxic substances landfilling. Focusing on the resource contribution, the landfilling can lead to overall fossil depletion which came from: depletion of petroleum oil (77.57 %) , depletion of hard coal (11.31%) and depletion of hard coal (9.68%).

Apart from previous impact, Metal depletion also contributed to endpoint resource depletion impact about 14%. The waste components from LCD landfilling that were the main contributor to this metal impact was fallen to the landfilling of LCD toxic substances, plastics, ferrous metal and inorganic substances. However, there are necessary for every landfilling to include metal resource for driving of operation system. To support this facts, the evaluating result founded that metal depletion contribute from 79.25% of iron depletion, 12.07% Nickel depletion and 3 % from chromium depletion.

c) Desktop PC landfilling

The PC landfilling can contribute to the resource depletion impact which quantitative results by distributed the surplus cost about 1.03E-02 $ which came from fossil and metal depletion (table 5-3).

Table 5-3: The contribution of resource depletion impact due to desktop PC landfilling

Resources impact	PC landfilling approach	% contribution
Fossil depletion($)	9.19E-03	89.68%
Metal depletion ($)	1.06E-03	10.32%
Total($)	1.03E-02	100.00%

As shown on the table, the fossil depletion can contribute about 89.68% (9.19E-03 $) of overall resource impact. Interestingly, some of waste type management can mostly affect to the fossil resource depletion including ferrous-metal, plastics and non-ferrous. When focusing on the resource contribution, the landfilling can lead to overall fossil depletion which came from: 81.9% depletion of petroleum oil, 9.7% depletion of natural gas and 8% depletion of hard coal.

Moreover, the metal depletion also contributed the impact to overall resource depletion category about 10.32 % (1.06E-03 $) of overall resource impact. As this result, Majority of metal depletion impact came from landfilling scheme of ferrous-metal, non-ferrous and plastics part. In particularly, during this operation of landfilling scheme, it can affect to raw metal resource depletion which higher in iron depletion (74.7%), nickel depletion (12.9%) and etc.

Overall, CRT computer screen landfilling possibly lead to highest resource depletion (figure 5-17), this may be explained by the fact that the components in CRT computer screen need the complicated processes in landfilling approach in order to reach the environmental profits. Consequently, this affected to requiring more resource in operation and ending with largely resource consumption. This reason is also the same for explained why desktop PC contributed higher impact than LCD computer screen landfilling. However, all of three equipment landfilling showed the same tend that fossil depletion impact contributed higher impact score than metal depletion impact.

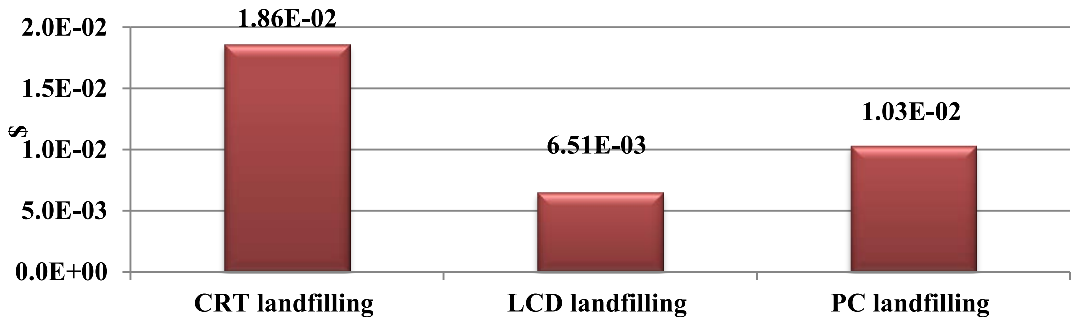


Figure 5-17: The resource depletion impact comparison between desktop PC equipment contributing from landfilling approach

5.1.3.2 The Recycling approach burden contributing to resource depletion impact

a) The recycling of CRT computer screen

This study founded that recycling can avoid the resource depletion impact showing as the subtraction of the resource extraction surplus cost about -4.02E+00 ($) .Overall, there are contributed from prevention of losing two type of resources as shown in the table 5-4 below.

Table 5-4: The contribution of resource depletion impact due to CRT screen recycling

Avoided Resources impact	CRT recycling approach	% contribution
Fossil depletion($)	-3.51E-01	91.25%
Metal depletion ($)	-3.67E+00	8.75%
Total($)	-4.02E+00	100.00%

The recycling scheme can subtract the total surplus cost; especially, from fossil depletion which it can subtract the 91.25% of total resource depletion impact. Moreover, this total benefits from recovery CRT scrap fraction were incorporated highest in steel recycling as the main promoter 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 (34.60%), petroleum oil (27.18%) and natural gas (26.52%). In other words, these also consequently avoided process of hard coal mining, petroleum oil production (off- and on- shore), and natural gas production

Aside from fossil depletion impact, recycling can bring the profits to metal availability by avoided metal extraction surplus cost about -3.51E-01 $ and totally subtracted 8.75% of overall resource depletion impact. This studied analysis shown that 63.6% of total impact subtraction came from copper recycling as highest level. In facts, this can avoid surplus cost of the chain process of primary copper production in future including copper beneficiation, SX/EW process. Not at all, other recycling processes also brought benefits according to precious metal recycling from PWBA (avoided 15.1 % depletion of gold and palladium) and steel recycling (8.19%).

b) The recycling of LCD computer screen

A prevention of resource depletion due to LCD recycling identified in this analysis. LCD computer screen recycling can avoid the surplus cost about 3.22E+00 $ in order to supply the future resource availability. This avoided score were aggregated from two types of resource impact as shown on the table 5-5 below.

Table 5-5: The contribution of resource depletion impact due to LCD screen recycling

Avoided Resources impact	LCD recycling approach	% contribution
Fossil depletion($)	-3.21E-01	90.02%
Metal depletion ($)	-2.90E+00	9.98%
Total($)	-3.22E+00	100.00%

The results, as shown on the table, revealed that recycling of LCD computer screen can avoid about 91.25% (-3.21E-01 $) of total resources depletion impact .When focusing on the Scarp recycling , it apparently shown that recovered copper fraction can bring the large proportion of benefits by subtracting the 67.2 % of fossil depletion. Not at all, there was also highly avoided fossil depletion impact about 48.9% from steel recycling and 27.6 % from precious metal recycling and. In this context, the energy extraction impact using in the primary production would be spontaneously avoided which consisting of hard coal (46.62%), petroleum oil (23.52%) and natural gas (21.65%). This also helpful to subtracted these fossil resource burdens.

For metal resource depletion impact, the recycling scheme can subtract this kind of impact about -2.90E+00 $ or approximately 9.98% of total impact. When scoping deeply into this impact, the recycling of LCD screen scrap could be subtracted about 72.2 % of total impact from copper recycling, 9.37% from precious metal group recycling (especially from gold) and 18.7 % from steel recycling. This recycling was dominated all the primary metal production burdens.

c) The recycling of desktop PC

Desktop PC recycling showed this avoided resource depletion impact through negative surplus cost totally -1.22E+01 $. As same as previous two devices, desktop PC also investigated from two types of resource impact as shown on the table 5-6 below.

Table 5-6: The contribution of resource depletion impact due to desktop PC recycling

Avoided Resources impact	PC recycling approach	% contribution
Fossil depletion($)	-1.44E+00	11.87%
Metal depletion ($)	-1.07E+01	88.13%
Total($)	-1.22E+01	100.00%

The subtraction of fossil depletion impact consequently provided 11.87% to total avoided resource depletion impact. The most benefits came from aluminum scrap recycling which can avoided about 25.8 % of entire fossil depletion impact. Not at all, there are also contributed 23.1 % from gold, 22.1% from palladium and 18.1% from 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 (34.1%), hard coal (28.73%) and natural gas (24.97%) and other.

Apart from the subtraction fossil depletion impact, The PC recycling also distributed the profits to metal resources sustainability by avoid the metal extraction surplus cost about -1.07E+01$. In other words, this can largely subtract 88.13% of total resource depletion impact. Interestingly, the analyzed result shown that 71.1% of total impact subtraction came from copper recycling which can avoid chain process of primary copper production .Following by, gold (about 18.6%), and steel (6.44%) respectively.

As shown on figure 5-18, the findings of this study suggest that PC recycling scheme can definitely avoided the resource depletion impact, following by LCD recycling and CRT recycling, respectively. As a result, It can describe that one unit of PC produced large amount of secondary precious metal than other device. Therefore, this is also the reason that why PC recycling has higher possibility to avoid resource depletion.

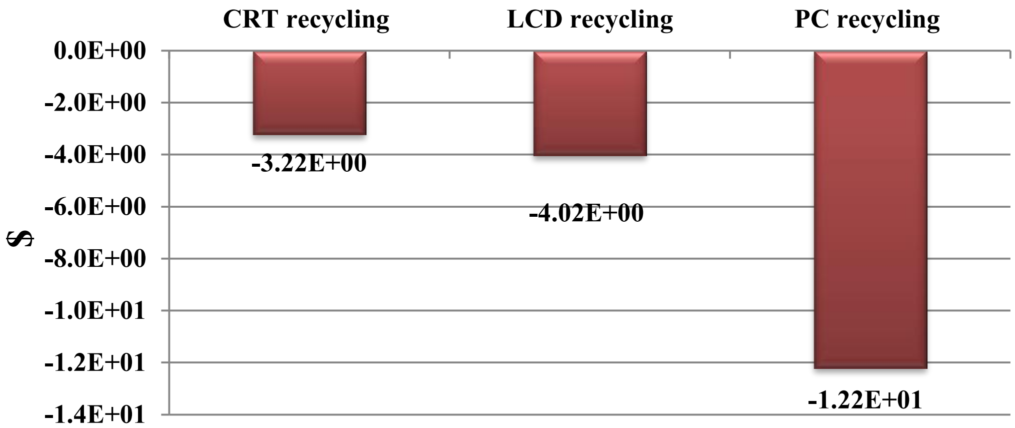


Figure 5-18: The resource depletion impact comparison between desktop PC equipment contributing from recycling approach

5.1.4 Environmental Single Score Comparison

Desktop PC devices cause different overall environmental impacts throughout the end of life stage. To sum up the overall 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 contributes burdens to the environment which opposite to the negative value of single score, it showed as avoided environmental burdens.

5.1.4.1 CRT Computer screen landfilling VS recycling scheme

As shown on (table 5-7), the characterized single score consists of three main endpoint categories. Overall, the CRT computer screen landfilling generated total environmental impact about 0.40 pt. of single score point, whereas the recycling approach can reduce about 10.98 pt. as shown in negative environmental impact. Two approaches have greatly different approximately 11.38 pt. Recycling would be better than landfilling about 28.53 fold of single score.

Table 5-7: The environmental single score contribution of CRT computer screen landfilling VS recycling approach impact

Damage category	CRT landfilling	CRT recycling
Human Health (pt.)	**3.72E-01**	**-6.04E+00**
Ecosystems (pt.)	**3.26E-03**	**-2.02E-02**
Resources (pt.)	**2.28E-02**	**-4.92E+00**
Total (pt.)	**3.98E-01**	**-1.10E+01**

This results also similar to the study by Parsons (2007). There studied also compared the endpoint score between landfilling and recycling environmental impact of copper yoke and all glass components in CRT screen. The results supported this study due to the enormous number of negative values of recycling of CRT screen.

The network diagrams of environmental impacts from two approaches show in Figure 5-19. CRT glass coating landfilling contributes about 89.20 % of total single score. In fact, the CRT glass coating substances is abundant with toxic substances especially in lead and phosphor. It properly requires detoxified processes before dumping into landfill. Therefore, these activities can intensify environmental burdens in the landfill. In other point of view, disposal of CRT tube contributed about 95.51% of total landfilling single score when focusing on subparts of CRT (Figure 5-20). Therefore, it can be concluded that CRT tube components generate significant environmental impact.

When recycling is implemented, the negative single score showed the advantage of CRT computer recycling. Almost 69.7% of avoided environmental score came from recycling CRT shredded fraction, and 32.9% from recycling of PWBA assembly board. Focusing on the avoided process, recycling method help to avoid impact from process of disposal of mining tailing (contributed 36.85% of total negative single score) and primary copper production (46.49 % of total negative single score).

This study provides the results which corroborate some parts of previous work in this field by Noon et. al (2011). The total reducing from recycling scheme is possibly from the avoided of main sources of CRT production. It was the clear dominant processes in avoided approximately 75% global of total warming potential, 96% total energy consumption, 76% of total fossil fuel consumption, and 50% total select air pollutants, respectively.

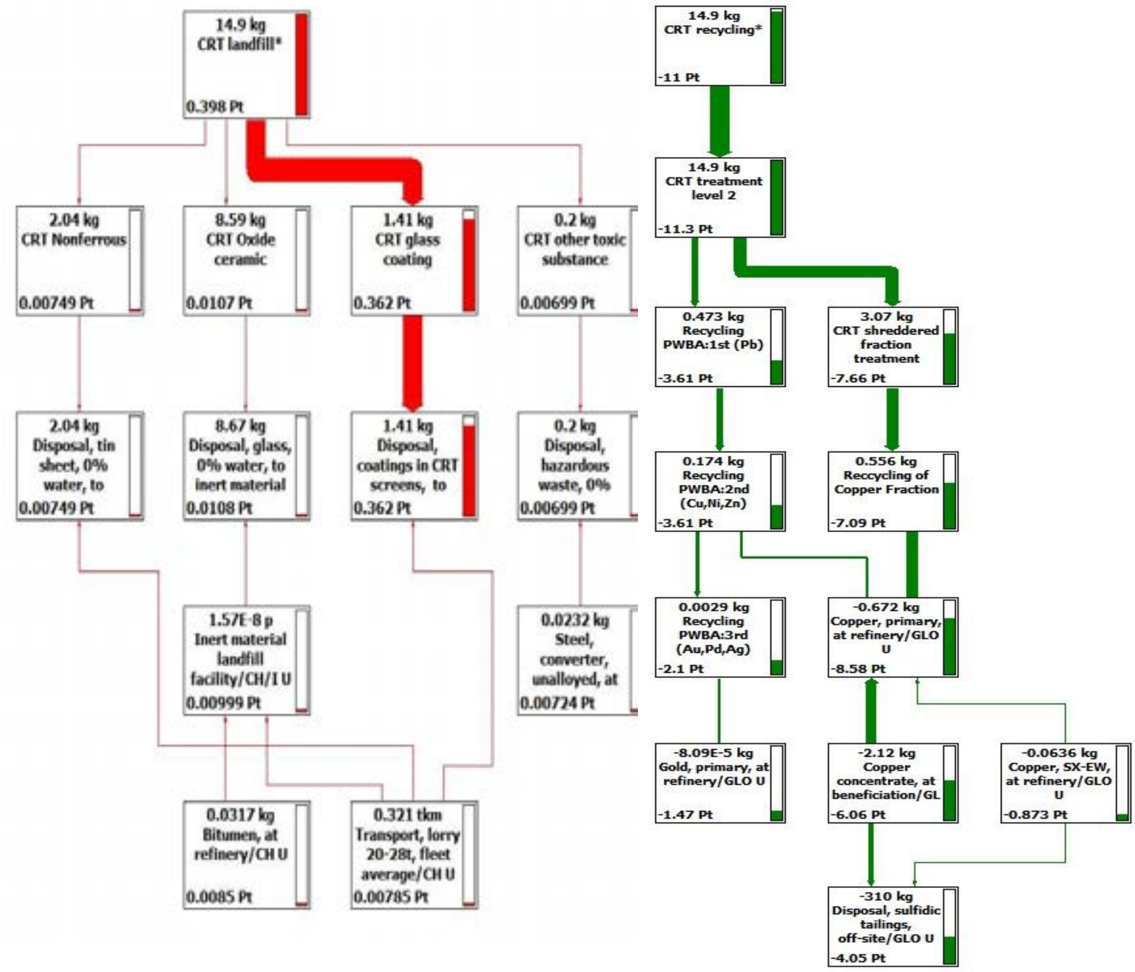


Figure 5-19: The environmental single score process network of CRT computer screen and recycling

(Left: Landfilling environmental burden, Right: Avoided environmental impact from recycling)

Note: The minor processes or some few impact contributor were not included in this figure because their impact indicator have a few value smaller than the cut-off level set in SimaPro 7.3.3. Nevertheless, these are already accounted for in overall impact calculation.

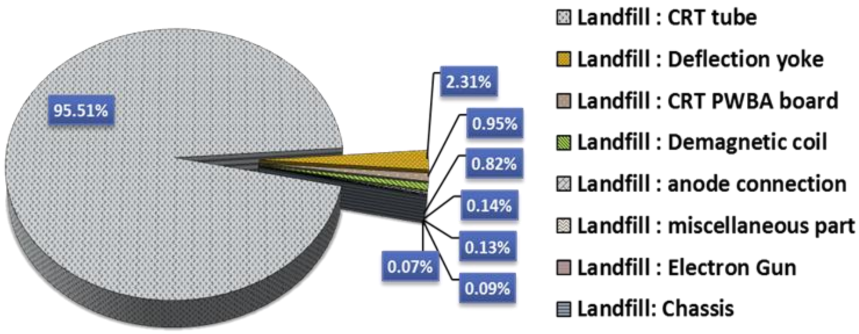


Figure 5-20: The environmental impact single score characterization result from main parts of CRT computer screen

5.1.4.2 LCD Computer Screen Landfilling VS Recycling Scheme

In case of LCD computer screen (as shown on table 5-8), three main endpoints are weighted into one environmental single score. The LCD landfilling generated small environmental impact which contributed about 0.03 pt. In the opposite to the recycling scheme, it significantly lessen impacts about -8.36 pt. The different impact score between two approaches is -8.39 pt. If recycling, this study showed excessive environmental benefits that can decrease about 289.76 fold as compared to landfilling single score.

Table 5-8: The environmental single score contribution of LCD computer screen landfilling VS recycling approach impact

Damage category	LCD landfilling	LCD recycling
Human Health (pt.)	2.01E-02	-4.41E+00
Ecosystems (pt.)	9.05E-04	-1.51E-02
Resources (pt.)	7.97E-03	-3.94E+00
Total (pt.)	2.90E-02	-8.36E+00

The single score contribution is showed on the network diagram in figure 5-21. These findings suggest that with landfilling approach the LCD screens plastic substances create the most impact about 72.6% of total single score (25.10% from ABS plastics and 12.77 % from other plastic). Moreover, the second and third rank of environmental burdens is ferrous metal landfilling (11.2%) and other toxic substances management (8.56%). In contrast, this LCD result is consistent with single score impact of each LCD subpart (figure 5-22). For instance; the backlight subpart can contribute at the first rank of single score comparing with other parts because it comprised of large amount of plastics. The second rank is base/stand subpart. This is probably because it contains large amount of ferrous metal substance but few amount of plastics.

For the environmental avoided impact according to the recycling scheme, the recycling of LCD shredded fraction can contribute of 39% of total avoided single score and following by 35.2 % from cable recycling. For avoided processes contribution, The avoided primary metal production can greatly reduce adverse impact from disposal of mining tailing (contributed 33.05 % of total negative single score) and primary copper production (45.26 % of total negative single score).

As mentioned in the previous study by Noon et al. (2011), there are several possible explanations for this result. When considering the recycling scenario, the avoidance of LCD were the clear dominant processes which can subtract 100%, global warming potential, 99%, total energy consumption, total 99%, fossil fuel consumption, and 98% total select air pollutants at and for LCD monitor.

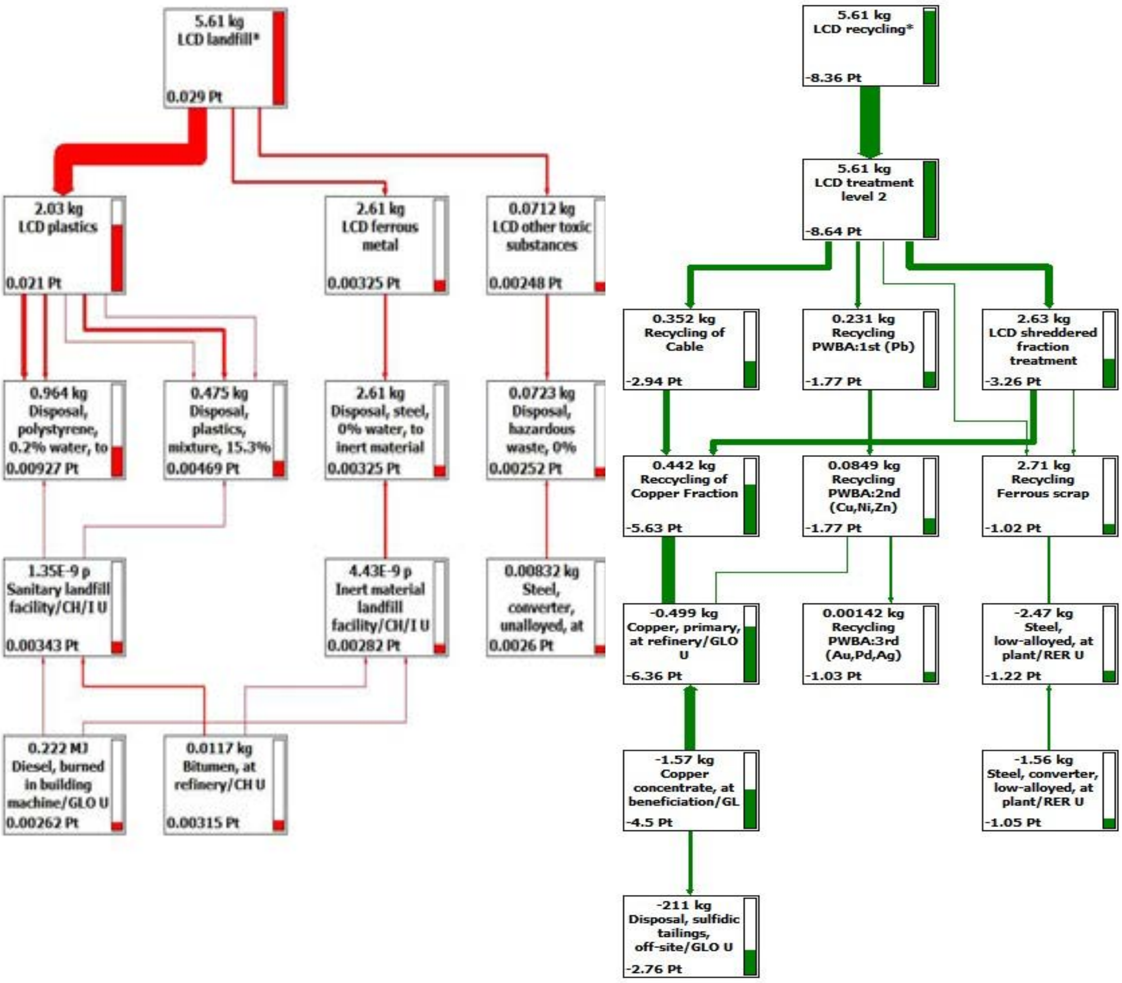


Figure 5-21: The environmental single score process network of LCD computer screen

(Left: Landfilling environmental burden, Right: Avoided environmental impact from recycling)

Note: The minor processes or some few impact contributor were not included in this figure because their impact indicator have a few value smaller than the cut-off level set in SimaPro 7.3.3. Nevertheless, these are already accounted for in overall impact calculation.

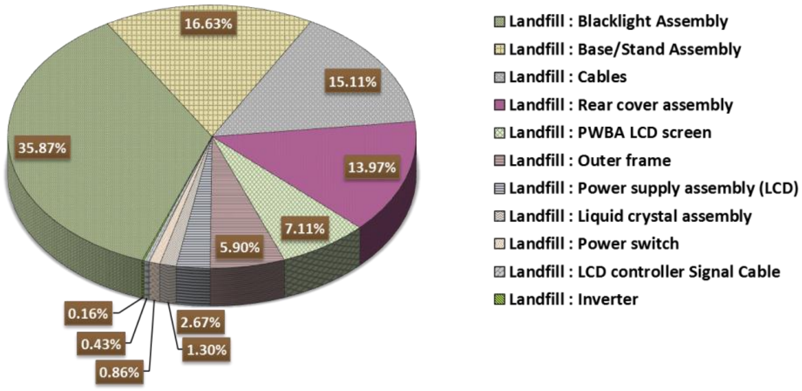


Figure 5-22: The environmental impact single score characterization result from entire parts of LCD computer screen

5.1.4.3 Desktop PC Computer landfilling VS recycling scheme

The table 5-9 revealed that landfilling approach possibly contributes the environmental impact about 0.04 pt. However, there indicated that negative single score from recycling generated net benefits for environment about -34.26 pt. As results, when emphasized the score as comparison unit, this result showed that the different between two approaches is about -34.26 pt. This negative means that recycling possibly to overcome the environmental benefits more than that by landfilling about 769.37 folds.

Table 5-9: The single score results comparison between PC Landfilling and recycling management approach

Damage category	PC landfilling	PC recycling
Human Health	**3.09E-02**	**-1.92E+01**
Ecosystems	**1.09E-03**	**-1.42E-01**
Resources	**1.25E-02**	**-1.49E+01**
Total	**4.45E-02**	**-3.42E+01**

The environmental burden landfilling burdens was shown in the figure 5-23. As a result, it apparently explained that each of desktop PC components also provided the different specific burdens. Almost 61.3% single score was exposed from plastics (especially in PE, Epoxy, and PVC), 18.1 % from nonferrous metal and 14.8% of ferrous metal, respectively. When look into specific desktop part (Figure 5-24), the highest environmental burdens is from the PC cabinet (29.90 % of the total single score) due to significant burden contribution from ferrous metal and plastics landfilling. Moreover, The other significant single score contributor are 26.98% from power supply, 10.21% from ATX-motherboard, and 10.16% from cooling body for processor and 10% from CD/DVD rom. As this matter, the total single score burden were mainly relied on the amount plastic and ferrous metal as usual. Some of desktop PC parts contributed around 10% of overall single score (such as HDD, FDD, RAM, GPU card) because there are less amounts of plastic substances.

Desktop PC recycling can contribute the negative environmental single score about -34.22 pt as shown in Figure 5-24. This evaluation found significant avoiding impact from recycling of PWBA (45.9%), PC shredded fraction (27.7%) and wire Cable (25.3%). Moreover, when scope into the processes contribution, recycling can reduce the impact from disposal of sulfidic tailing (36.57%), 1st copper production (40.37) but surprisingly low in precious metal extraction such as primary palladium (1.54%) and gold respectively (1.36%).

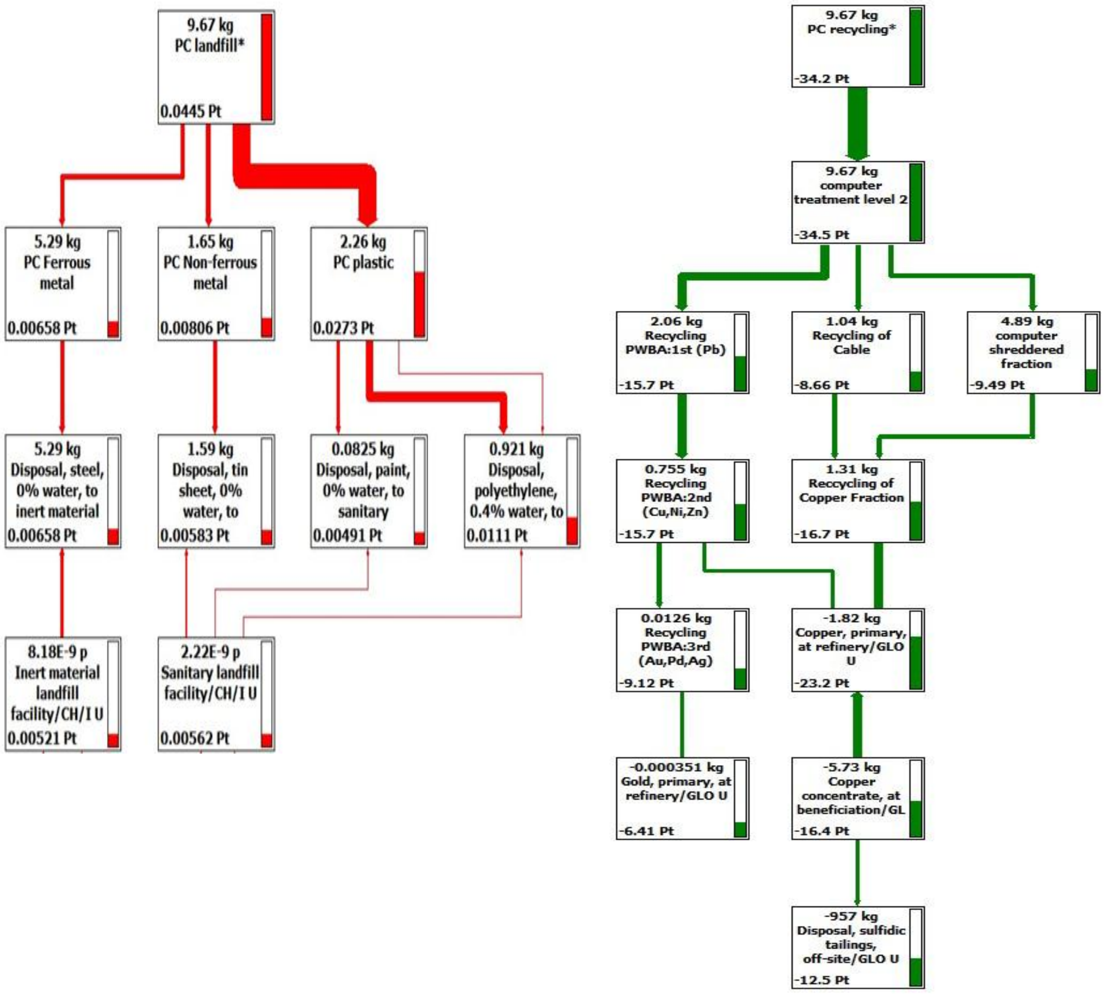


Figure 5-23: The environmental single score process network of desktop computer
(Left: Landfilling environmental burden, Right: Avoided environmental impact from recycling)

Note: The minor processes or some few impact contributor did not included in this figure because their impact indicator have insignificant value which is smaller than the cut-off level set in SimaPro 7.3.3. Nevertheless, these are already accounted for in the impact calculation.

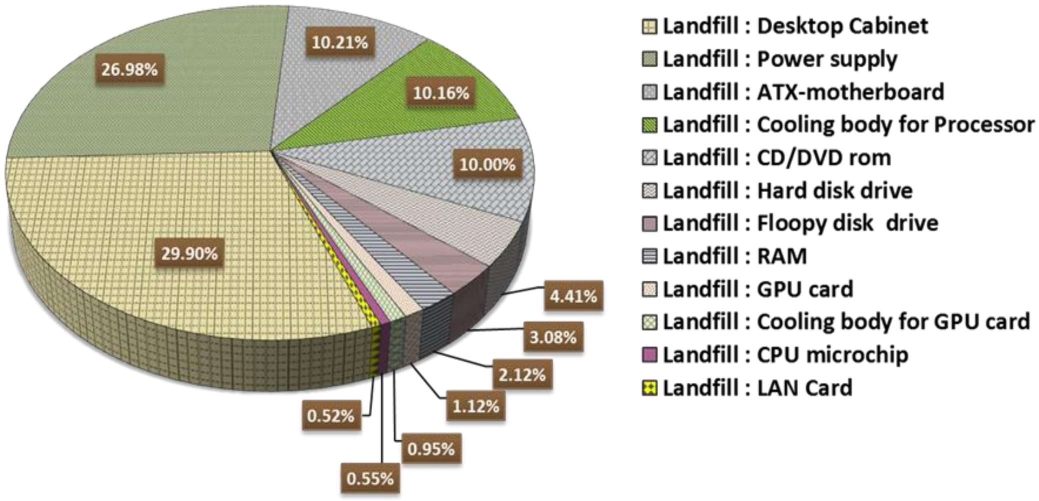


Figure 5-24: The environmental impact single score characterization result from entire parts desktop computer

The key result finding from the analysis is that all devices showed the high net advantage of environmental impact. The assumption of the same inherent properties in recovered metal can completely subtract the scoping primary metal acquisition steps, which require high level of energy and material input as well as release pollution emission from mining process. The present findings seem to be consistent with other research which found that negative impact coming from avoided virgin material extraction which requires energy and material input as high level as previous desktop computer equipment LCA studies by Choi et al. (2006) and Duan et al. (2009).

5.2 The End of life scenario analysis: projection of the potential environmental impact according to 2012-2021

The single scores were applied for analyzing possible future projections. The way of projection occurred based on three scenarios which varied in the recycling and landfilling collection rate including: scenario 1 (100% landfilling dumping rate), scenario 2 (95% landfilling rate, 5%) and scenario 3 (80% landfilling rate, 20 %). Overall, the comparison between scenarios was done in each of equipment and these results were described below.

5.2.1 The end of life of CRT computer screen scenario

The CRT computer screen evaluating results showed that Sceanario 1 has the highest environmental impact,while scenario 2 and scenario 3 showed negative environmental single score which both implemented recycling scheme (Figure 5-25). The baseline scenario or scenario 1 (100 % landfilling dumping rate) was compared to other alternative scenarios. As the results, scenario 2 single score contributed environmental benefit higher than that of Scenario 1 about 1.10E+06 pt or 1.44 –fold. As well as scenario 3, this also consequently contributed higher level of environmental advanrtage than scenario 1 about 4.40E+06 pt or lessen about 5.73-fold of scenario 1 impact. Scenario 3 contributed the highest benefits compared to other scenarios because implemented the high recycling collection rate.

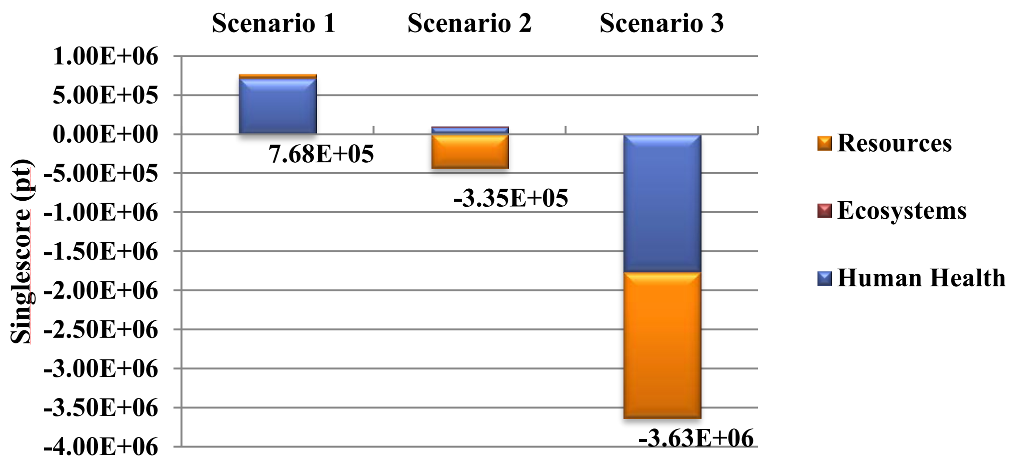


Figure 5-25: The projection of end of life of CRT computer screen impact

5.2.2 The end of life of LCD computer screen scenario

Evaluation of LCD computer screen scenario results as shown in figure 5-26. Scenario 3 created the highest benefits for environmental potentials when comparing to 100% landfilling (baseline scenario). Scenario 3 reduce environmental impact compared to baseline scenario about -3.62E+06 pt or decrease 14.49-fold . Meanwhile, scenario 2 also reduced around 1.45E+07 pt or 57.95-fold compared to scenario 1 approach.

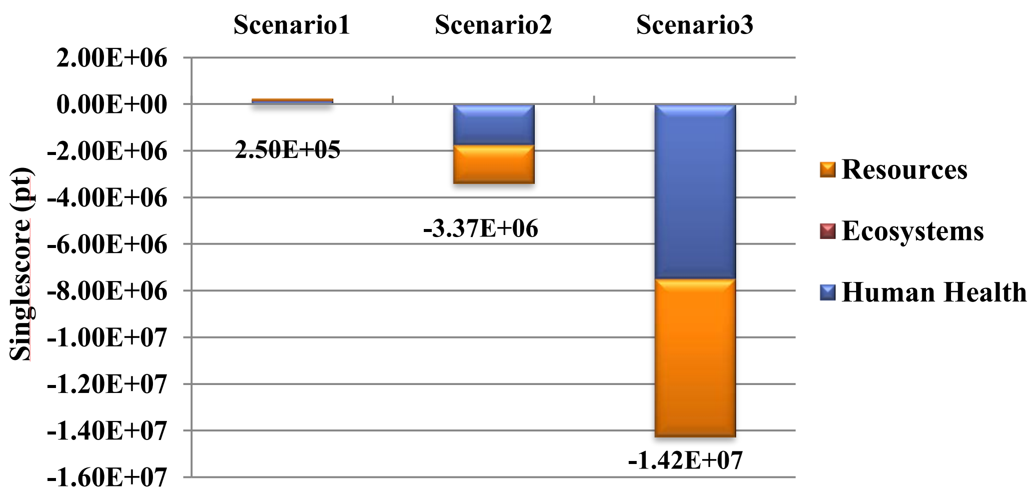


Figure 5-26: The projection of end of life of LCD computer screen impact

5.2.3 The end of life of desktop computer screen scenario

As the results showed in Figure 5-27, scenario 3 contributes the highest environmental benefits comparing to other management scenario. Scenario 3 can contribute environmental benefit higher than baseline scenario about 7.24E+07 pt. or 154.07 fold. Scenario 2 reduces about 1.81E+07 as compared to scenario 1 or about 38.52-fold.

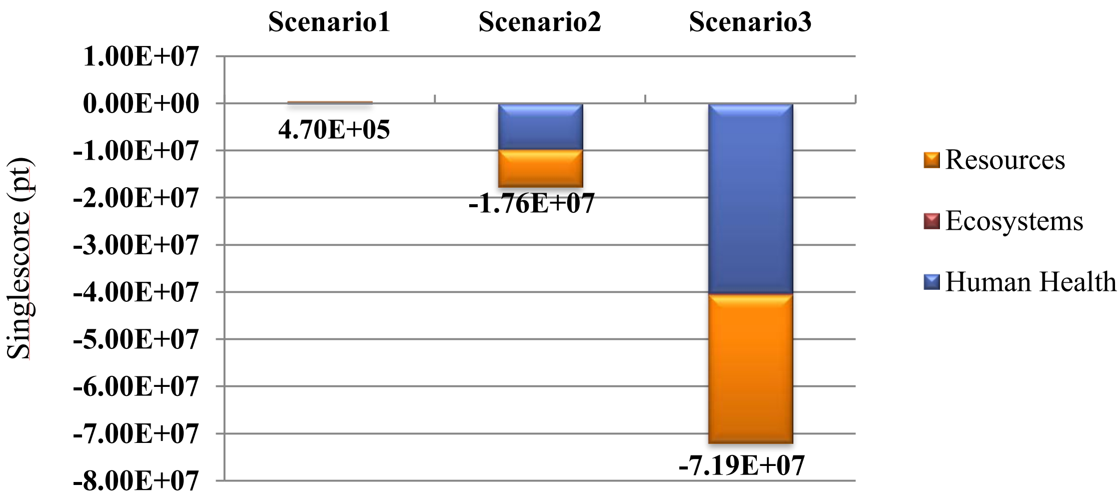


Figure 5-27: The projection of end of life of desktop PC impact

In this scenario analysis, there have a similar trend in the avoided impact of recycling system. Interestingly, using the LCA results in comparison the disposal stage, there found a linear relationship between environmental impacts and the recycling rate which similarly to previous study in end of life of computer by Choi et al. (2006) . Therefore, LCA perspective apparently showed recycling scheme is possible to improve the environmental performance of personal computers.

5.3 The sensitivity analysis

This part was done to evaluate the degree of data uncertainty. The error during mass measurement step assumed that possibly effect to the magnitude of impact. Consequently, the one-way sensitivity analysis was used by varying only one parameter, while other parameter is constant in order to show the sensitivity of this parameter to overall impact. Therefore, this study investigated consequence to the level of single score according to the 5% to 10% of weight variation.

The results of each scheme were explained as shown in Figure 5-28 and 5-29. The bar graph is described as a certain environmental burdens; while vertical error bar showed maximum and minimum possible impact which different in each of item. As showed on the figure 5-28, in case of 5 % mass weight error occurred, this effected to environmental single score by increasing and decreasing in all of equipment burden. The possible single score changing rate in maximum side is about 5.07 % and 4.91 % in minimum side. Apart from this, in case of 10% error in mass weighting, this effected to the result in maximum side about 9.90% and minimal side about 10.02%.

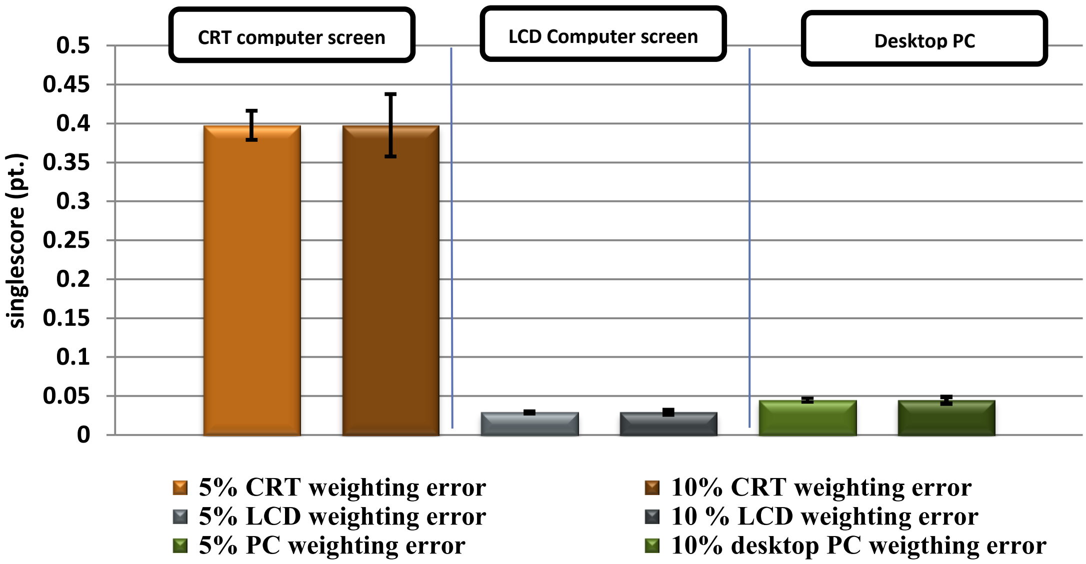


Figure 5-28: The Sensitivity analysis of landfilling scheme

For the recycling scheme, the 5 % and 10% mass variation rate also affected to the singe score as shown in the figure 5-30 in both of additional minimum and maximum score range. Particularly, this change is also contributed the same rate as landfilling scheme. Entirely, this sensitivity evaluating showed that single score point could be constantly changed correlating with the level of mass error. The result is not quite sensitive to measurement error. This is important to put together in life cycle inventory in order to understand cumulative effects from this type of parameter.

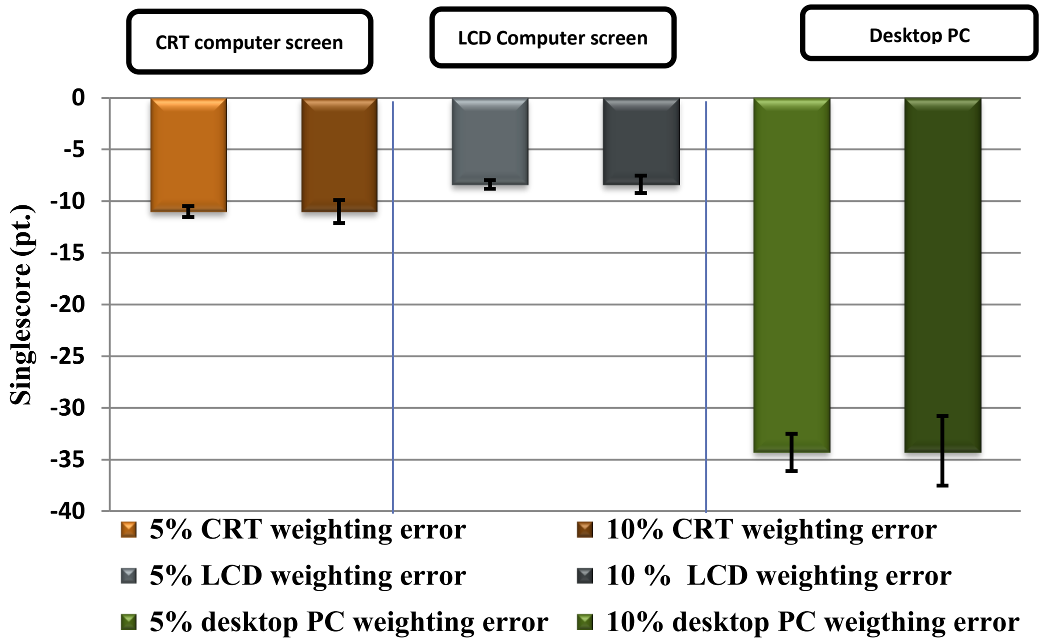


Figure 5-29: The Sensitivity analysis of recycling scheme

CHAPTER VI

Public Opinion and Recommendation for EoL Desktop PC Management

To develop recommendations for improving desktop PC waste management scheme in Thailand, this study also conducted public surveys to investigate existing situations of PC wastes and opinions about preferable solutions from the public. Accordingly, the recommendation plans also suggested including comprehensive issues relevant to desktop PC 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 PC 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 501questionnairs participants through online surveying (141 persons) and paper surveying (360 persons). The result analysis can be described as following:

6.1.1 Background of questionnaires' participants

The information about the participants acquired includes gender, ages, individual highest education level, occupations, salary income and old PC equipment in possession. The results were summarized as shown in Figure 6-1 to Figure 6-4. The proportion of female (53%) and male (47%) who answered the questionnaire are within a closed range. Ages of participants are mainly during 20-30 year olds (details in Figure 6-1). Majority of participants graduated with bachelor degree about 78 % (Figure 6-2). Occupation of the participants mainly is student because the surveys have done mainly in university areas but there were also others respondents with different occupation as well (Figure 6-3). The participants' incomes are largely less than <10,000 baht, Figure 6-4.

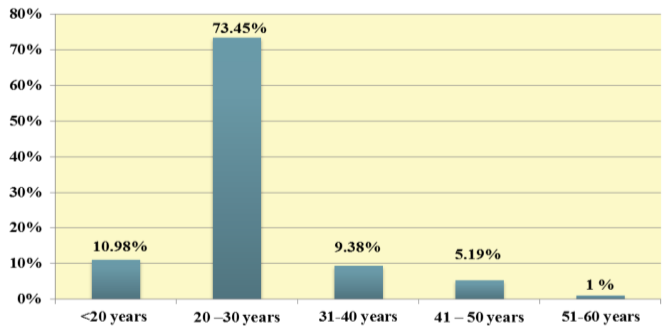


Figure 6-1: Ages of participants in this survey

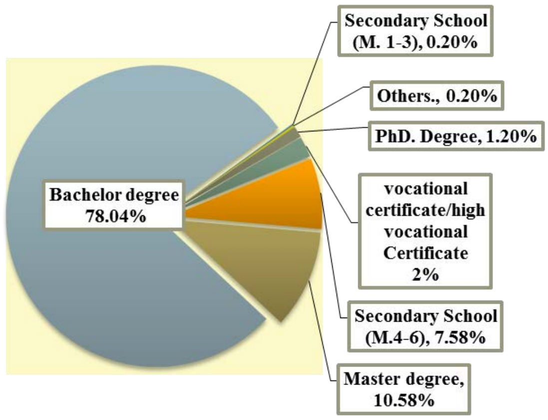


Figure 6-2: Individuals education background in the survey

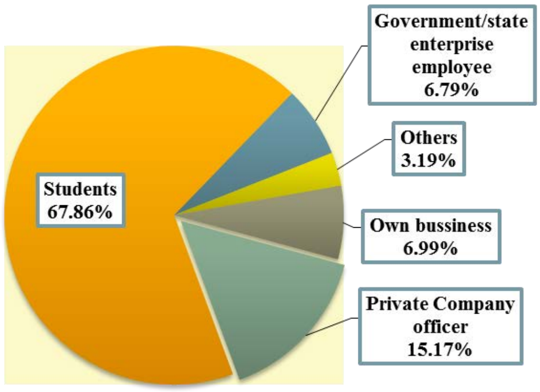


Figure 6-3: Occupation of participants in the survey

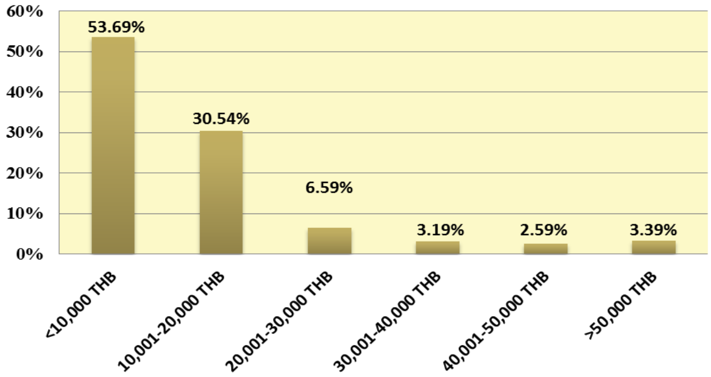


Figure 6-4: Salary of participants in the survey

6.1.2 Current PC waste management practice

This surveying part firstly asked about the possession of the desktop PC equipment and how the discarded desktop PC equipment is managed. As the results, 58.08% of all participants have PC equipment in their possession. Among people who own old desktop PC control units, 90% having old CRT computer screen and 63% having LCD computer screen.

As shown in Figure 6.5-6.7 about management practice for discarded PC equipment, there are three main options which most participants did in practice including (1) ***keeping at home*** (52 % for desktop PC contribution, 48.67% for CRT and 52.97% for LCD computer screen, respectively) as the first priority, (2) ***giving or donation to others*** (19 % for desktop PC contribution, 21.67 % for CRT, and 19.46% for LCD computer screen, respectively) and followed by (3) ***selling to tri-cycler waste buyer*** (Sa-leang) as the third priority (12 % for desktop PC contribution, 14.07% for CRT and 10% for LCD computer screen, respectively)

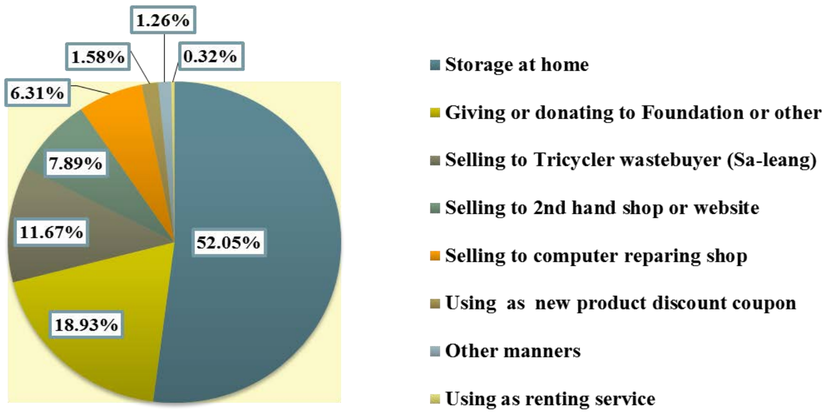


Figure 6-5: The current managing approach of discarded desktop PC

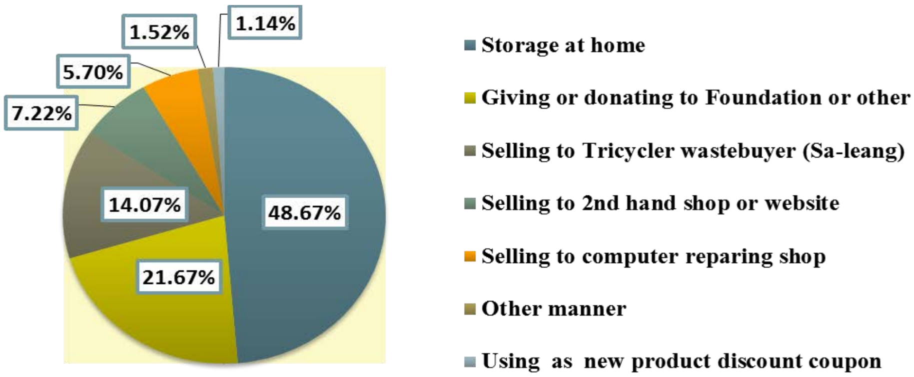


Figure 6-6: The current managing approach of discarded CRT computer screen

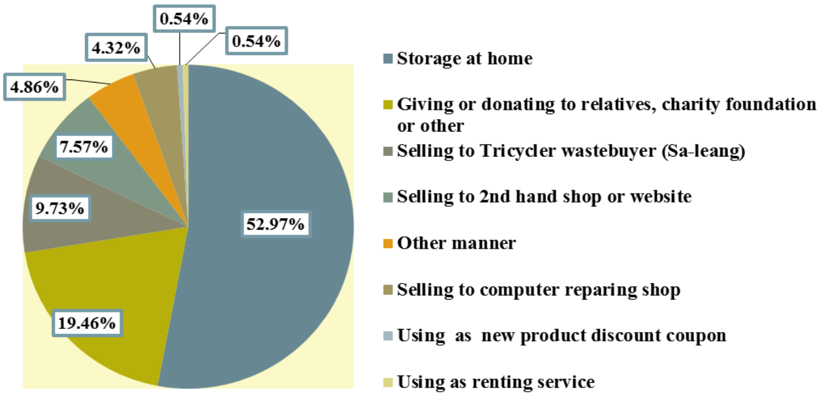


Figure 6-7: The current managing approach of discarded LCD computer screen

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

Response for considering PC equipment reached end of life stage was analysis as shown in Figure 6-8. A majority of participants (30.75%) indicated the reason that computer breakdown is mostly related to define end of life of computer. Similarly, the replacing the old equipment for using new and latest model equipment, people also defined as most relevant reason for reaching end of use phase about 31.94 %. For other reasons, low speed of processing in computer can affect productivity also considered as the end of life phase, which contributed about 33.52% of higher related level. Apart from this, the reason that computer cannot work with higher technology equipment were preferred reason to end the use of computer contributed 31.72 % moderate relevant reason.

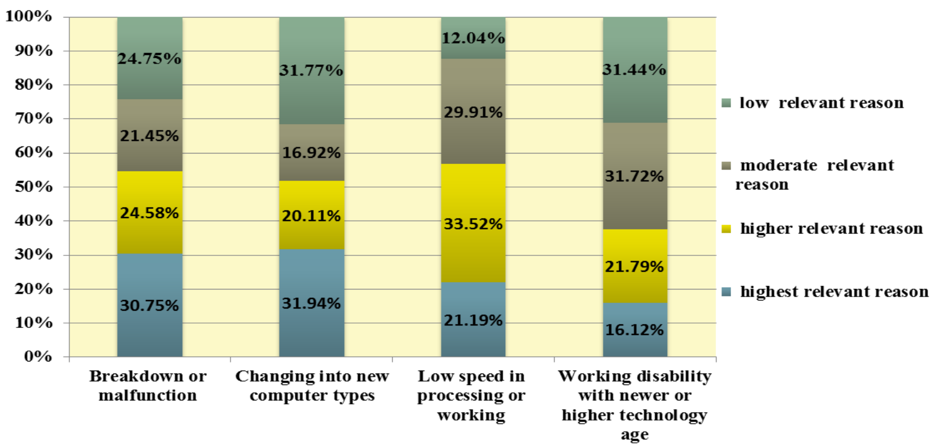


Figure 6-8: The preference end of life phase definition in desktop PC

In order to provide information for supporting the main reason of discarded desktop computer, the most related reason according to the survey were analyzed (in Figure 6-9).

Almost thirty two percent (32%) of participants replacing their old equipment by using new model and equipment instead is the main reason to discard the computer. This can be concluded that people tend to discard computers earlier than expected design and physical lifespan. Moreover, the reason that computer equipment breakdown also contributed as second rank (30.75%) for discarding computer screen equipment because it is not worth to fix the broken model.

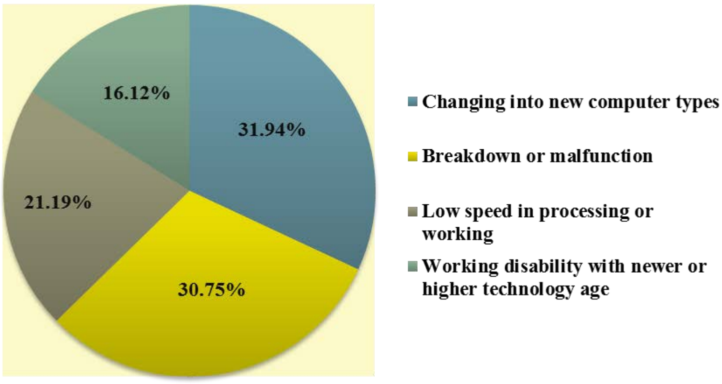


Figure 6-9: The most relevant reason for end of life phase definition in desktop PC

6.1.3 Public opinions on PC 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.

Firstly, the surveying results showed that almost of three-fourths of the participants (74.05%) have already known that there are precious metals contained in the computer. Secondly, the existing of toxic substances in computer equipment is also the important issue. Majority of participants who responded already know about this information 78 % of overall participants, except for the rest of 21.36 % did not know about this fact. Thirdly, 64.87% 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 thirty percent does not know this information.

The results of this investigation show that majority of respondents already known about the substances containing in the desktop PC and advantage of recycling process. However, only a small proportion of respondents which can increase their awareness about proper management by providing useful information through recycling campaign.

6.1.4 Preferred policy and management plan

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

6.1.4.1 The effective approach for returning the discarded desktop PC 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 surveyed about what the policy approach for operating discarded PC collection system is preferable. Participants have to prioritize the choices as preference rating method to rank the most preferred approach including: (i) paying a waste management fees when buying PC product, (ii) reselling PC wastes as product to responsible sector, and (iii) paying a waste management fees when buying PC product.

The result showed the proportion of preferred rating in 3 options (Figure 6-10). It was found that 53.52 % of participants mostly selected "*reselling PC waste as product to responsible sector*" as the most preferred option, about 46.77% preferred to "*Using restricted act or regulation forcing in E-waste management*" as moderate option, and about 67.24% selected mostly in "*Paying a waste management fees when buying PC product"* as the least preferred option.

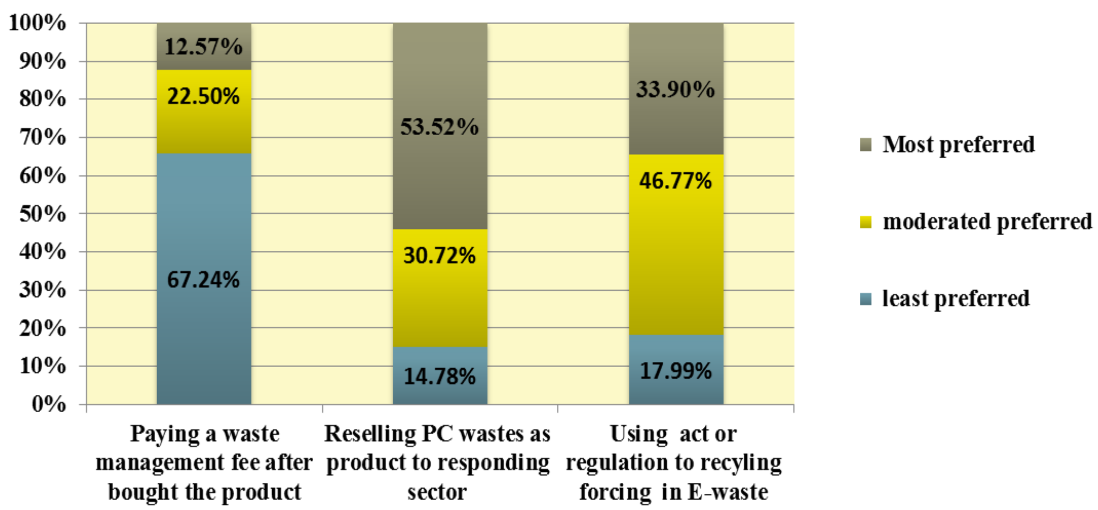


Figure 6-10: The preferred approaches for returning end-of-life PC waste management

Figure 6-11 provides analyzed results about reasons from citizens for returning end-of-life of PC waste management. The results show that reselling PC waste as product to collection center is the most preferred option. Typically, this is understandable because people could receive a return directly after discarded PC equipment as familiar with tri-cycler waste buyer. Meanwhile, using restricted act or regulation in E-waste management is the option that participants described as an important tool to control PC equipment returning to collection center; however, it might be considered as stringent tool which may be unsuitable for Thailand culture. Similarly, the paying a waste management fee when buying a new model is the least preferred option. This system actually related to level of willingness to pay for waste management which very much depends on people awareness.

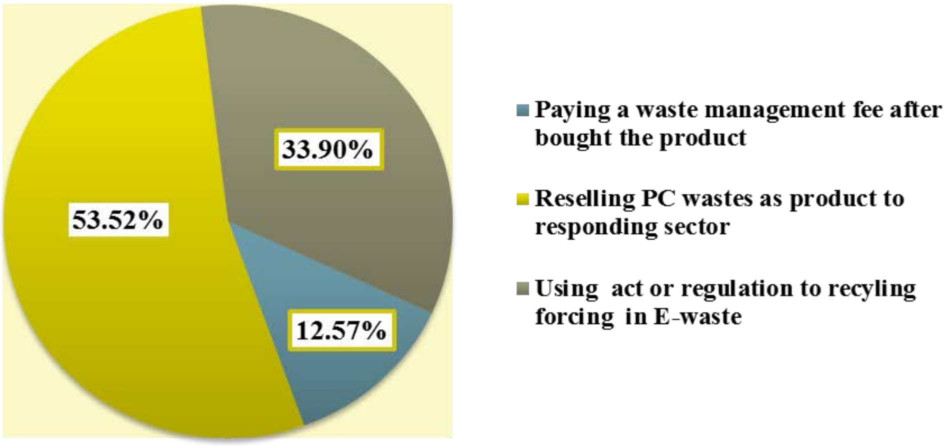


Figure 6-11: The most preferred approaches for return end-of-life PC waste management

6.1.4.2 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 about what kind of incentives that can convince people to implement PC waste collecting scheme. Hence, participants have to prioritize the scale of satisfaction in every option including:

Option 1: Granted monetary subsidy from reselling PC waste to collecting system
Option 2: Rewarding the buying new PC equipment price discount coupon after returning old discarded PC to collection system
Option 3: Social acknowledgement as following " Go Green" after returning PC back to collection system
Option 4: Tax reduction credit when returning back PC waste to collection system
Option 5: Environmental benefits promotion according to campaign announcement
Option 6: The convenient facilities supporting to the returning discarded equipment to collection center
Option 7: Social acknowledge following religion concept of good merit

The survey result shows the contribution of satisfied levels for different options in Figure 6-12. Interestingly, people tend to be interested in monetary benefits because participants highly satisfied to option 1, 2 and 6 by largely expressed “most preferred option (33.46 % of entire option 1 score)” and “higher preferred option” (26.48% and 20.16 % of each overall option 2 and option 6 score). In additions, taxes reducing incentive (option 4), which is also monetary privilege function, was selected for “moderate preferred option”, contributed 17.14 %. For non-monetary incentive, participants expressed their opinion in option 3, 5 and 7.Results showed that these choices is not too attractive to them by ranked into “low and least preferred options”

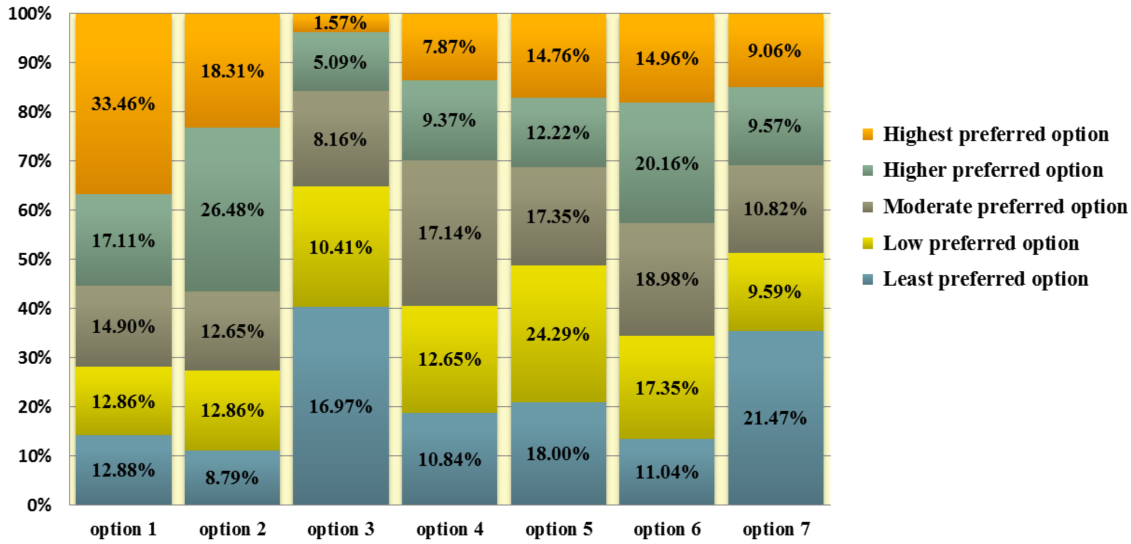


Figure 6-12: The preferred incentive for promoting electronic waste collection for recycling system

According to previous described results (Figure 6-12) and contribution of particular “most preferred option” as shown in Figure 6-13, 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 PC 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 PC wastes to the collection system. Apart from this, the collection system of PC waste is also need to be addressed to be located near convenient areas for implementation. Advertising about recycling profits has to be done as well since it can help increasing people awareness about the environment and people welfare.

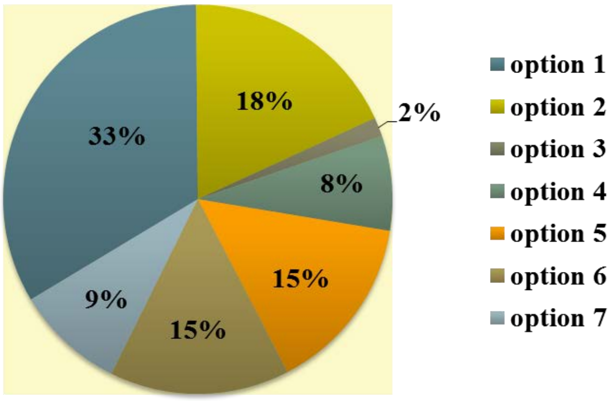


Figure 6-13: The most preferred incentive for promoting electronic waste collection for recycling system

6.1.4.3 The PC waste or E-waste collection system administrative body

Typically, the administrative body is important institution to manage the collected PC 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 (41.72%) suggested that government has to be the main body in the waste management, and also many people gave their trusts to private sector for 32.73% and 19.36% for community sector (Figure 6-14). However, there is about 6.19% preferred the other options such as temple or school. Moreover, there are additional opinions in e-management system which should be cooperated in every social sector.

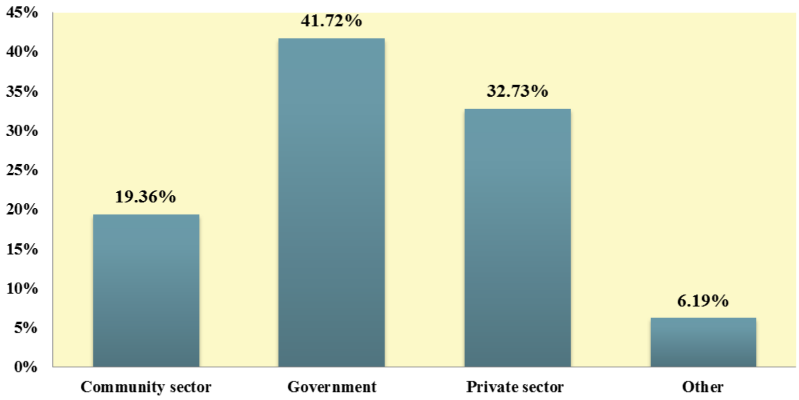
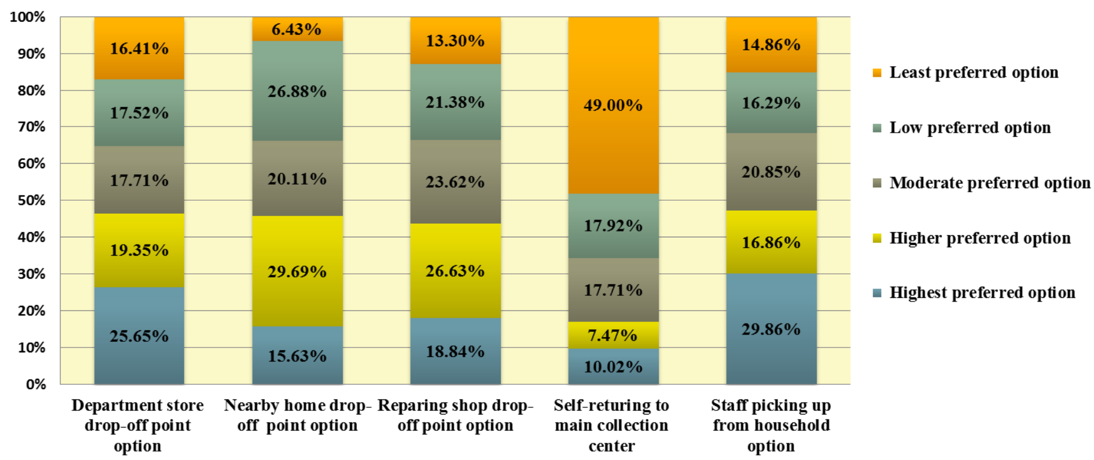


Figure 6-14: The administrative body surveying result for PC waste collecting for recycling in Thailand

6.1.4.4 The proper approach for returning PC waste into collection system

The PC 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 PC equipment back to collection center" to identify preferred collection system. This question requires all participants prioritize the different options of returning back of the PC 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 (figure 6-15). The options of returning PC waste back to drop-off point at department store were given the most satisfied scale in " highest preferred options"(25.65% of overall score in this option). As the same tends, people most satisfied in the option of returning PC to collecting service from home (for 29.86% of entire option score). For the medium level of satisfaction, people prefer the choices to return their PC equipment to local collecting center near their home, which contributed for 29.69% of overall level in this option. As same as returning back to authorized PC repairing shop, participants also interested as medium level (contributed for 29.69% of overall score in this option). Apart of this, people feel that it is inconvenient if they have to go to collection center for returning their equipment by themselves, which revealed through the most contributed fraction of "least preferred options" (contributed 49% of overall score in this option), unless they were enforced to return by



themselves.

Figure 6-15: Surveying result for selecting the comfortable and suitable option for returning disuse desktop PC to waste collection system

To select the best option of returning PC equipment, this survey also compared only most preferred option from people references which already showed on the pie chart below (figure 6-16). The results show that most selected option is the picking up directly by collecting staff from customers' home which this finding is consistent with the previous research by Pollution Control Department (2010). 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.

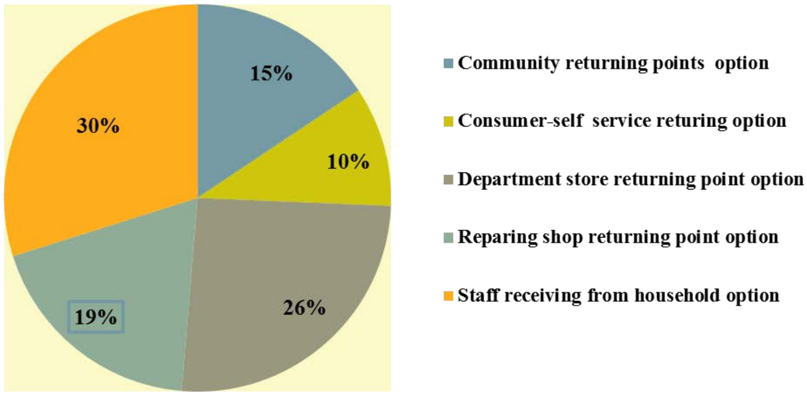


Figure 6-16: Surveying result for selecting the most preferred comfortable and suitable option for returning disuse desktop PC to waste collection system

6.1.4.5 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 Figure 6-17, the results showed that the most important concerns include: about 34.90% have a concern on the improper approach in transportation system while 34.78 % are afraid of the problem in financial supports. Apart from these, the administrative sector should not neglect the issues about illegal and trans-boundary wastes which people concerned as high as 15.5%. This can be a possible problem of market share competition with private company (about 13.84 % of people concerned in this topic).

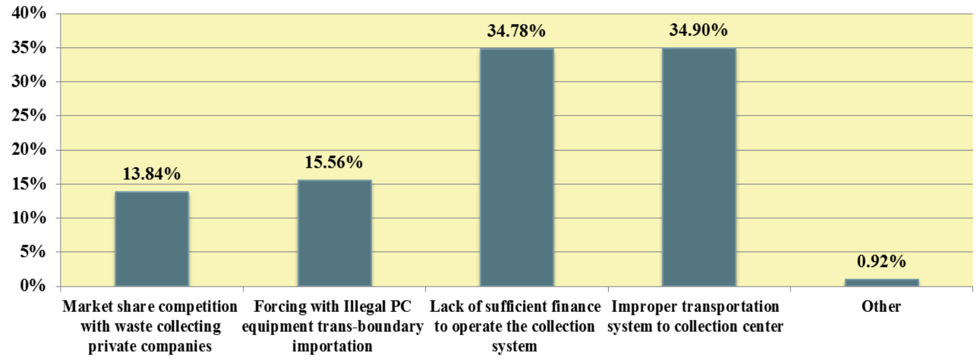


Figure 6-17: Surveying result for potential obstacles occurring in waste collection process

6.1.4.6 Recommendation from participants to improve the PC waste collection plan

More information from participants 'opinion given from this surveying is useful to fulfill the gap of information in other issues which have not been concerned before. Summary of the suggestions of all participants explained in groups of topics below.

a) Suggestion in PC waste collecting strategies

- Participants recommended that desktop PC 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 PC equipment.

- Consumers should be required to pay the deposit money on PC equipment as a good faith deposit for future returning PC equipment back after its' end-of-life. However, the money will be refund at certain amount. While part of deposit money will be contributed or used as a waste management fund. There are separated some portion to waste collection funds.

- The PC manufacture or seller can grant some privilege such as discount coupon for buying new equipment as the incentive for returning back discarded equipment. In other word, this might be useful for promoting the extended producer responsibility strategy in Thailand.

- It is possible to promote collecting the discarded desktop PC or other through the auction system, which equipment will be input the proper system of recycling.

- The collected PC equipment, which is still able to function properly or repairable are recommended for upgrading, sealing the barcode and donating to some school or foundation. Obviously, this is also the effective way to prolong equipment life span.

b) Suggestion in PC waste management administrative body

- The environmental law or regulation which involved E-waste management has to be issued in order to generate the concrete managing framework.

- The government-owned corporation which has a duty of E-waste or recyclable waste collection system should be established. Actually, this sector is can be entirely or partly owned by government to support commercial activities in e-waste collection system.

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

c) Suggestion in collection center system

- Collection center should be easy to access and avoid the complicated system which difficult to understand and not time consuming.

- Tri-cycler waste buyer would help to drive PC waste collecting system by picking up equipment; however, they have to pass the training in proper collecting process.

d) Suggestion in E-waste campaign for collection system to recycling

- Presently, there are many ways to communicate with other people such as TV, website, poster. Therefore, it would be good to use all directions to advertise the project to everyone in society.

- It needs to launch the campaign exhibition to school or community to state problem of E-waste in order to create more awareness to people.

- In the benefits of recycling, there should emphasize mainly in environmental advantages if everyone apply in the proper way and disadvantages of doing nothing. Providing more information of PC mass flow analysis could be reasonable and acceptable for university students, which might be interested to them as the discussion topic to solved E-waste problem.

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

6.2 Recommendation of PC equipment for Thailand

To promote the proper waste management schemes, the social, environmental and economic context is taken into account for establishing the comprehensive structure. This study recommended four strategies designed to stimulate the overall upstream and downstream PC waste management in Thailand. All strategies are classified and described below.

6.2.1 Strategy I: Increase people awareness and participation in desktop PC waste management

This strategy aims to stimulate people awareness in environmental performance from proper and improper PC waste management. Government administrative body should use the authority to set up the policy framework for further implementing as planned. Desktop PC waste campaigns need a creative design in order to create the clear picture of desktop PC management. As shown in table 6-1, the fundamental system gradually creates for supporting both upstream and downstream desktop PC management. These policy plans are in short term and long term.

Table 6-1: The suggestion detailed for developing desktop PC end-of-life management strategy I

Strategies	Implementation plan	Time span
Developing campaign to increase consciousness in desktop PC waste management a) Providing knowledge about PC-waste Stimulate people awareness by giving the basic information including: - Toxic substances and valuable material existing in computer equipment - Reduce, Reuse , recycling strategy concept (3Rs) for waste management - Advantage of Proper end-of-life management resource recovery - Disadvantages of landfilling of toxic substance, backyard recycling and other social problem.	Government administrative body and academic sector - Implement the campaign in academic universities, secondary and primary school through the activities - Recruit the representative of each community or organization to announce the strategies - Support voluntary group of desktop PC waste surveillance	Short to long-term
	Private sector and international OEMs - Create recycling campaign as the cooperate social responsibility program (CSRs) - Implement the campaign throught the media advertisement as well as local community forum	Short to long-term
b) Creating the online-database knowledge establishing Enhance people to accessible resource by providing the online database including: - The Desktop PC waste status and other updating situation - Online Database and open-source software suitable for reused PC - Schedule, NEWS and other updating activities - Lessons preparing for academic learning	Government administrative body sector and academic sectors - Clarify and represent the current status of desktop PC waste status in Thailand - Represent the overall E-waste study as central online library	Short to long-term
	Private sector (PC manufacturer, supplier) - PC manufacturing, OEM and supplier in Thailand requesting to showing their own policy and planning - Create application on mobile-phone , Tablet PC and other to promoting campaign	Short to long-term

6.2.2 Strategy II: Extended lifespan by using proper upstream management

Strategy II was designed to prolong the lifespan of desktop PC equipment to reach the certain lifespan. Therefore, the overall activities in this scheme response to play the important role to create the pathways as well as relevant stakeholder mechanism. Based on table 6-2, this strategy attempts to develop and strengthen the legal processes of upstream management, it also decreases the current ambiguity mechanism as well. Moreover, this stage also link to the collection system, which detailed in further strategy III, in the case of using collection system as the one of take back system facilities. The results of this strategy would be reflected through the several results; for example, the increasing of desktop PC lifespan, the economic growth of relevant reused, reselling and leasing PC market.

Table 6-2: The suggestion detailed for developing desktop PC end-of-life management strategy II

<table>
<tr><th>Strategy</th><th>Implementation plan</th><th>Time span</th></tr>
<tr><td rowspan="2">Promoting and improving policy to take into account the extended lifespan waste management scheme

This strategy aim to establish facilitating application to build the extended lifespan capacity in Thailand. Overall ,this strategy should promote in many context including:

- Law and regulation
- Market sector
- Technical and service support</td><td>Government sector or administrative sector

- Develop the administrative body directly to manipulate and control all of activities in this phase

- Develop the proper reused PC market supporting to the higher rate of demand

- Establish the policy supporting for taking-back used PC into the collection step

- Releasing the law for preventing the leaking of data according to reused processes

- Prevent the illegal importing/export of PC goods by setting the supporting plan

- Evaluate the environmental quality and financial flow of extended life span program according to corruption

- Educate the repairing technical and skills to jobless people

- Draw policy and funding aid planning to support the charity association groups and EPR system</td><td>Short to long-term</td></tr>
<tr><td>Private and sector (Public company, desktop PC manufacturer ,seller, and OEM)

- Extend the warranty period of desktop PC equipment in order to prolong one-hand PC lifespan

- Create the high quality of customer service and maintenance in order to promoting the repairing PC equipment campaign

- Use the leasing desktop PC equipment as a choice for some company to cut the company cost.

- Announcing the demanded computer in ordering to meet the need of recipients

- Promoting the marketing of used desktop PC through auction mechanism or extended producer responsibility in Thailand

- Donating desktop PC through the Corporate social responsibility Organization and customer</td><td>Short to long-term</td></tr>
</table>

6.2.3 Strategy III: Promoting creation of appropriate desktop PC waste collection center/scheme

Collection services in Thailand and other developing countries tend to be in-effective. The collected waste is also send to improper recycling plant; moreover, some of uncollected waste are also burned or dumped with municipal waste, which leading to air, water, and soil pollution. To promote proper end-of-life management, the establishing of collection center or formal collecting network can possible to apply in Thailand. In facts, the proper flow of end-of-life management would be well-managed by collection center or proper network, that directly permitted by law and regulations. Therefore, it possibly guarantees that a bulky of desktop PC equipment is aggregated from appropriate manners before send to other management approach. Table 6-3 suggests strategies to convince people to apply the collection scheme by increasing of motivation, capacity and opportunity.

Table 6-3: The suggestion detailed for developing desktop PC end-of-life management strategy III

Strategies	The Implementation plans	Time span
1.Developing policies and implementation plans to establish people confidents in the collection system project This strategy aim to establish regulation and support tools for inducing people to follow this collection scheme.	<u>Government or administrative sector</u> - Promote and support the Thai WEE policy proposal in order to enhance the establishing of formal collection scheme - Release the law and regulation to cheering up collection scheme - Support and facilitate the extended producer responsibility program in Thailand - Establish the collection funding program to induce investor to joining in this program - Forecast the establishing and operating capitals demanding of this scheme <u>Private sector (desktop PC manufacturer ,seller, OEM, consumer and private companies)</u> - Adopt the government collection scheme as the organization plans - Create the EPR system of disused desktop computer planning suitable for Thailand - Establish " the privileged coupon campaign" reward to people who apply this collection scheme - Tailor the financial aid to this project by set up the investment forum - Develop the potential impact evaluation contributing from this program - Promote CSR through the applying the collection scheme	**Short to long term**

Table 6-3 (continued): The suggestion detailed for developing desktop PC end-of-life management strategy III

Strategies	The Implementation plans	Time span
1. Developing policies and implementation plans to establish people confidents in the collection system project	Government or administrative sector - Develop the international law to support the collecting of waste Establish the tax-reduction policy as monetary incentive - Establishing the collection center funding program - Forcing the improper scrap collecting and recycling waste to pay higher tax to support the collection scheme	**Long-term**
	Private sector (desktop PC manufacturer ,seller, OEM, consumer and private companies) - Set up the campaign framework activities in short and long term - Advertise this program to international level to promote the potential of PC waste management in Thailand - Creating PC business network to subsidize the feasible collecting scheme	
2. Establishing the suitable site and service of collection system This strategy aims to provide the overall infrastructure in order to properly operate the collecting scheme.	Government sector or administrative sector - Establish the collection center near IT shopping area which fully authorized by government. - Encourage the local government to run and manipulate the local collection system. - Give the permission to private waste company attending to this program. - Study the people about the manner of disposal of desktops PC to adjust the collection scheme suitable to them	**Short to long term**
	Private sector (desktop PC manufacturer, seller, OEM, consumer and private companies) - Develop the organization policy to facilitate the collection system. - Promote reverse supply chains supporting to computer and other scrap. - Advertise people about benefit for applying the PC collection system. - Harmonize the EPR program with the central collection system as the investment Partnerships.	
	Government sector ,public sector and private sector - Develop the knock-down temporary collecting scheme at community center in order to bring people the comfortable choice in returning/reselling back to this scheme. - Develop call-center and online operating service to connecting between stakeholders and update the situation of PC waste. - Promote the transportation system network in collecting of PC waste based on energy efficiency and environmental friendly concept. - Cope with local administrative government to schedule the collecting time and planning in case of up-country collecting scenario.	**Short to long term**

Table 6-3 (continued): The suggestion detailed for developing desktop PC end-of-life management strategy III

Strategies	The Implementation plans	Time span
3. **Developing the safety Plans during operating** This strategy aims to develop the human health quality during drive the collecting center Moreover, this also include evaluating plan to ensure people about the achieving the proper manner.	Government sector or administrative sector - Evaluate the environmental potential impacts around collection site, transportation and other related area as well as the occupation health into appropriate standard to confirm the quality of collection scheme - Evaluate the financial strength of this program to prevent the occurrence of the insolvency event - Erect the piracy protection plans in disused computer to confirm the remaining storage files will be eliminate properly. - Accept the third-parties sector to check the total performance of this scheme	**Short to long term**

6.2.4 Strategy IV: Gradually changing the improper into proper recycling scheme

The recycling approach is the following step of extended lifespan approach. This approach is suitable for desktop PC which are not cost-effective to repair, reused and upgrade anymore. The scraps from waste collecting process are consequently reprocessed into new materials again. Currently, this useful material mostly found in informal recycling companies. This fact showed improperly approach which still does not satisfied in environmental and social term. Therefore, it is necessary to establish the appropriate recycling program, which brings advantage to environmental, social and economics. Table 6-4 represents some of the implementation plan that should be concerned. This overview represents the integrated recycling scheme supporting by several sectors. Therefore, the benefits from this program might contribute to all sectors; especially, to environmental and resource availability.

Table 6-4: The suggestion detailed for developing desktop PC end-of-life management strategy IV

Strategies	The Implementation plans	Time span
1. **Developing policies and implementation plans to establish the recycling scheme** This strategy purpose to create the social measurement to drive the establishing the proper recycling center and reduce the improper recycling activities in Thailand	Government sector or administrative sector - Establish the campaign to increase an understanding in the important of recycling center - Develop the law and regulation in order to manipulate the mechanism of recycling scheme (e.g. environmental , health and social awareness policy) - Develop the recycling fee policy to supporting	**Short-term and Long-term**
	Public and private sector (Public company, desktop PC manufacturer ,seller, OEM, consumer, academic sectors) - Prepare the activities to compliance with the proper regulation - Support the government to create the regulations and law relating to recycling practice	**Short-term and Long-term**

Table 6-4: The suggestion detailed for developing desktop PC end-of-life management strategy IV (continued)

Strategies	The Implementation plans	Time span
1. Developing policies and implementation plans to establish the recycling scheme	Government sector or administrative sector - Compliance with international laws and regulation in recycling activities - Develop the law and measurement to inhibit the informal recycling activities in Thailand - Study the development social gain and economic development by promote recycling center as the public enterprise - Forecast the short and long term of financials and assumptions	**Long term**
	Public and private sector (Public company, desktop PC manufacturer ,seller, OEM, consumer, academic sectors) - Predict the possible problem and represent the recommendation of the precautionary plans - Look further to apply this recycling scheme to other equipment such as Tablet PC, note book PC, all-in-one PC and smart phone.	
2. Shifting the informal recycling firm to formal recycling network This strategy purpose to eliminate the informal recycling activities by using the different measurement and incentive.	Government sector or administrative sector - Convince the informal recycling plant to shift their operational system into appropriate manner by offering the investment supports - Generate the central database about the recycling scheme management providing to relevant stakeholder - Release the policy or regulation to overcome the informal recycling market share	**Short term To long term**
	Public and private sector - Ban and avoid to the informal recycling activities - Make the privilege to sector which declared the attending the formal recycling scheme	
	Public and private sector - Integrated the formal recycling companies network with central government program to facilitating experience and relationship of this projects	**Long-term**
3.Design the proper structure of recycling facilities and maintaining plans This strategy aim to develop the suitable tools and structure in order to more feasible to apply to Thailand based on the sustainable concept	Government sector or administrative sector - Find the suitable technology appropriate to Thailand based on sustainability concept - allocate sites to support the pattern of recycling facilities - Promote Pilot plant to public to show feasibility in further full scale recycling scheme - Prepare the waste residue output managing plan appropriate for waste type	**Short to long term**

Table 6-4: The suggestion detailed for developing desktop PC end-of-life management strategy IV (continued)

Strategies	The Implementation plans	Time span
3.Design the proper structure of recycling facilities and maintaining plans (continued)	<u>Public and private sector</u> - Response to the recycling plant in Thailand by offering the machine maintenance program to the formal recycling processors - Provide the systems will help to measure the quality service and environmental quality - Make profit from establish the supply chain companies relating to this recycling scheme	**Short to long term**
	<u>Public and private sector</u> - Set up the remanufacturing plant in Thailand by using the recycled resource from this scheme - Establish the recycled material utilization applying in the academic program to induce the further investment in this field. - Create the plan to dealing with commodity price fluctuations - Make the environmental surveillance program as well as occupational health	
	<u>Government sector or administrative sector</u> - Establish the secondary resource market in Thailand and look forward to supporting the international trade (e.g. opening of ASEAN Economic Community 2015) - Schedule the suitable period of time to feed the resource to this plan - Develop the plan in uncertain situation occurrences such as disaster ,political crisis - Extend the operation unit of recycling plants - Generate social welfare for employee who attend to this proper scheme - Co-work with the academic in order to bring the knowledge and long-term - Provide the proper information management within the scheme in purpose of showing and clarify to the public	**Long term**
	<u>Public and private sector</u> - Set up the remanufacturing plant in Thailand by using the recycled resource from this scheme - Establish the recycled material utilization applying in the academic program to induce the further investment in this field. - Create the plan to dealing with commodity price fluctuations - Make the environmental surveillance program as well as occupational health	

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

6.3 Implementation Timeline

Based on all recommended strategies, there are can deliberated into three phases including: (1) initiate phase, (2) short-term, and (3) long-term implementation phase.

The initiate phase should set up the working groups or responsible parties in order to startup the operation. This have to begin with the setting up the pragmatic framework including the law enactment and related regulation. This is appreciable to use strategy I, II, III and IV for motivating this phase.

For short-term implementation phase, this phase purpose to implement a pilot project in both collecting and recycling system. The evaluating at end of this phase is necessary because this use as the success indicator to improve the operating efficiency before applying to the long-term implementation plan.

The full scale of operation in this last phase would be the evidence that this scheme is feasible to Thailand. For these two phase of implementation, the strategy III and IV are the mainly driver to fulfill this plan because there could be provide overall resource of entire operation panels and workforce.

Moreover, it is recommended to create and sustain the people awareness in E-waste problem. Therefore, this can implement through the campaign and learning system which provide the knowledge about the proper manage way to desktop PC waste or E-waste status update in Thailand. Nevertheless, it necessary to apply through all implementation phase which strategy is recommend to fulfill this goal.

Figure 6-18: The implementation plan for desktop PC management

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 desktop PC waste management. Furthermore, the research recommends strategies to better improve the PC waste management in Thailand. The key findings from this research are explained as follows:

7.1 Life cycle inventory development

Three desktop PC equipment inputs (including desktop PC, CRT and LCD computer screen) were used as case studies as computer-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 computer screen has the highest weight due to the panel and funnel glass components. For LCD and desktop computer, the weights come from structural part which mainly contributes from ferrous-metal fraction. Nevertheless, all three equipment founded plastic components embedded inside as the second most substances.

- Lead oxide notable is the significant toxic substance in CRT computer. Lead compounds are contained in glass approximately 8.4 % of total glass weight. For Mercury in LCD device is about 3.96E-07% of total weight or 2.22E-06 kg. PWBA is the main source of hazardous substance in desktop PC usually embedded in as the soldering material including lead approximately 2.77E-02l kg per one unit of computer.

- According to the final disposal of three PC 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 to the third rank and underground deposit as the fourth.

- Focusing on recycled materials, these all equipment are contained with various amounts of valuable material that could be recovered. The CRT computer monitor has highest % of recoverable material per device (66.6%) following by LCD (52.6%) and desktop computer (51.7%), respectively.

- The PWBA quality and weight can use to define the final amount of precious metals. In this study, desktop computer has large amount of high grade PWBA. Therefore, this can contribute the highest amount of precious metal (9.51E-01 kg) following by CRT computer screen (4.73E-01 kg) and LCD (2.31E-01 kg), respectively.

- The higher the rate of collection and recycling is related to the higher potential of resource recovery and source of income from e-waste management.

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

7.2.1.1 Human health endpoint impact summary

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

- Besides landfilling approach, the recycling of PC equipment can help avoid human toxicity impact which showed as negative DALY score in major the human health indicator. This overall avoided come from neglected the disposal of sulfidic tailing in mining process. However, recycling the desktop computer potential to avoid the highest human health impact, compared to CRT recycling and LCD recycling, respectively.

7.2.1.2 Ecosystem endpoint impact summary

- Ecosystem endpoint impact score (species*yr.) is mostly distributed from freshwater eco-toxicity indicator impact regarding to the CRT computer screen landfilling. In case of LCD and desktop PC 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 due to the avoided primary material acquisition. All recycling scheme greatly reduce the ecosystem impact mostly from avoided both climate change ecosystem and urban land occupation. Nevertheless, recycling of desktop PC can contribute the highest benefits to the ecosystem compared to the other two devices.

7.2.1.3 Resource depletion endpoint impact summary

- The landfilling of all PC equipment affects fossil resource depletion and metal depletion. But there is lower impact on metal depletion. Particularly in CRT computer 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. CRT and LCD computer screen recycling can gains the benefits mostly from avoiding fossil depletion, while the desktop PC recycling bring greatly benefits to metal sustainable resource.

7.2.2 Environmental single score comparison: landfilling vs. recycling approach

7.2.2.1 CRT computer single score comparison

- The comparison reveals that landfilling approach highly affects to the environment compared to recycling approach. Recycling performs better than landfilling by reducing 28.53 fold of single score.

- The CRT screen landfilling approach provides positive single score in environmental impact. Especially in disposal of CRT glass coating, in opposite to the recycling scheme, overall benefits provided from recovered metal according to shredder fraction and PWBA recycling.

7.2.2.2 LCD computer single score comparison

- LCD computer screen landfilling provides the positive environmental impact single score. Recycling help reducing the environmental impact compared to landfilling which decrease about 289.76 fold of landfilling approach single score.

- The positive environmental single score impact mainly contributed from landfilling of plastic fraction (72.6% of total impact). The main component in LCD contributing to the impact is backlight assembly part.

- For recycling avoided single score, the significant contributor of this scheme is from PWBA, cable and shredded fraction recycling.

7.2.2.3 Desktop computer single score comparison

- The single score of desktop PC regarding to landfilling approach causes only few amount of impact, while negative single score from recycling conduct enormous benefits to environment. In other words, this recycling can achieve higher benefits than landfilling approach by about 769.37 folds.

Almost of landfill single score was from plastics (61.3%). For the landfill burdens from PC components, desktop PC cabinets can generate the highest impact to landfill. For recycling approach, the mostly avoided impact contributes from PWBA recycling.

In summary, system processes in landfilling approach and other background system (e.g. energy and resource extraction) release pollutants during operation. When compared with other two devices, CRT computer screen caused the highest environmental impact due to the processes in de-toxicity of coating glass. Nevertheless, the interesting point is that overall plastic waste management possibly creates significant burdens regarding to both LCD screen and desktop PC. 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 PC equipment.

7.2.3 The End of life scenario analysis

The forecasting of future impacts during 2012-2021 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 PC 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 PC equipment.

- The environmental benefits can initially start up by only applying 5% recycling rate (S2) in all equipment. Due to comparing with the baseline scenario, the desktop PC can greatly reduce environmental impact compared to baseline scenario (38.52-fold), following by LCD (14.49-fold) and CRT computer screen (1.44–fold), respectively.

- Generally, the attempt to increase the recycling rate to 20% can enhance total environmental benefit. Comparing with the baseline scenario, Desktop PC recycling greatly provide benefits from Scenario 3 (154.07 fold) more than LCD (57.95-fold) and CRT computer screen (5.73-fold), respectively.

Interestingly, this correlation between recycling rate of PC 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 Desktop PC Management summary**

7.4.1 The results from questionnaire survey

7.4.1.1 Current PC waste management practice and Public opinions on PC waste management

- The survey founded that people tend to discard computers earlier than expected design and physical lifespan.

- People prefer to keep their PC equipment at their household without do anything. Apart from this, people considered to do something with the wastes in order to sustain their value through such as upgrading, donation and reselling.

- Focusing on the people awareness in desktop PC waste, this study revealed that approximately three-fourth of the participants have already known about precious metal and toxicity in desktop PC as well as benefits from proper recycling.

7.4.1.2 Preferred policy and management plan

- Feasible managing plan of the desktop PC collection system should set up based on acceptability from the public. In this study, reselling PC waste as product to collection center policy is the most preferred option. The effective approach for returning the discarded desktop PC back to collection center apart from the reselling back policy, it seem to be difficult to apply other policies or regulations without providing benefit as long as people still considered that their equipment still have value.

- 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 sustainable of environmental benefits, convenient system for returning device, and religion concept of good merit.

- For desktop PC 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 government 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 PC 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. People indicated their attitudes and concerns in low-quality of waste logistic problem as similar as financial problem are the main problems. Nevertheless, illegal trading and competition with informal companies are also the issues that formal collecting processor should prepare proper plans to increase the competition.

7.4.2 The desktop PC management recommendations from this research

- The four strategies are recommended for enhancing practicality and effectiveness of PC waste management system. There is necessary to integrate the disposal system from relevant stakeholder such as governmental or non-governmental sector, formal or informal, profit or nonprofit and public sector. Four strategies for motivating and generating the proper desktop PC waste management in Thailand are as following;

7.4.2.1 Strategy I: Increasing people awareness and participation in desktop PC waste management summary

- This strategy has to implement together and concurrently by government administrative body, private sector, public sector and academic 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.

7.4.2.2 Strategy II: Extending lifespan by using proper upstream management

- This strategy encourages developing policies and implementation plans to establish people confidents in the collection system. Government administrative sector has to create policy supporting all "state-of-art approaches" such as reusing, donating, reselling, take-backing and other.

- For private sector, the computer manufacturing and computer selling company have to build their own strategy or facilitating plans to induce clients to prolong computer lifespan. Furthermore, the private company also needs to conduct the extended lifespan concept as organization policy. In term of donation scheme, this should create through media and other pathway to suitable to contact with the donor.

7.4.2.3 Strategy III: Promoting creation of appropriate desktop PC waste collection center/scheme summary

- To promote the appropriate waste collection center/scheme, the several strategies are involved which including: (a) developing policies and implementation plans to establish people confidents in the collection system project, (b) establishing the suitable site and service of collection system, (c) developing the safety plans during operating

- The government sector has to start up overall collecting framework through the releasing law, regulation, measurement and policy. Moreover, there have to provide the facilities for private sector mechanism. Particularly, private sector or computer manufacturer should support the government waste collecting scheme as well as set up the campaign to advertise their activities in short and long term.

7.4.2.4 Strategy IV: Gradually changing the improper into proper recycling scheme summary

- This approach is planned for desktop PC which are not suitable to repair, reused and upgrade anymore. The planned frameworks are including: (a) developing policies and implementation plans to establish the recycling scheme, (b) shifting the informal recycling firm to formal recycling network, (c) design the proper structure of recycling facilities and maintaining plans.

- The national framework such as law and regulation need to pave the way for proper recycling scheme. Furthermore, financial and technology supports also useful to achieve the gradually changing into proper recycling scheme. As the private and private sector, there also similar to the previous strategies which private sector should to follow the law and regulation as well as support the recycling scheme operation.

7.5 The recommendation for future work

There are many aspects that need further investigation to expand the implication of the research, including:

- A more comprehensive study would include all the groups of brominated flame retardant substances which to reflect all of toxic substances in every equipment.

- Waste transportation system is also needed to take into account for comprehensive evaluating of environmental impact during the operation.

- In this study using the background database based on international database which already defined as best practice approach. Therefore, interpretation of impact results would not stand for the current situation of improper technology in Thailand. Therefore, the future improvement can be done by particularly applying the current technology in waste management Thailand.

- For scenario analysis, this study showed primarily evaluates on the possible future impact which assumed from the future goal perspective (including both 5% and 20% collection to recycling rate).Therefore, the results in this study can used to reveal the benefits from recycling scheme. However, the further research scenario should to apply the business as usual scenario (BAU) which recycling collection rate might come from Mass flow analysis (MFA) study. This helps to provide appreciable results to reveal deeply into the local situation in future as well.

- There are still more options for desktop PC treatment management which may be interesting to investigate e.g. Incineration or incineration energy recovering

- The further study in questionnaire part is should be survey from several stakeholders such as desktop PC manufacturer, private firm and government administrative body in order to create the recommendation plans which can be appreciable to major of all related sectors.

- This will be useful to determine costs and benefits of both all management scenarios to calculate the cost-efficiency in desktop PC waste management.

- For sensitivity analysis, It recommend to create the assumption through the specific “hotspot substances” management such as precious metal or toxic substances. This might reflect the apparent sensitivity because there are the main significant contributors to the environment burdens.

REFERENCES

Andersen, O., Walnum, H. J., and Andrae, A. Life Cycle Assessment of Electronics Ball Grid Array and Chip Scale Packaging [online]. 2010. Available from: www.vestforsk.no/filear chive/sluttrapport-conpart-6-10.pdf [2012, April 10]

Arora, R. Best Practices for E-waste Management in developing Nations. GTZ-ASEM report [online]. 2008. Available from:http://www.smallb.in/sites/default/files/knowledge _base/bestpracticesforEwasteManagement-developedcountries.pdf. [2012, April 15]

Atlantic Consulting. LCA Study of the Product Group Personal Computers in the EU. Ecolabel Scheme Technical Annex report [Online]. 1998. Available from:http://ec.europa.eu/environment/ecolabel/about_ecolabel/reports/lcastudy_pc_ 1998.pdf[2013, Febuary 13]

Ayres, R. U. Metals recycling: economic and environmental implications. Resources, Conservation and Recycling 21 (November 1997) : 145–173.

Chancerel, P., Meskers, C. E. M., Hageluken, C., and Rotter, V. S. Assessment of Precious Metal Flows During Preprocessing of Waste Electrical and Electronic Equipment. Journal of Industrial Ecology 13(5) (October 2009) : 791-810.

Chatterjee, S., and Kumar, K. Effective electronic waste management and recycling process involving formal and non-formal sectors International. Journal of Physical Sciences 4 (13) (December 2009) : 893-905.

Cherubini, F., Bargigli, S., and Ulgiati, S. Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. Energy 34(12) (December 2009) : 2116-2123.

Choi, B. C., Shin, H. S., Lee, S. Y., and Hur, T. Life Cycle Assessment of a Personal Computer and its Effective Recycling Rate. The International Journal of Life Cycle Assessment 11(2) (December 2006) : 122-128.

Classen, M., Althaus, H. J., Blaser, S., and Scharnhorst, W. Life Cycle Inventories of Metals. Ecoinvent report No.10. Final Report Ecoinvent Database v.2.1 [Online]. 2009. Available from: http://www.ecoinvent.ch [2012,April 21]

CPM. Recyling of metallic material in LCA: recommendations [Online]. 2001. Avialable from :http://www.cpm.chalmers.se/document/reports/01/2001_15.pdf [2013,January 10]

Cui, J., and Forssberg, E. Mechanical recycling of waste electric and electronic equipment: a review. Journal of Hazardous Materials 99 (August 2007) : 243-263.

Culver, J. (2005). The Life Cycle of a CPU [Online]. 2005. Available from : http://www.cpushack.com/life-cycle-of-cpu.html [2012, March 16]

Deng, W. J., Zheng, J. S., Bi, X. H., Fu, J. M., and Wong, M. H. (2007). Distribution of PBDEs in air particles from an electronic waste recycling site compared with

Guangzhou and Hong Kong, South China. Environment International 33(8) (November 2007) : 1063-1069.

Doka, G. Life Cycle Inventories of Waste Treatment Services No. 13 (Vol. 2). Final Report Ecoinvent Database v.2.1 [Online]. 2009. Available from: http://www.ecoin vent.ch [2012, April 21]

Duan, H., Eugster, M., Hischier, R., Streicher-Porte, M., and Li, J. Life cycle assessment study of a Chinese desktop personal computer. Science of the Total Environment 407 (February 2009): 1755-1764.

EC. Implementation of the Waste Electric and Electronic Equipment Directive in the EU 25 [Online]. 2006. Avaliable from:ftp://ftp.jrc.es/pub/EURdoc/eur22231en.pdf. [2012,April 21]

EEI. (2007). Development of E-Waste Inventory in Thailand Thailand: Electrical and Electronics Institute. Electrical and Electronics Institute [Online]. 2007. Avaliable from: http://www.iisd.org/pdf/2007/rtea_thai_electrical.pdf [2013, January 9]

EIA. Lead in Cathode Ray Tubes (CRTs) Information Sheet [Online]. 2001. Avaliable from : https://www.premierinc.com/quality-safety/tools-services/safety/topics/computers/ downloads/k_3_lead_in_crts.pdf [2013, Febuary 14]

Electronics Take Back Coalition. Facts and Figures on E-Waste and Recycling. 2007. Available from : http://www.electronicstakeback.com/wp-content/uploads/Facts _and_Figures_on_EWaste_and_Recycling.pdf [2012, February 21]

EPA. Can the lead, mercury, and liquid crystals in computer displays pose health risks . 2001. Avaliable from : http://www.epa.gov/dfe/pubs/comp-dic/lca-sum/ques8.pdf. [2013, Febuary 13]

Fang, G.C., Wu, Y.S., Huang, S.H., and Rau, J.Y. Review of atmospheric metallic elements in Asia during 2000–2004. Atmospheric Environment 39(17) (June 2005) : 3003-3013.

Forrester. (2007). Worldwide PC Adoption Forecast, 2007 To 2015 [Online]. 2007. Avialable from : http://www.forrester.com/Worldwide+PC+Adoption+Forecast+2007+To+ 2015/fulltext/-/E-RES42496 [2012, June 11]

Gartner. worldwide PC shipments situation in 2009 [Online]. 2009. avaliable from : http://www.gartner.com/it/page.jsp?id=1233213 [2012,July 13]

Grossman, E. High Tech Trash: Digital Devices, Hidden Toxics, and Human Health [Online]. 2006. Avaliable from : http://www.ncbi.nlm.nih.gov/pmc /articles/PMC 1551981/ [2012,July 13]

Hageluken, C. Improving metal returns and eco-efficiency in electronics recycling - a holistic approach for interface optimisation between pre-processing and integrated metals smelting and refining. Proceedings of the 2006 IEEE International Symposium on Electronics and the Environment [Online]. 2006. Avaliable from : http://ieeexp lore.ieee.org/xpls/abs_all.jsp?arnumber=1650064&tag=1[2012, July 13]

Hagelüken, C., Buchert, M., and Ryan, P. Materials flow of platinum group metals Umicore AG & Co. KG and Oko-Institut [Online]. 2005. Avaliable from :

www.preciousmetals.umicore.com/.../show_materialsFlowOfPGMs.pdf[2013,March 10]

Hagelüken, C., Refining, U. P. M., and Greinerstraat, A. Recycling of electronic scrap at Umicore's integrated metals smelter and refinery. Proceedings of EMC [Online]. Avaliable from : http://www.preciousmetals.umicore.com/PMR/Media/e-scrap/show_recyclingOfEscrapAtUPMR.pdf [2012,July 13]

Hikwama, B. P. Life Cycle Assessment of a Personal Computer. Bachelor’s dissertation, Department of Engineering , Faculty of Engineering and Surveying, University of Southern Queensland, 2005.

Hino, T., and others. Techniques to separate metal from waste printed circuit boards from discarded personal computers. Journal of Material Cycles and Waste Management 11(1) (January 2009): 42-54.

Hischier, R., and Baudin, I. LCA study of a plasma television device. The International Jour nal of Life Cycle Assessment 15(5) (June 2010) : 428-438.

Hischier, R., Wäger, P., and Gauglhofer, J. Does WEEE recycling make sense from an environmental perspective?: The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). Environmental Impact Assessment Review 25(5) (July 2005) : 525-539.

Hischier R., Classen M., Lehmann M., and Scharnhorst W. Life cycle inventories of Electric and Electronic Equipment: Production, Use and Disposal : Ecoinvent report No. 13 (Vol. 2). Final Report Ecoinvent Database v.2.1 [Online]. 2007. Available from: http://www.ecoinvent.ch [2012, April 21]

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

Huisman, J., and others. (2008). Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE): Bonn, Germany: United Nations University, 2008.

Huo, X., and others. Elevated Blood Lead Levels of Children in Guiyu, an Electronic Waste Recycling Town in China. Environmental Health Perspectives 115 (July 2007) : 1113-1117.

ISO. ISO 14040:2006 Environmental management – life cycle assessment – requirements and guidelines. Geneva ,Switzerland: ISO, 2006.

Jang, Y.C., and Townsend, T. G. Leaching of lead from computer printed wire boards and cathode ray tubes by municipal solid waste landfill leachates. Environmental Science & Technology 37(20) (September 2003) : 4778-4784.

Jung, L. B., and Bartel, J. T. Computer take-back and recycling, an economic analysis for used consumer equipment. Journal of Electronics Manufacturing 9 (August 1999) : 67-77.

Keller, M. Assessment of gold recovery processes in Bangalore, India and evaluation of an alternative recycling path for printed wiring boards[Online]. 2006. Available from : http://www.empa.ch/plugin/template/empa/*/59244/---/l=2. [2012, August 1]

Khetriwal, D. S., Kraeuchi, P., and Widmer, R. Producer responsibility for e-waste management: Key issues for consideration – Learning from the Swiss experience. Journal of Environmental Management 90(1) (January 2009) : 153-165.

Lee, C.H., Chang, C.T., Fan, K.S., and Chang, T.C. An overview of recycling and treatment of scrap computers. Journal of Hazardous Materials 114 (3) (October 2004) : 93-100.

Legarth, J. B., and others. A New Strategy in the Recycling of Printed Circuit Boards. Circuit World 21(3) (January 1995) : 10-15.

Leung, A. O. W., Duzgoren-Aydin, N. S., Cheung, K. C., and Wong, M. H. (2008). Heavy Metals Concentrations of Surface Dust from e-Waste Recycling and Its Human Health Implications in Southeast China. Environmental Science & Technology 42(7) (March 2008) : 2674-2680.

Li, H., Yu, L., Sheng, G., Fu, J., and Peng, P. A. (2007). Severe PCDD/F and PBDD/F Pollution in Air around an Electronic Waste Dismantling Area in China. Environmental Science & Technology 41(16) (August 2007) : 5641-5646.

Liu, H., and others (2008). E-waste recycling induced polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzo-furans pollution in the ambient environment. Environment International 34(1) (January 2008) : 67-72.

Lundgren, K. The global impact of e-waste: addressing the challenge [Online]. 2012. Avalaible from : http://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_196105.pdf [2013, August 2]

Manomaivibool, P., Lindhqvist, T., and Tojo, N. Extended Producer Responsibility in a non-OECD context:The Management of Waste Electrical and Electronic Equipment in Thailand. Sweden: International Institute for Industrial Environmental Economics, 2009.

McDonnell, T. J., and Williams, K. S. The location and character of mercury in waste LCD backlights. In J. French-Brooks (ed.), Summary research report, pp.9-18. England: the School of Built and Natural Environment, 2010.

Mohite, S., and Zhang, H.C. Disassembly analysis, material composition analysis and environmental impact analysis for computer drives. Proceedings of the International Symposium on Electronics and the Environment [Online]. 2005. Avaliable from : http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1437028&userType=inst [2013,January 9]

Morf, L. S., and others. Metals, non-metals and PCB in electrical and electronic waste – Actual levels in Switzerland. Waste Management 27(10) (January 2007) : 1306-1316.

Musson, S. E., and others. (2006). RCRA Toxicity Characterization of Discarded Electronic Devices. Environmental Science & Technology 40(8) (April 2006) : 2721-2726.

Nnorom, I. C., and Osibanjo, O. (2008). Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resources, Conservation and Recycling 52(6) (April 2008) : 843-858.

Noon, M. S., Lee, S.J., and Cooper, J. S. A life cycle assessment of end-of-life computer monitor management in the Seattle metropolitan region. Resources, Conservation and Recycling 57 (December 2011) : 22-29.

Parsons, D. End-of-life cathode ray tubes: a life cycle assessment for Australia. The Environmental Engineer 8(4) (January 2008) : 7-13.

PCD. (2010). The study project on rules, procedures,and fees of Thailand's WEEE management Bangkok [Online]. 2010. Available from : http://www.unep.or.jp/ietc/spc/news-jul10/Thailand_(Mr.SurinAree).pdf [2012,November 2]

Pirzada, D. S., and Pirzada, F. N. E-Waste: An Impending Challenge 4 [Online]. 2006. Availa ble from : http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2796756/ [2012, November,2]

Qu, W., and others. Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. Environment International 33(8) (November 2007) : 1029-1034.

Reimer, B., & Bernecker, G. (1992). Recycling of fluorescent lamps. physica status solidi 130(2) (April 1992): 219-220.

Reimer B. D. Review of Lamp Recycling. Berlin, Germany: WEREC, 2001.

Robinson, B. H. (2009). An assessment of global production and environmental impacts. Science of The Total Environment 408(2) (December 2009) : 183-191.

Sepúlveda, A., and others. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. Environmental Impact Assessment Review 30(1) (January 2010) : 28-41.

Socolof, M. L., Overly, J. G., and Geibig, J. R. Environmental life-cycle impacts of CRT and LCD desktop computer displays. Journal of Cleaner Production 13(13) (December 2005) : 1281-1294.

Socolof., M. L., and other. (2001). Desktop Computer Displays: A Life Cycle Assessment [Online]. 2001. Available from : http://www.epa.gov/dfe/pubs/comp-dic/lca/ [2012, November,21]

Song, Q., Wang, Z., Li, J., and Yuan, W. Life cycle assessment of desktop PCs in Macau. The International Journal of Life Cycle Assessment 18(3) (March 2013) : 553-566.

StEP. (2009). Recycling from E-waste to Resources [Online]. 2009. Avalaible from : http://www.unep.org/pdf/pressreleases/E-waste_publication_screen_finalversion-sml.pdf. [2013, Januray,31]

StEP. (2009). Solving the e-waste problem: a synthetic approach (StEP)[Online]. 2009. Avaliable from : http://step.ewaste.ch [2013,March 21]

Technology Recycling. (2003). Frequently Asked Questions[Online]. 2003. Avaliable from : http://www.techrecycle.com/faq.asp

Teehan, P., and Kandlikar, M. (2012). Sources of Variation in Life Cycle Assessments of Desktop Computers. Journal of Industrial Ecology 16(1) (March 2012) : 182-194.

Tekwawa, M., Miyamoto, S., and Inaba, A. Life cycle assessment; an approach to environmentally friendly PCs. ISEE-1997., Proceedings of the 1997 IEEE International Symposium on Electronics and the Environment [Online]. 1997. Avaliable from : http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=605287 [2013,March 28]

The Basel Action Network. Exporting Harm: The High-Tech Trashing of Asia 10-12 [Online]. 2002. Avaliable from : www.ban.org/E-waste/technotrashfinalcomp.pdf [2013,March 28]

Tohka A., and Lehto, H. Mechanical and Thermal Recycling of Waste from Electric and Electrical Equipment. Helsinki Finland : University of Technology Department of Mechanical Engineering, 2005.

UNEP. E-waste:Inventory Assessment Manual. Osaka Japan : United Nations Environmental Programme Division of Technology, 2007.

USEPA. (2008). Electronics waste management in the United States: approach 1.Washington, DC: Office of Solid Waste U.S. Environmental Protection Agency, 2008.

Vassanadumrongdee, S.,and Manomaivibools P. Extended Producer Responsibility in Thailand. Journal of Industrial Ecology 15(2) (March 2011) : 20-25.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., and Böni, H. Global perspectives on e-waste. Environmental Impact Assessment Review 25(5) (April 2005) : 436-458.

Williams, E. Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input−Output Methods. Environmental Science & Technology 38(22) (October 2004) : 6166-6174.

Williams, E., Kahhat, R., Allenby, B., Kavazanjian, E., Kim, J., & Xu, M. Environmental, Social, and Economic Implications of Global Reuse and Recycling of Personal Computers. Environmental Science & Technology 42(17) (August 2008) : 6446-6454.

Williams, E., & Sasaki, Y. Strategizing the End-of-Life handling of personal computer :resell, upgrade, recycle. In E. Williams (ed.), Computer and the Environment :understanding and managing their impacts, pp.183-196. Netherlands: Kluwer Academic Publishers, 2003.

Wittmaier, M., Langer, S., and Sawilla, B. Possibilities and limitations of life cycle assessment (LCA) in the development of waste utilization systems – Applied examples for a region in Northern Germany. Waste Management 29(5) (Jan 2009) : 1732-1738.

WRAP. The location and character of mercury in waste LCD backlights. In T. J. McDonnell & K. S. Williams (Eds.), pp. 17-18. England : the School of Built and Natural Environment, University of Central Lancashire, 2010.

Yamane, T. Statistics: an introductory analysis. New York: Harper and Row,1973.

Yindee, K. Obsolete personal computer (PCs):the feasibility end-of-life options for Thailand. Master's thesis,Department of Environmental Managment, Faculty of Science, Mahidol University, 2004.

Zumbühl, D. (2006). Mass flow assessment and assessment of recycling strategies for cathode ray tubes for the Cape Metropolian Area ,South Africa [Online]. 2006. Avaliable from : [2013 ,August 7]

Appendices

Appendix A

Landfilling and Recycling system

1. Waste managing system in this study

This appendix part described the overall system of waste management approach including both landfilling and recycling approach addition from previous methodology part

1.1. Landfilling system

There is no actual landfill type that directly supports PC waste. Consequently, PC waste has to define into various waste type disposed in different landfills which considered from capable of database. The main type Landfill in this study including:

1.1.1. Sanitary landfill

As the limitation of landfill data available in Thailand, therefore, this study used Elbisgraben as the representative which is the Swiss sanitary landfills (Doka G., 2003).The size of landfill is approximately as box shape, landfill volume is 1.8 million m3.density of the waste distributed for 1000 kg/m3 which has maximum capacity is thus 1.8 million tons of waste. Landfill is sealed around for supporting the leachate collection system. For operational of landfill, For the landfill operation, this landfill also apply loader truck to transfer and dense the waste .the collecting pipe embedded in landfill body is necessary to gain gas enhancing by landfill gas pump. However, the landfill gas is collected and incinerated either in open flares without energy production (Doka G., 2003). For leachate treatment plant, this is assumed that leachate can flow by gravitational force without pumping directly to waste water treatment.

1.1.2. The inert material landfills

The inert material landfills can characterize by containing highly of inorganic and low carbon compounds wastes. For example, incineration residues, construction wastes, Slag compartments. In facts, there can effort to overall unproblematic inorganic inert wastes or has low toxicity. This study is restricted to assumed that no direct leachate emitted because ETH inventories has not leachate inventories (Doka G., 2003). As infrastructure details, this inert material landfill normally has familiar system as sanitary landfills except for base seal or collection system, which is inventories mix all of 50:50 system mixture between have/ have not of base seal. The inert landfill volume in this study is 450,000m3 and capacity is 675,000 ton of residual material. Neither leachate collecting tube nor sewer network inside the landfill body is available to this landfill type as same as gas collection system.

1.1.3. Underground deposits

In this study, the representative underground deposit is located in Germany –Europe. This system is operating under old potash or rock salt mines (figure3-6). This landfill consists of infrastructure unit that use in subsurface for underground work consists of base and side seals which made from 48m wide brick wall. In this model, there is no emission from actual underground landfill. Therefore, the burdens in the inventory stem involved transport, packaging and conditioning.

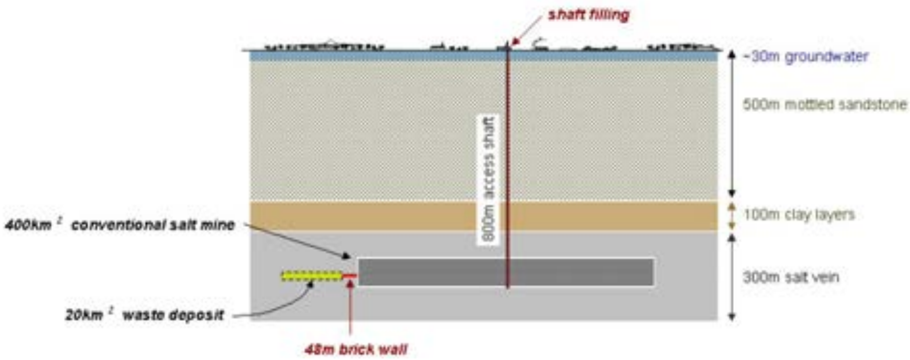


Figure A-1: the Herfa-Neurode waste deposit model obtained in Ecoinvent

As the operation of landfill, Deposit wastes are stored in steel drums, large steel containers or big bags collection system. The underground deposit is particularly use for deposits for non-radioactive waste such as incineration ashes and some hazardous chemical wastes which also related to this study in deposit of electronic components like transformers and condensers (Doka, 2009).

1.2 Recycling managing system

The recycling scheme in this study established in modular way. The overall system is the chain process connected by waste mass flow. In other words, the recycling treatment I will be connected by treatment level II. The overall system of recycling scheme is described below.

1.2.1 Recycling treatment level I

This step of recycling is defined as pretreatment of E-scrap. This stage involved the first level for the treatment of devices comprising the dismantling of entire devices into a number of different fractions either for further treatment or for disposal.

a) Manual treatment : Depollution stage

It is important to note that this system is important to ensure that hazardous substances are well manipulated and upgraded to treat in further level two recycling process. This work by using manual depollution approach in order to select the material for sequential shredding stage For example, backlight lamp in LCD screen, CRT tube, cable line or other equipment. In this study is based on Ecoinvent report No.18 in manual treatment process (Hischier R. et al., 2007).

b) Shredding and Separation steps

To prepare the materials suitable for the final refining process by grinding and separating into separated groups of material. In this study is based on Ecoinvent report No.18 researched in German and Dutch recycling units., The operational information about shredding and separation processes, It includes comprehensive infrastructure, the energy consumption of all shredding and separation activities, emissions to air and some transportation necessary for this process.

These datasets recommended that are able to use as global situation. The information provides comprising an initial shredder, a magnetic separator and an Eddy-current separator, a smaller shredder, then, thoroughly followed by a magnetic separator and an Eddy-current separator. Additionally, all processes are linked by conveyer belts (Figure 3-9). The multi output including aluminum, Ferro and copper will turn to refinery process input dataset

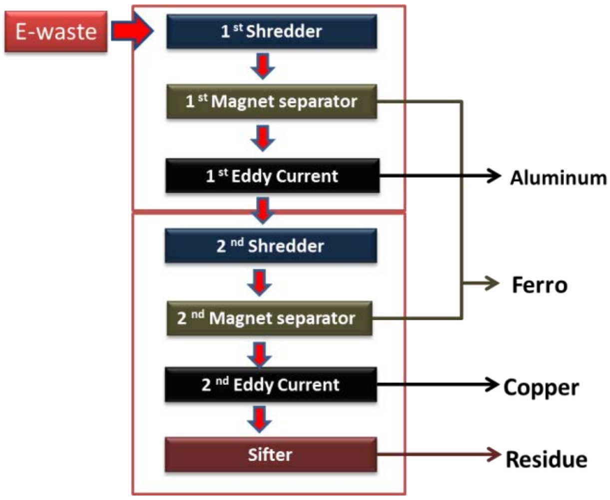


Figure A-2: The subsequently shredder process described in data source (Huisman, 2003)

1.1.2 Treatment Level 2 Recycling

This level for the treatment of WEEE devices have relevant process aim to release the impurity and recovery the PC waste scraps. This overall process is described below.

a) Ferro recycling

Metal recycling processes in this study is retrieved from Ecoinvent database report No. 10: LCI of metals, part II steel the dataset based on EU technology mix (mainly furnace with 4th hole, partly with additional evacuation of building atmosphere). For this study, the metal scraps are defined as the iron-containing materials which mainly embedded in PC equipment housing. This is import to be the major feed stock for steel recycling. The metal refining process is performed in electric arc furnace (EAF) which metal scrap will directly attend to furnace cascade process including Raw material handling and storages, furnace charging with or without scrap preheating, EAF scrap melting, steel and slag tapping, ladle furnace treatment, slag handling and continuous casting.

b) Secondary copper production

For copper recycling approach in this study, is retrieved from Ecoinvent database report No. 10: LCI of metals, part III copper production(Classen et al., 2009). The dataset established from the production of secondary copper in Germany. According to this study, the copper-containing fraction considered to be raw material scarp into copper refining including blast furnace, converters and anode furnaces. In addition, Waste water is led to a communal treatment plant as well.

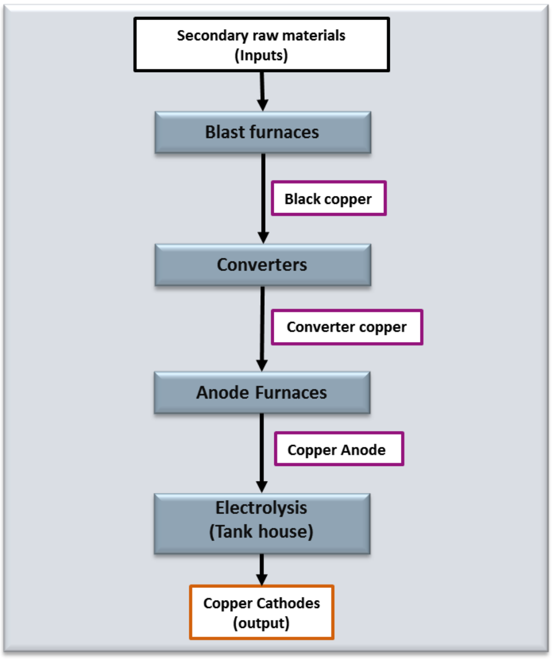


Figure A-3: Secondary copper production processes embedded in Ecoinvent No.10, Part III (Classen et al., 2009)

As the figure A-4 shown, Scrap firstly input as raw material to blast furnaces and mixed with coke material .Then, the product from this process shown as black copper which is the mattes form (containing iron sulfide) .After that, there is transferred to the converters process which will removed out the sulfur and gas. Then, converter copper will be purified again in anode furnace and cast into copper anode. Lastly, the anode is dissolved in the electrolyte and pure copper metal is deposited on the cathode.

c) Precious metal processes

The Printed wired board assembly embedded in PC equipment is defined as input to precious metal recycling scheme. The system dataset in this study are retrieved from in Ecoinvent database report No. 10: LCI of metals, part IX Gold and silver (Classen et al., 2009). The dataset here constructed from Boliden Rönnskär site recycling plant. This plant technology is based on copper-lead smelter that can refine complex ore and electronic scrap. Basically, processes have performed through several stages consist of a three consequential muti-output processes:

- **Secondary Copper Conversion**

This overall stage is described in figure A-4. This step is firstly input Scrap to Kaldo furnace which plastic in the input raw material provides sufficient energy for the smelting process. The large amounts of energy released are recycled and converted to electricity or district heating. This process will turn E-waste scrap into black copper form and then subsequently send to Aisle converter for removing iron, sulfur and other impurities. Overall, the result is shown as multi-output that including the blister copper (inputs into the next step) and secondary lead, respectively.

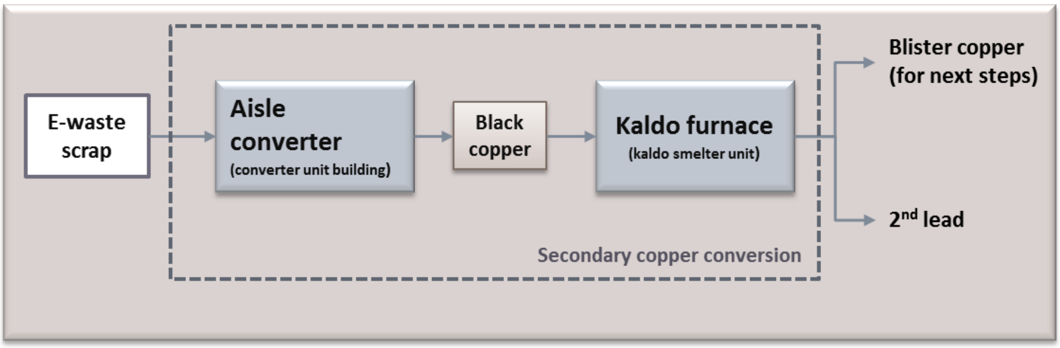


Figure A-4: The unit process presentation of the conversion step within the secondary copper plant

- **Secondary copper refining**

This step turn blister copper which containing precious metal is poured anode molds. Then, the complete solid anode sheets which contain precious metal substances inside will be processed in the electrolytic refinery (Figure A-5). In principle, this process will remove impurities in the copper anode and several precious metals including gold and silver. The copper in here is changes to cathode copper and other precious metal are also coagulated as a sludge call anode-slime.

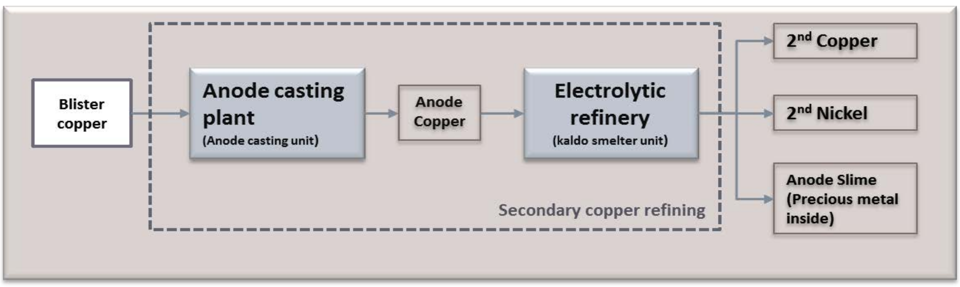


Figure A-5: The unit process of the electro refining step within the secondary copper plant

- **Precious metal refining secondary copper**

This is the last stages of precious metal refining which contains two main sector are slime conversion and precious metal extraction(figure A-6). Focusing on the anode slime conversion, firstly, the pressure leaching and drying process are require to remove out the remaining copper and dry the residues in anode slime. Secondly, Smelting and converting of the residue are acquire to refine the rich Doree metal which casted into anode .Thirdly, Doree metal will be input into each electrowining of silver (Moebius electrolysis) and gold

(Wohlwill electrolysis).The other precious platinum group metal is also recovered through electrolytic refining. The results will be shown as the multiple outputs through this step

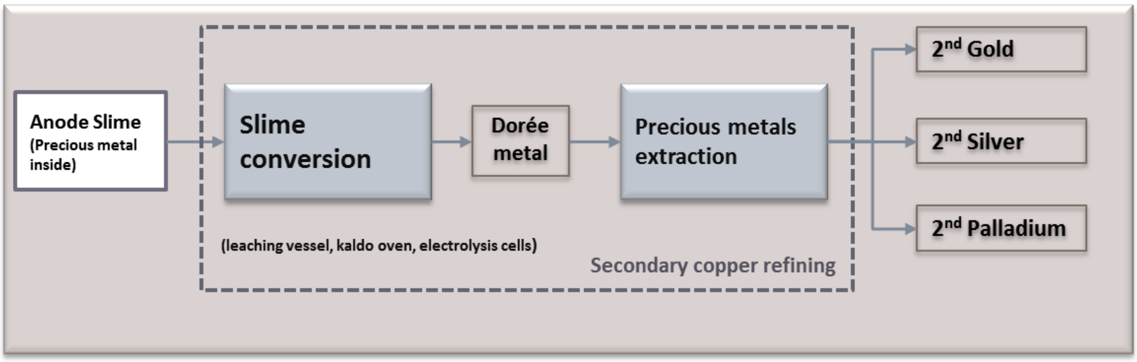


Figure A-6: The unit process of the precious metal refinery within the secondary copper plant

d) Aluminum recycling

Aluminum recycling processes is embedded already in Ecoinvent database report No. 10: LCI of metals, part I Aluminum production(Classen et al., 2009) (Classen et al., 2007) which the dataset based on Swiss database. The recycling process of aluminum requires melting furnaces to refine. After that, the molten aluminum is transferred into a holding furnace, to remove impurities before casting the aluminum into ingot.

e) CRT tube treatment process

CRT tube is the important part mainly found in CRT computer screen in this study. The information about end-of-life management of this device were retrieved from Ecoinvent database No.18 which mainly based on SwissGlas Ltd recycling dataset (Zumbühl, 2006). The main process includes crushing and removal coating and metals inside as shown on figure A-7. CRT tube will sieve and separate into fine glass cullet, and then cut off other ferrous metals by magnetic separator. The thin layer on glass commonly known as the iron oxide coating from the funnel glass have to delete for satisfied in term of environmental safety and recycling standard. Hence, these coatings are physically removed by washing the glass cullet. After that, the cleaned cullet will be dried using electric dryer .For deeper separation. The density of glass will be detect in order to separate glass cullet type (CRT panel glass is less density than funnel glass due to less lead content) .Apart of glass fractions, waste fraction is assume to be terminated by incineration.

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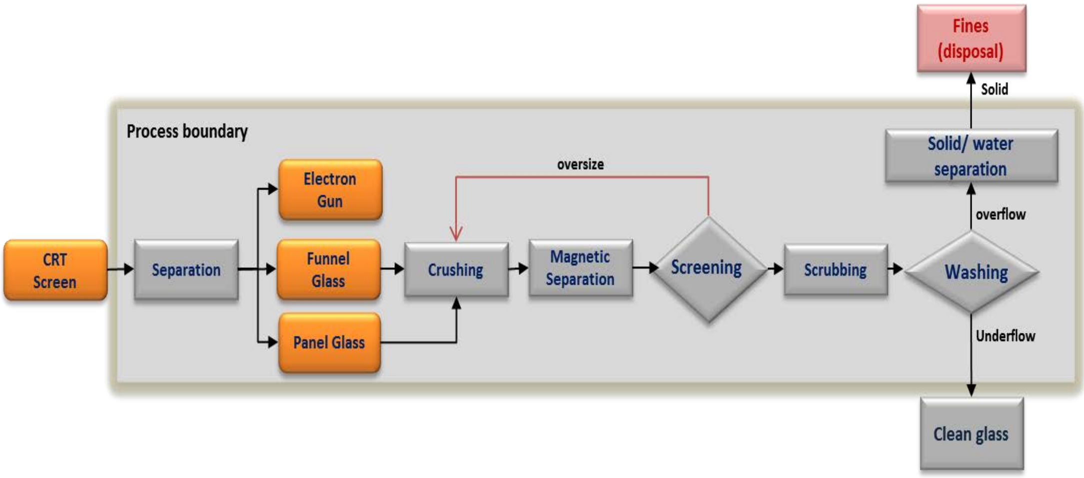

Figure A-7: CRT glass recycling system in this study (Zumbühl, 2006).

Overall, the data source in this study comprises all activities for the separation of CRT tubes from devices to glass cullet fractions which shown in term of the energy consumption, the using of infrastructure and emission into several phase (LCI)

f) LCD screen backlight lamp treatment

LCD screen backlight lamp in this study obtained from European lamp recycling industries obtained in Ecoinvent database report No.18 which obtained dry treatment technology. For this case, this dataset suitable to support research because established as state-of-art approach by many companies(Reimer , 2001). However, these might be different in some detailed but there have a similar operational processes as shown an overall process in figure A-8.(Reimer and Bernecker, 1992)

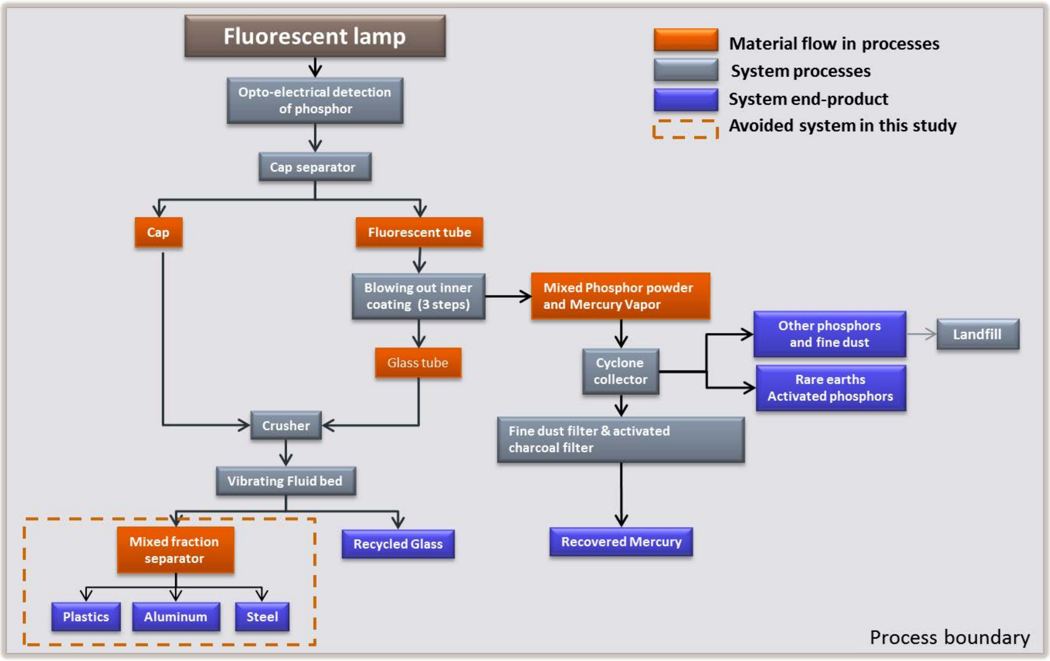

Figure A-8: Fluorescent lamp recycling system boundary process (Reimer and Bernecker, 1992)

LCD backlight lamp is taken from previous step in depollution step to here. Firstly, Cutting cap process take out, then, fluorescent tubes have to enter the blowing step in order to split out the inner coating. After this step, coating material which contained phosphor powder and mercury vapor is will be collected and separated by filter. For glass recycling, the cleaned glass tube would be grind into glass cullet and output as further raw material. However, the recycled metal from cap of fluorescent lamp is consider to avoided in this study because CCFL lamp in LCD backlight does not existed.

Appendix B

Bill of Materials

Bill of materials for PC equipment disassembly analysis

Due to the inaccessible material data from PC 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.

- **Bill of material using for CRT and LCD disassembly analysis**

Both of CRT and LCD computer screen disassembled following the material list in previous research by Socolof et. al (2001)**.** This studied shown the comprehensive view of material and appropriate for this study also. The table B-1 is the CRT material list and table B-2 is the LCD material list.

Table B-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 Funnel 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 B-2: **the bill of components in LCD computer 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
3 LCD Controller	4.1 LDVS/LCD interface cable
4 Power Supply Assembly	5.1 Metal housing
	5.2 Insulator plate in housing
	5.3 Aluminum heat sink
5 LCD Inverter	6.1 Inverter cable line
6 Power Switch	7.1 Human interface button
7 Controller Board	8.1 Printed wired board assembly (controller board , Universal LVDS/LCD interface board, Power supply control board, Inverter board Switch console board)
8 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

- **Bill of material using in PC disassembly**

Disassembly lists of desktop PC modified from other literatures as shown on table B-3 (Atlantic Consulting, 1998; Hikwama, 2005 ; Mohite & Zhang, 2005). This list involved the overall parts of one regular computer.

Table B-3: The bill of components in desktop computer

Sub-Assembly	Components
1. CPU Microchip	1.1 Integrated circuit (logic type)
2. Cooling body for CPU	2.1 ventilation fan 2.2 Printed wired board assembly 2.3 CPU heat sink
3. ATX-Motherboard	3.1 Mainboard Printed wired board assembly
4. Random-access memory (RAM)	4.1 RAM Printed wired board assembly
5. Graphic Processing Unit (GPU)	5.1 Printed Wired Board Assembly
6. Local Area Network (LAN)	6.1 Printed Wired Board Assembly
7. Cooling unit for GPU card	7.1 ventilation fan
8. Hard disk drive (HDD)	8.1 Top cover 8.2 Metal frame 8.3 Pointer assembly 8.4 plastic parts 8.5 main back frame 8.6 hard disk platter 8.7 screws 8.8 Printed wiring board assembly (mixed mounted type)
9. Power Supply	9.1 Housing material 9.2 ventilation fan 9.3 Printed wiring board assembly (Pb containing) 9.4 Plugs(inlet and outlet) 9.5 ribbon Cable (20-pin) 9.6 computer cable
10. CD/DVD Rom	10.1 Bottom cover 10.2 Plastic frame 10.3 optical drive motor 10.4 front cover 10.5 Disk Tray 10.6 Screws 10.7 Printed wired board assembly
11. 3½" floppy drive	11.1 plastic part 11.2 headset assembly 11.3 driving motor 11.4 metal casing 11.5 screws / spring 11.6 printed wired board assembly
12. Desktop cabinet	12.1 steel housing 12.2 side cover plate 12.3 plastic front cover 12.4 screws 12.6 ventilation fan 12.6 cable - inner cover steel 12.7 PWB switch board

Appendix C

ReCiPe 2008 Methodology

C) The ReCiPe Endpoint methodology

C.1 General Information

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 C-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

C.2 Endpoint impact and Singlescore using in this study

Typically, this method has to point of focus which there is both advantages and disadvantages to using midpoints and endpoints. Midpoints are generally moderately provided accuracy of data, but it 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 to visualize. Endpoints are expressed in concrete 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. In particularly, 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. **(Figure C-1)** For calculating in SimaPro program, three steps are needed:

Firstly, This 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 analyses the damages of these flows which might causing the Human Health, Ecosystem Quality and Resources. The way to success 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.

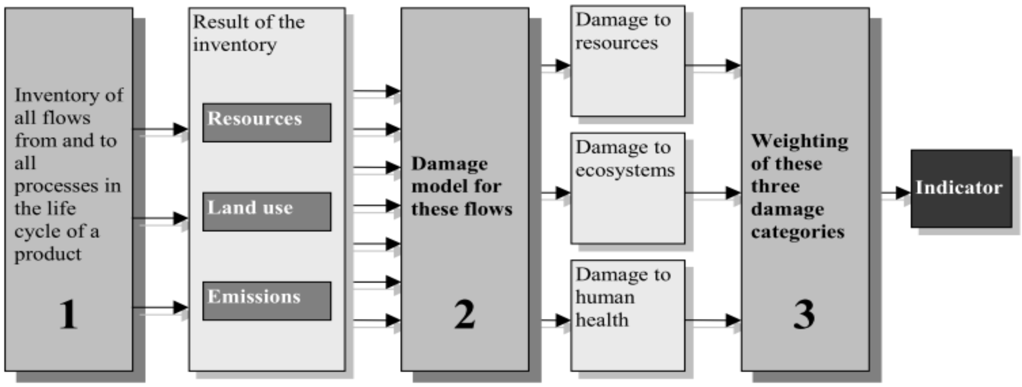

Figure c-1: General procedure for the calculation of singlescore indicator. The light colored boxes refer to procedures; the dark colored boxes refer to intermediate results.

C.3 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.

C.4 Details of midpoint impact related to endpoint impact of this study

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)

C.4 Details of midpoint impact related to endpoint impact of this study

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)
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 ×yr. of agricultural land) urban land occupation potential (m^2 ×yr. 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)

C.4 Details endpoint impact of this study

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 D

Disassembly analysis results

A. The Disassembly analysis results of desktop computer

Table C-1: Disassembly Analysis of desktop PC

Components	Sub-Assembly	Amount (kg)
1. CPU Microchip	1.1 Integrated circuit (logic type)	1.900E-02
2. Cooling body for CPU	2.1 ventilation fan 2.2 Printed wired board assembly 2.3 CPU heat sink	2.776E-01 4.334E-02 1.140E-01
3. ATX-Motherboard	3.1 Mainboard Printed wired board assembly	6.481E-01
4. Random-access memory (RAM)	4.1 RAM Printed wired board assembly	1.599E-01
5. Graphic Processing Unit (GPU)	5.1 Printed Wired Board Assembly	9.600E-02
6. Local Area Network (LAN)	6.1 Printed Wired Board Assembly	4.400E-02
7. Cooling unit for GPU card	7.1 ventilation fan	3.500E-02
8. Hard disk drive (HDD)	8.1 Top cover 8.2 Metal frame 8.3 Pointer assembly 8.4 plastic parts 8.5 main back frame 8.6 hard disk platter 8.7 screws 8.8 Printed wiring board assembly (mixed mounted type)	1.250E-01 4.800E-02 5.000E-03 2.000E-03 2.280E-01 2.300E-02 6.000E-03 5.000E-02
9. Power Supply	9.1 Housing material 9.2 ventilation fan 9.3 Printed wiring board assembly (Pb containing) 9.4 Plugs(inlet and outlet) 9.5 ribbon Cable (20-pin) 9.6 computer cable	3.450E-01 8.400E-02 1.430E-01 1.490E-01 1.960E-01 6.100E-01
10. CD/DVD Rom	10.1 Bottom cover 10.2 Plastic frame 10.3 optical drive motor 10.4 front cover 10.5 Disk Tray 10.6 Screws 10.7 Printed wired board assembly	5.417E-01 1.999E-01 2.215E-02 1.500E-02 4.500E-02 8.000E-03 6.120E-02
11. 3½" floppy drive	11.1 plastic part 11.2 headset assembly 11.3 driving motor 11.4 metal casing 11.5 screws / spring 11.6 printed wired board assembly	9.000E-03 1.920E-01 7.800E-02 1.000E-01 4.000E-03 2.600E-02
12. Desktop cabinet	12.1 steel housing 12.2 side cover plate 12.3 plastic front cover 12.4 screws 12.5 ventilation fan 12.6 cable - inner cover steel 12.7 PWB switch board	2.283E+00 1.763E+00 2.800E-01 2.100E-02 1.800E-01 1.240E-01 1.100E-02
	Total	9.667E+00

Table C-2: allocate desktop PC into sub-components using ecoinvent database 2.1

Components	Sub-Assembly	Materials or Sub-Assembly level 2	Amount (Kg)
1. CPU Microchip	**1.1 Integrated circuit (logic type)**	Organic substances	1.656E-04
		Copper	1.579E-03
		Epoxy resin	3.447E-03
		SiO2	5.170E-03
		Epoxy resin	4.815E-05
		Glass fiber reinforced plastic	6.103E-03
		Gold	2.084E-04
		Lead (Pb)	7.126E-04
		Nickel (Ni)	6.317E-05
		Silver (Ag)	1.444E-04
		Tin (Sn)	1.213E-03
		Zinc (Zn)	1.456E-04
		Total	**1.900E-02**
2. Cooling body for CPU	**2.1 ventilation fan**	Brass	2.660E-02
		Polyethylene plastic (HDPE)	2.510E-01
	2.2 Printed wired board assembly (PWBA)	Aluminum steel	8.090E-03
		Capacitor-Electrolyte type (< 2cm height)	1.104E-03
		Capacitor-Electrolyte type (> 2cm height)	1.868E-03
		Capacitor-film type (through-hole mounting)	3.864E-03
		Capacitor-Unspecified type	6.346E-04
		Diode-glass type (through-hole mounting)	3.075E-04
		Inductor-ring core choke type	1.672E-02
		Integrated circuit-logic type	9.080E-04
		Printed wiring board (lead-containing surface)	3.787E-03
		Printed wiring board (lead-free surface)	5.302E-03
		Resistor-metal film type (through-hole mounting)	1.037E-03
		Transformer-high voltage	4.891E-03
		Transformer-low voltage	1.553E-03
		Transistor-wired big size (through-hole mounting)	1.326E-03
		Transistor-wired small size (through-hole mounting)	4.530E-05
	2.3 Heat sink	Aluminum steel	1.140E-01
		Total	**4.430E-01**
3. ATX-Motherboard	**3.1 Mainboard Printed wired board assembly**	Capacitor-Electrolyte type (< 2cm height)	1.168E-01
		Capacitor-SMD type(surface-mounting)	7.042E-03
		Capacitor-Tantalum type (through-hole mounting)	2.921E-02
		Connector-peripheral type	3.912E-02
		Connector-PCI bus	1.174E-01
		Printed wiring board (lead-free surface mount)	2.282E-01
		Diode-Glass type (SMD type, surface mounting)	1.095E-03
		Inductor-ring core choke type	7.303E-03
		Integrated circuit (logic type)	5.216E-02
		Integrated circuit (memory type)	1.304E-02
		Light emitting diode (LED)	4.697E-04
		Resistor-SMD type (surface mounting)	7.042E-03
		Transistor-wired small size (through-hole mounting)	2.921E-02
		Total	**6.481E-01**
4. Random-access memory (RAM)	**4.1 RAM Printed wired board assembly**	Capacitor-SMD type(surface-mounting)	5.113E-03
		Connector-PCI bus	3.036E-03
		Diode-Glass type (SMD type, surface mounting)	6.392E-04
		Integrated circuit-logic type	2.716E-02
		Light emitting diode (LED)	1.597E-04
		Resistor-SMD type (surface mounting)	3.675E-03
		Transistor-SMD type (surface mounting)	1.598E-03
		Printed wiring board (lead-free surface mounting)	1.186E-01

		Total	**1.599E-01**
5. Graphic Processing Unit card (GPU card)	**5.1 Printed Wired Board Assembly**	Capacitor-SMD type(surface-mounting)	1.395E-03
		Connector-PCI bus	8.283E-04
		Diode-Glass type (SMD type, surface mounting)	1.744E-04
		Integrated circuit-logic type	7.411E-03
		Light emitting diode, LED	4.358E-05
		Printed wiring board lead-containing surface mount	1.617E-02
		Printed wiring board lead-free surface mount	1.617E-02
		Resistor -SMD type (surface mounting)	1.003E-03
		Transistor,-SMD type (surface mounting)	4.359E-04
		Aluminum alloy	8.236E-03
		Capacitor-electrolyte type (< 2cm height)	1.124E-03
		Capacitor-electrolyte type (> 2cm height)	1.901E-03
		Capacitor-film type (through-hole mounting)	3.934E-03
		Capacitor-unspecified type	6.461E-04
		Diode-Glass type (through-hole mounting)	3.131E-04
		Inductor-ring core choke type	1.702E-02
		Integrated circuit-logic type	9.244E-04
		Printed wiring board (through-hole, lead containing	3.856E-03
		surface)	5.398E-03
		Printed wiring board (through-hole, lead-free	1.056E-03
		surface)	4.979E-03
		Resistor-metal film type, (through-hole mounting)	1.581E-03
		Transformer-high voltage	1.350E-03
		Transformer-low voltage	4.612E-05
		Transistor-wired big size (through-hole mounting)	
		Transistor-wired small size (through-hole mounting)	
		Total	**9.600E-02**
6. Local Area Network Card (LAN card)	**6.1 Printed Wired Board Assembly**	Capacitor-SMD type(surface-mounting)	6.394E-04
		Connector-PCI bus	3.796E-04
		Diode-Glass type (SMD type, surface mounting)	7.992E-05
		Integrated circuit-logic type	3.397E-03
		Light emitting diode, LED	1.998E-05
		Printed wiring board lead-containing surface mount	7.413E-03
		Printed wiring board lead-free surface mount	7.413E-03
		Resistor -SMD type (surface mounting)	4.595E-04
		Transistor,-SMD type (surface mounting)	1.998E-04
		Aluminum alloy	3.775E-03
		Capacitor-electrolyte type (< 2cm height)	5.152E-04
		Capacitor-electrolyte type (> 2cm height)	8.715E-04
		Capacitor-film type (through-hole mounting)	1.803E-03
		Capacitor-unspecified type	2.961E-04
		Diode-Glass type (through-hole mounting)	1.435E-04
		Inductor-ring core choke type	7.800E-03
		Integrated circuit-logic type	4.237E-04
		Printed wiring board (through-hole, lead containing	1.767E-03
		surface)	2.474E-03
		Printed wiring board (through-hole, lead-free	4.839E-04
		surface)	2.282E-03
		Resistor-metal film type, (through-hole mounting)	7.246E-04
		Transformer-high voltage	6.187E-04
		Transformer-low voltage	2.114E-05
		Transistor-wired big size (through-hole mounting)	
		Transistor-wired small size (through-hole mounting)	
		Total	**4.400E-02**
7. Cooling unit for GPU card	**7.1 ventilation fan**	Brass	2.830E-03
		HDPE	2.670E-02
		Aluminum alloy	8.606E-04
		Capacitor-Electrolyte type (< 2cm height)	1.175E-04
		Capacitor-Electrolyte type (> 2cm height)	1.987E-04

		Capacitor-film type (through-hole mounting) Capacitor-Unspecified type Diode-Glass type (through-hole mounting) Inductor-ring core choke type Integrated circuit (logic type) Printed wiring board (through-hole, lead-containing surface) Printed wiring board (through-hole, lead-free surface) Resistor-metal film type (through-hole mounting) Transformer -high voltage Transformer -low voltage Transistor-wired big size (through-hole mounting) Transistor-wired small size (through-hole mounting)	4.111E-04 6.751E-05 6.751E-05 3.271E-05 1.778E-03 9.660E-05 4.029E-04 5.641E-04 1.103E-04 5.203E-04 1.652E-04 1.411E-04 4.819E-06
		Total	**3.500E-02**
8. Hard disk drive (HDD)	**8.1 Top cover**	Aluminum steel	1.250E-01
	8.2 Metal frame	Steel -low-alloyed	4.800E-02
	8.3 Pointer assembly	Aluminum steel	5.000E-03
	8.4 plastic parts	Acrylonitrile-butadiene-styrene (ABS) plastic	2.000E-03
	8.5 main back frame	Aluminum steel	2.280E-01
	8.6 hard disk platter	Aluminum steel	2.300E-02
	8.7 screws	Chromium steel (18/8)	6.000E-03
9. Power Supply	**8.8 Printed wiring board assembly**	Capacitor-SMD type (surface-mounting) Connector-PCI bus Diode-Glass type (SMD type, surface mounting) Integrated circuit - logic type Light emitting diode, LED, Printed wiring board - lead-containing surface mount Printed wiring board - lead-free surface mount Resistor- SMD type (surface mounting) Transistor - SMD type (surface mounting) Aluminum alloy Capacitor - electrolyte type(< 2cm height) Capacitor- electrolyte type (> 2cm height) Capacitor- film type (through-hole mounting) Capacitor- unspecified type Diode-Glass type (through-hole mounting) Inductor -ring core choke type Integrated circuit- logic type Printed wiring board -through-hole (lead- containing) Printed wiring board -through-hole (lead-free) Resistor- metal film type (through-hole mounting) Transformer - high voltage Transformer - low voltage Transistor - wired big size (through-hole mounting) Transistor - wired small size (through-hole mounting)	3.633E-04 2.157E-04 4.541E-05 1.930E-03 1.135E-05 4.212E-03 4.212E-03 2.611E-04 1.135E-04 2.145E-03 2.927E-04 4.952E-04 1.025E-03 1.682E-04 8.152E-05 4.432E-03 2.407E-04 1.004E-03 1.406E-03 2.749E-04 1.297E-03 4.117E-04 3.515E-04 1.201E-05
		total	**4.620E-01**
	9.1 Housing material	**Steel (low-alloy)**	3.450E-01

10. Power Supply	**9.2 ventilation fan**	**Brass** **Polyethylene, HDPE plastic** **Aluminum alloy** **Capacitor - electrolyte type (< 2cm height)** **Capacitor - electrolyte type (> 2cm height)** **Capacitor - film type (through-hole mounting)** **Capacitor - unspecified type** **Diode-Glass type (through-hole mounting)** **Integrated circuit - logic type**	6.793E-03 6.408E-02 2.065E-03 2.819E-04 4.768E-04 9.866E-04 1.620E-04 7.851E-05 4.268E-03
	9.2 ventilation fan	Inductor - ring core choke type Printed wiring board - through-hole (lead-containing) Printed wiring board - through-hole (lead-free) Resistor - metal film type (through-hole mounting) Transformer - high voltage use Transformer- low voltage use Transistor - wired big size (through-hole mounting) Transistor - wired small size (through-hole mounting)	2.318E-04 9.669E-04 1.354E-03 2.648E-04 1.249E-03 3.965E-04 3.385E-04 1.157E-05
	9.3 Printed wiring board assembly (Pb containing)	Aluminum alloy Capacitor - electrolyte type (< 2cm height) Capacitor - electrolyte type (> 2cm height) Capacitor - film type (through-hole mounting) Capacitor - unspecified type Diode-Glass type (through-hole mounting) Inductor -ring core choke type Integrated circuit - logic type Printed wiring board -through-hole (lead-containing surface) Resistor- metal film type (through-hole mounting) Transformer - high voltage use Transformer - low voltage use Transistor - wired big size (through-hole mounting) Transistor - wired small size (through-hole mounting)	1.827E-02 6.136E-03 1.038E-02 3.168E-03 3.513E-03 9.133E-04 3.599E-02 4.344E-04 2.128E-02 1.706E-03 2.724E-02 8.645E-03 5.075E-03 2.523E-04
	9.4 Plugs (inlet and outlet)	Brass Copper Polyethylene plastic (HDPE) polyvinyl chloride plastic (PVC)	2.585E-02 8.215E-03 1.304E-02 1.019E-01
	9.5 Ribbon Cable (20-pin)	Brass Copper Polyethylene plastic (HDPE) polyvinyl chloride plastic (PVC)	6.479E-04 3.037E-02 1.346E-01 3.037E-02
	9.6 Computer cable	Copper polyvinyl chloride plastic (PVC) Synthetic rubber polyvinyl chloride plastic (PVC) Polyurethane (PU)	1.833E-01 3.055E-01 1.064E-01 8.578E-03 6.302E-03
	9.7 Main Inductor	Inductor-ring core choke type	9.100E-02
	9.8 Main Capacitor	Capacitor - electrolyte type (< 2cm height)	7.300E-02
	9.9 Transformer	Transformer- low voltage use	1.050E-01
		Total	**1.796E+00**
10. **CD/DVD Rom**	**10.1 Bottom cover**	Steel - low-alloyed	5.417E-01
	10.2 Plastic frame	Polyethylene, HDPE, granulate, at plant/RER U	1.999E-01
	10.3 optical drive motor	Copper	2.215E-02
	10.4 front cover	Acrylonitrile-butadiene-styrene plastic (ABS)	1.500E-02
	10.5 Disk Tray	Polycarbonate plastic	4.500E-02
	10.6 Screws	Chromium steel 18/8	8.000E-03
		Capacitor-SMD type (surface-mounting)	8.893E-04

	10.7 Printed wired board assembly	Connector-PCI bus Diode-Glass type (SMD type, surface mounting) Integrated circuit, IC, logic type, at plant/GLO U Light emitting diode, LED, at plant/GLO U Printed wiring board - lead-containing surface mount Printed wiring board - lead-free surface mount Resistor- SMD type (surface mounting) Transistor - SMD type (surface mounting) Aluminum alloy Capacitor - electrolyte type(< 2cm height) Capacitor- electrolyte type (> 2cm height) Capacitor- film type (through-hole mounting) Capacitor- unspecified type Diode-Glass type (through-hole mounting) Inductor -ring core choke type Integrated circuit- logic type Printed wiring board -through-hole (lead-containing) Printed wiring board -through-hole (lead-free) Resistor- metal film type (through-hole mounting) Transformer - high voltage Transformer - low voltage Transistor - wired big size (through-hole mounting) Transistor - wired small size (through-hole mounting)	5.280E-04 1.112E-04 4.724E-03 2.778E-05 1.031E-02 1.031E-02 6.392E-04 2.779E-04 5.250E-03 7.166E-04 1.212E-03 2.508E-03 4.119E-04 1.996E-04 1.085E-02 5.893E-04 2.458E-03 3.441E-03 6.730E-04 3.174E-03 1.008E-03 8.606E-04 2.940E-05
		Total	**8.929E-01**
11. 3½" floppy drive	11.1 plastic part	Polyethylene plastic (HDPE)	9.000E-03
	11.2 headset assembly	Steel ,low-alloy	1.920E-01
	11.3 driving motor	Aluminum steel	7.800E-02
	11.4 metal casing	Aluminum steel	1.000E-01
	11.5 screws / spring	Chromium steel	4.000E-03
	11.6 Printed wiring board assembly	Capacitor-SMD type (surface-mounting) Connector-PCI bus Diode-Glass type (SMD type, surface mounting) Integrated circuit, IC, logic type, at plant/GLO U Light emitting diode, LED, at plant/GLO U Printed wiring board - lead-containing surface mount Printed wiring board - lead-free surface mount Resistor- SMD type (surface mounting) Transistor - SMD type (surface mounting) Aluminum alloy Capacitor - electrolyte type(< 2cm height) Capacitor- electrolyte type (> 2cm height) Capacitor- film type (through-hole mounting) Capacitor- unspecified type Diode-Glass type (through-hole mounting) Inductor -ring core choke type Integrated circuit- logic type Printed wiring board -through-hole (lead-containing) Printed wiring board -through-hole (lead-free) Resistor- metal film type (through-hole mounting) Transformer - high voltage use Transformer - low voltage use Transistor - wired big size (through-hole mounting) Transistor - wired small size (through-hole mounting)	3.778E-04 2.243E-04 4.723E-05 2.007E-03 1.180E-05 4.380E-03 4.380E-03 2.715E-04 1.181E-04 2.231E-03 3.044E-04 5.150E-04 1.066E-03 1.750E-04 8.479E-05 4.609E-03 2.504E-04 1.044E-03 1.462E-03 2.859E-04 1.349E-03 4.282E-04 3.656E-04 1.249E-05
		Total	**4.090E-01**
12. Desktop cabinet	12.1 steel housing	Steel ,low-alloy	2.283E+00
	12.2 side cover plate	Steel ,low-alloy	1.763E+00

	12.3 front plastic cover	Acrylonitrile-butadiene-styrene plastic (ABS)	2.800E-01
	12.4 screws	Chromium steel (18/8)	2.100E-02
		Brass	1.456E-02
		Polyethylene plastic (HDPE)	1.373E-01
		Aluminum alloy	4.426E-03
		Capacitor - electrolyte type (< 2cm height)	6.041E-04
		Capacitor - electrolyte type (> 2cm height)	1.022E-03
		Capacitor - film type(through-hole mounting)	2.114E-03
	12.5 ventilation fan	Capacitor, unspecified, at plant/GLO U	3.472E-04
		Diode-Glass type (through-hole mounting)	1.682E-04
		Inductor - ring core choke type	9.145E-03
		Integrated circuit - logic type	4.968E-04
		Printed wiring board - through-hole (lead-	2.072E-03
		containing)	2.901E-03
		Printed wiring board - through-hole (lead-free)	5.674E-04
		Resistor- metal film type (through-hole mounting)	2.676E-03
		Transformer - high voltage use	8.496E-04
		Transformer- low voltage use	7.254E-04
		Transistor - wired big size (through-hole mounting)	2.478E-05
		Transistor - wired small size (through-hole mounting)	
		Brass	4.099E-04
	12.6 cable - inner cover steel	Copper	1.921E-02
		Polyethylene plastic (HDPE)	8.516E-02
		polyvinyl chloride plastic (PVC)	1.921E-02
	12.7 PWB switch board	Capacitor-SMD type (surface-mounting)	1.598E-04
		Connector-PCI bus	9.491E-05
		Diode-Glass type (SMD type, surface mounting)	1.998E-05
		Integrated circuit, IC, logic type, at plant/GLO U	8.492E-04
		Light emitting diode, LED, at plant/GLO U	4.994E-06
		Printed wiring board - lead-containing surface	1.853E-03
		mount	1.853E-03
		Printed wiring board - lead-free surface mount	1.149E-04
		Resistor- SMD type (surface mounting)	4.995E-05
		Transistor - SMD type (surface mounting)	9.437E-04
		Aluminum alloy	1.288E-04
		Capacitor - electrolyte type(< 2cm height)	2.179E-04
		Capacitor- electrolyte type (> 2cm height)	4.508E-04
		Capacitor- film type (through-hole mounting)	7.403E-05
		Capacitor- unspecified type	3.587E-05
		Diode-Glass type (through-hole mounting)	1.950E-03
		Inductor -ring core choke type	1.059E-04
		Integrated circuit- logic type	4.418E-04
		Printed wiring board -through-hole (lead-	6.185E-04
		containing)	1.210E-04
		Printed wiring board -through-hole (lead-free)	5.706E-04
		Resistor- metal film type (through-hole mounting)	1.812E-04
		Transformer - high voltage use	1.547E-04
		Transformer - low voltage use	5.284E-06
		Transistor - wired big size (through-hole mounting)	
		Transistor - wired small size (through-hole mounting)	
		Total	**4.662E+00**
Total computer weight			**9.667E+00**

Table C-3: material composition in one computer

Material Categories	Material description	Amount (kg)	%
1. **Ferrous metal**	Iron Steel	1.142E-01 5.173E+00	1.18E+00 5.35E+01
2. **Non-ferrous metal**	Ag Al Au Cr Cu Mn Mo Ni Pb Pd Si Sn Ta Zn Zr	7.434E-03 8.611E-01 1.718E-03 3.901E-02 7.005E-01 1.125E-03 4.052E-04 5.272E-03 2.771E-02 3.440E-05 1.652E-04 2.012E-02 1.150E-02 3.434E-02 2.746E-03	7.69E-02 8.91E+00 1.78E-02 4.04E-01 7.25E+00 1.16E-02 4.19E-03 5.45E-02 2.87E-01 3.56E-04 1.71E-03 2.08E-01 1.19E-01 3.55E-01 2.84E-02
3. **Inorganic compounds**	Magnesium-Silicon (Mg-Si) Phosphorus compound other inorganic compounds	1.347E-06 4.261E-06 3.322E-02	3.44E-01 1.39E-05 4.41E-05
4. **Oxide ceramic**	SiO2	8.941E-02	9.25E-01
5. **Plastics**	ABS Epoxy HDPE LLDPE Nylon other(plastics) other(thermoplastics) PC PE PET PMMA PP PU PVC	2.970E-01 9.017E-02 9.207E-01 3.896E-04 1.384E-01 1.938E-02 3.995E-03 1.908E-01 8.702E-02 1.106E-02 8.619E-05 1.392E-03 6.714E-03 4.987E-01	3.07E+00 9.33E-01 9.52E+00 4.03E-03 1.43E+00 2.01E-01 4.13E-02 1.97E+00 9.00E-01 1.14E-01 8.92E-04 1.44E-02 6.95E-02 5.16E+00
6. **Rubber**	synthetic rubber	1.248E-01	1.29E+00
7. **Glass**	flat glass	1.309E-01	1.35E+00
8. **Paper**	Kraft paper	1.643E-02	1.70E-01
9. **Organic compounds**	Other	5.753E-03	5.95E-02
Total		**9.667E+00**	**1.00E+02**

B. the Disassembly analysis results of CRT Computer Screen

Table C-4: Disassembly Analysis of CRT Screen

Subassembly	components	Material	Weight kg)
1. **cabinet**	1.1 Base 1.2 Front 1.3 Back cover 1.4 Back metal sheet 1.5 Inner cover	ABS ABS ABS steel steel	2.940E-01 4.180E-01 1.046E+00 6.490E-01 2.880E-01
		Total	**2.695E+00**

2. De-magnetic coil	2.1 Copper coil around CRT tube 2.2 Coated wrapped	Cu PU	9.540E-02 1.260E-02
		Total	**1.080E-01**
3. anode connection	3.1 Anode steel 3.2 Anode rubber cap 3.3 Anode cap insert 3.4 Copper wire	steel rubber steel Cu	2.124E-03 1.056E-02 2.318E-03 2.400E-02
		Total	**3.900E-02**
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)	PS PS PS PS PS Fe Cu Cu Cu Polysulfone Cu Zn rubber	1.817E-02 1.714E-02 5.143E-03 4.572E-03 1.657E-02 3.379E-01 1.537E-01 1.245E-01 4.572E-04 1.875E-02 1.680E-03 7.201E-04 1.372E-02
		Total	**7.130E-01**
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	steel PC other(plastic) PC PC Al steel	1.896E-02 5.668E-03 2.834E-03 4.105E-03 1.065E-02 7.818E-04 5.400E-02
		Total	**9.700E-02**

6. Controller, switch and power supply board	6.**1 Printed Wired Board Assembly**	Ag	1.807E-03
		Al	7.159E-02
		Au	6.312E-04
		BaSO4	6.410E-03
		Cr	5.681E-06
		Cu	1.588E-01
		Epoxy	3.534E-02
		Glass	7.412E-02
		Iron	2.583E-02
		LLDPE	3.542E-04
		Mb	2.154E-04
		Mn	2.998E-05
		Ni	2.161E-03
		other(inorganic)	6.993E-03
		other(organic)	3.081E-03
		other(plastics)	3.129E-02
		paper	2.058E-03
		Pb	1.345E-02
		PC	6.735E-02
		Pd	1.747E-05
		PE	4.927E-02
		PET	1.915E-03
		PMMA	4.040E-05
		PP	1.572E-03
		PU	8.222E-06
		PVC	1.295E-03
		rubber	8.034E-04
		Si	5.398E-05
		silicon	6.312E-07
		SiO2	3.419E-02
		Sn	9.063E-03
		steel	5.508E-04
		Ta	3.064E-04
		Zn	3.408E-03
	6.**4 Fly-back Transformer**	Cu	2.409E-02
		Epoxy	8.487E-02
		Fe	1.147E-01
		PC	3.216E-02
		Steel	1.146E-03
	6.2 Heat sink (electron gun PWBA board)	Al	1.400E-02
	6.3 Heat sink (Power supply PWBA board)	Al	7.100E-02
		Total	**9.460E-01**
9. CRT Tube	**7.1 Funnel glass**	Pb	8.044E-01
		SiO2	1.879E+00
	7.2 Panel glass	Ni	2.049E-01
		SiO2	6.664E+00
		Zn	2.049E-01
	7.3 Frit	Pb	5.619E-02
		SiO2	1.498E-03
		Zn	8.991E-03
	7.4 Glass coated (aquadag)**	graphite	2.059E-02
	7.5 Shadow mask(invar)	Ni	9.813E-02
		steel	1.740E-01
	7.6 Phosphor	Zn	1.019E-02
10. Other part	**8.1 Aluminum connector**	Al	1.900E-02
	8.2 Rubber feet	rubber	3.000E-02
	8.3 Screws	steel	1.032E-01
		Total	**1.522E-01**

Total	1.488E+01

Table C-5: Material Composition in CRT computer screen

Material Categories	Material description	Amount (kg)	%
1. Ferrous metal	Iron	4.784E-01	3.216E+00
	Steel	1.293E+00	8.693E+00
2. Non-Ferrous metal	Ag	1.807E-03	1.215E-02
	Al	1.764E-01	1.186E+00
	Au	6.312E-04	4.243E-03
	Cr	5.681E-06	3.818E-05
	Cu	5.826E-01	3.916E+00
	Mb	2.154E-04	1.448E-03
	Mn	2.998E-05	2.015E-04
	Ni	3.051E-01	2.051E+00
	Pb	8.740E-01	5.875E+00
	Pd	1.747E-05	1.174E-04
	Si	5.398E-05	3.628E-04
	silicon	6.312E-07	4.243E-06
	Sn	9.063E-03	6.092E-02
	Ta	3.064E-04	2.059E-03
	Zn	2.282E-01	1.534E+00
3. Inorganic	BaSO4	6.410E-03	4.308E-02
	graphite	2.059E-02	1.384E-01
	other(inorganic)	6.993E-03	4.701E-02
4. Oxide Ceramic	SiO2	8.579E+00	5.767E+01
5. plastics	ABS	1.758E+00	1.182E+01
	Epoxy	1.202E-01	8.080E-01
	LLDPE	3.542E-04	2.381E-03
	other(plastic)	2.834E-03	1.905E-02
	other(plastics)	3.129E-02	2.103E-01
	PC	1.199E-01	8.061E-01
	PE	4.927E-02	3.311E-01
	PET	1.915E-03	1.287E-02
	PMMA	4.040E-05	2.715E-04
	polysulphone	1.875E-02	1.260E-01
	PP	1.572E-03	1.057E-02
	PS	6.161E-02	4.141E-01
	PU	1.261E-02	8.475E-02
	PVC	1.295E-03	8.707E-03
6. Rubber	Synthetic Rubber	5.508E-02	3.702E-01
7. Glass	Glass	7.412E-02	4.982E-01
8. Paper	paper	2.058E-03	1.383E-02
9. Organic Compound	Other	3.081E-03	2.071E-02
	Total	**1.488E+01**	**1.000E+02**

C. The Disassembly analysis results of LCD Screen components

Table C-6: Disassembly Analysis of LCD Screen

Assembly	Sub-Assembly	Material	Amount (kg)

4. 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**	ABS/ PC steel ABS/PC ABS/PC Steel	1.980E-01 9.320E-01 3.480E-01 3.880E-01 1.317E+0
	Total		**3.183**
5. 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**	Metal steel Plastics chromium steel PE PE PE PE PMMA PE	9.900E-02 4.900E-02 1.570E-01 1.200E-02 1.400E-02 1.100E-02 2.000E-02 4.480E-01 2.600E-02
	2.10 Cold cathode fluorescent tube	glass Pb Hg Zn Cu HDPE PVC	2.301E-02 1.078E-03 2.220E-06 1.890E-06 3.000E-04 1.309E-03 2.950E-04
	Total		**8.620E-01**
6. Active matrix liquid crystal display cell	**3.1 Connection flex**	Cu	2.789E-03
	3.2 Row/column driver TAB (integrated circuit, IC logic type)	Cu epoxy SiO2 Nylon Au Pb Ni Ag Sn Zn	6.430E-04 1.348E-03 1.993E-03 2.412E-03 8.230E-05 2.820E-04 2.500E-05 5.710E-05 4.790E-04 5.750E-05
	3.3 Liquid Crystal	Glass (ITO covered)	2.668E-01
	3.4 Other	Synthetic rubber	3.644E-03
	Total		**2.806E-01**
7. LCD Controller	**4.1 LDVS/LCD interface cable**	Cu PVC Synthetic rubber PVC PU	6.009E-03 1.002E-02 3.487E-03 2.810E-04 2.070E-04
	Total		**2.000E-02**
8. Power Supply Assembly	**5.1 Metal housing**	steel	2.020E-01
	5.2 Insulator plate in housing	PE	1.600E-02
	5.3 Aluminum heat sink	Al	2.700E-02
	Total		**2.450E-01**
9. LCD Inverter	**6.1 Inverter cable line**	Zn Cu HDPE PVC	4.960E-06 7.860E-04 3.434E-03 7.750E-04
	Total		
10. Power Switch	**7.1 Human interface button**	ABS	2.900E-02
	Total		**2.900E-02**
		Ag Al Au Cr Cu epoxy	1.363E-03 5.398E-02 4.756E-04 4.280E-06 1.197E-01 2.664E-02

11. Controller Board (controller board , Universal LVDS/LCD interface board, Power supply control board, Inverter board Switch console board)	**8.1 Printed wired board assembly**	glass	5.589E-02
		iron	1.947E-02
		LLDPE	2.670E-04
		Mb	1.620E-04
		Mn	2.260E-05
		Ni	1.629E-03
		Nylon	1.637E-02
		other(inorganic)	8.137E-03
		other(organic)	4.176E-03
		other(plastics)	7.226E-03
		paper	1.552E-03
		Pb	1.014E-02
		PC	5.078E-02
		Pd	1.320E-05
		PE	3.715E-02
		PET	1.444E-03
		PMMA	3.050E-05
		polymer	1.170E-04
		PP	1.186E-03
		PU	6.200E-06
		PVC	9.770E-04
		rubber	6.060E-04
		Si	4.070E-05
		silicon	4.760E-07
		SiO2	2.578E-02
		Sn	6.833E-03
		steel	4.150E-04
		Ta	2.310E-04
		Zn	2.569E-03
	Total		**4.554E-01**
12. Cable part and miscellaneous components	9.1 Signal cable - inner line	Cu	8.178E-03
		HDPE	3.571E-02
		PVC	8.058E-03
		Zn	5.160E-05
	9.2 Input Signal cable	Al	2.885E-03
		Cu	6.283E-02
		PVC	1.683E-01
	9.3 Bracket materials,	Steel	4.300E-02
	9.4 Holding Screws	Chromium steel	4.000E-02
	9.5 LCD frame screw	Chromium steel	1.000E-02
	9.6 Power Cord	Cu	3.554E-02
		HDPE	6.099E-03
		PU	7.990E-04
		PVC	8.746E-02
		rubber	1.348E-02
		Zn	3.627E-03
		Total	**5.260E-01**
	Total		**5.606**

Table C-7: Material composition in LCD computer screen

Material Categories	Material description	Amount (kg)	%
1. Ferrous	iron	9.515E-01	1.697E+01
	steel	1.661E+00	2.964E+01

2. Non-ferrous	Ag Al Au Cr Cu Hg Mb Mn Ni Pb Pd Si Sn Ta Zn	1.420E-03 8.386E-02 5.579E-04 2.070E-01 2.368E-01 2.220E-06 1.620E-04 2.260E-05 1.654E-03 1.150E-02 1.320E-05 4.118E-05 7.312E-03 2.310E-04 6.312E-03	2.533E-02 1.496E+00 9.952E-03 3.693E+00 4.224E+00 3.960E-05 2.890E-03 4.031E-04 2.950E-02 2.051E-01 2.355E-04 7.345E-04 1.304E-01 4.121E-03 1.126E-01
3. Inorganic compounds	Other	1.127E-02	2.011E-01
4. Oxide ceramic	SiO2	2.777E-02	4.954E-01
5. Plastic	ABS ABS/PC epoxy HDPE LLDPE Nylon other(plastics) PC PE PET PMMA PP PU PVC	3.770E-01 5.860E-01 2.799E-02 4.655E-02 2.670E-04 1.878E-02 7.226E-03 9.978E-02 1.361E-01 1.444E-03 4.480E-01 1.186E-03 1.012E-03 2.761E-01	6.725E+00 1.045E+01 4.993E-01 8.304E-01 4.763E-03 3.349E-01 1.289E-01 1.780E+00 2.429E+00 2.576E-02 7.992E+00 2.116E-02 1.806E-02 4.926E+00
6. Rubber	Synthetic Rubber	**2.122E-02**	**3.785E-01**
7. Glass	Liquid Crystal	2.668E-01	4.759E+00
	Flat glass	7.890E-02	1.407E+00
8. Paper	Kraft paper	1.552E-03	2.768E-02
9. Organic Compound	polymer	1.170E-04	2.087E-03
10. Ceramic Compound		1.042E-03	1.859E-02
	Total	**5.606E+00**	**100.00%**

Appendix E

Endpoint impacts and single score of PC

a) The characterization of environmental impact according to Recipe 2008 method

Table C-1: the distribution of Endpoint impact of waste management in different equipment

Impact category	Unit	CRT landfilling approach	LCD landfilling approach	PC landfilling approach
Climate change Human Health	DALY	3.70E-07	3.49E-07	4.51E-07
Ozone depletion	DALY	1.08E-10	3.78E-11	6.52E-11
Human toxicity	DALY	1.62E-05	5.03E-07	8.58E-07
Photochemical oxidant formation	DALY	8.90E-11	2.57E-11	4.21E-11
Particulate matter formation	DALY	1.73E-07	5.15E-08	8.03E-08
Ionizing radiation	DALY	4.02E-10	1.65E-10	2.81E-10
Climate change Ecosystems	species.yr	2.10E-09	1.98E-09	2.55E-09
Terrestrial acidification	species.yr	7.60E-12	2.12E-12	3.48E-12
Freshwater eutrophication	species.yr	1.60E-12	5.73E-13	7.47E-13
Terrestrial Eco-toxicity	species.yr	2.62E-11	8.18E-11	3.25E-11
Freshwater Eco-toxicity	species.yr	4.85E-09	6.55E-11	9.11E-11
Marine Eco-toxicity	species.yr	7.97E-10	8.28E-12	1.61E-11
Agricultural land occupation	species.yr	3.44E-10	1.27E-10	1.42E-10
Urban land occupation	species.yr	5.54E-10	2.55E-10	4.28E-10
Natural land transformation	species.yr	-1.20E-09	-4.38E-10	-7.69E-10
Metal depletion	$	2.51E-03	9.12E-04	1.06E-03
Fossil depletion	$	1.61E-02	5.60E-03	9.19E-03

Table C-2: the distribution of Endpoint impact of waste management in different equipment

Impact category	Unit	CRT recycling	LCD recycling	PC recycling
Climate change Human Health	DALY	-2.36E-06	-1.91E-06	-3.70E-05
Ozone depletion	DALY	-1.21E-09	-9.44E-10	-5.59E-09
Human toxicity	DALY	-2.36E-04	-1.71E-04	-7.21E-04
Photochemical oxidant formation	DALY	-3.70E-09	-2.78E-09	-1.27E-08
Particulate matter formation	DALY	-3.44E-05	-2.60E-05	-1.05E-04

Ionising radiation	DALY	-3.32E-08	-2.08E-08	-1.47E-07
Climate change Ecosystems	species.yr	-1.34E-08	-1.08E-08	-2.09E-07
Terrestrial acidification	species.yr	-2.27E-09	-1.63E-09	-6.91E-09
Freshwater eutrophication	species.yr	-7.05E-09	-4.84E-09	-2.19E-08
Terrestrial ecotoxicity	species.yr	-1.32E-09	-1.13E-09	-6.04E-09
Freshwater ecotoxicity	species.yr	-2.04E-09	-1.43E-09	-8.23E-09
Marine ecotoxicity	species.yr	-5.97E-10	-4.29E-10	-2.01E-09
Agricultural land occupation	species.yr	-2.77E-09	-2.58E-09	-1.05E-08
Urban land occupation	species.yr	-1.19E-08	-8.05E-09	-4.11E-08
Natural land transformation	species.yr	-5.11E-09	-3.78E-09	-2.00E-08
Metal depletion	$	-3.67E+00	-2.90E+00	-1.07E+01
Fossil depletion	$	-3.52E-01	-3.21E-01	-1.44E+00

b) The characterization of single score based on desktop PC components landfilling approach

Table C-3: the distribution of singlescore impact of waste management of CRT computer screen

CRT computer components	Total (pt)	Human Health (pt)	Ecosystems (pt)	Resources (pt)
PWBA	3.68E-03	2.10E-03	8.89E-05	1.49E-03
DE magnetic coil	4.83E-04	3.13E-04	8.71E-06	1.62E-04
Chassis	1.81E-02	1.39E-02	8.10E-04	3.34E-03
Anode connection wire	1.98E-04	1.38E-04	4.52E-06	5.51E-05
CRT Electron gun	3.37E-04	2.28E-04	7.77E-06	1.01E-04
Deflection yoke	2.52E-03	1.56E-03	5.59E-05	9.10E-04
CRT tube	3.72E-01	3.57E-01	2.60E-03	1.21E-02
Miscellaneous part	4.95E-04	3.21E-04	1.06E-05	1.63E-04
Total	**3.98E-01**	**3.76E-01**	**3.58E-03**	**1.83E-02**

Table C-4: the distribution of singlescore impact of waste management of LCD computer screen

LCD screen components	Total (pt)	Human Health (pt)	Ecosystems (pt)	Resources (pt)
LCD screen PWBA	2.30E-03	1.36E-03	6.47E-05	8.69E-04
Base/Stand assembly	5.37E-03	3.47E-03	1.80E-04	1.73E-03
Rear-cover assembly	4.51E-03	3.02E-03	1.61E-04	1.33E-03
Power switch	2.79E-04	2.24E-04	1.33E-05	4.13E-05
Power supply Assembly	8.61E-04	5.79E-04	3.05E-05	2.52E-04
Outer frame	1.90E-03	1.53E-03	9.11E-05	2.82E-04
Miscellaneous Part	4.88E-03	2.89E-03	1.54E-04	1.83E-03
Liquid crystal assembly	4.21E-04	1.56E-04	2.81E-06	2.62E-04
controller cable	1.38E-04	1.05E-04	3.90E-06	2.89E-05

Backlight assembly	1.16E-02	6.58E-03	3.96E-04	4.64E-03
Inverter line assembly	5.01E-05	4.12E-05	1.66E-06	7.17E-06
Total	**3.23E-02**	**2.00E-02**	**1.10E-03**	**1.13E-02**

Table C-5: the distribution of singlescore impact of waste management of desktop PC

Desktop PC components	Total (pt)	Human Health (pt)	Ecosystems (pt)	Resources (pt)
RAM	8.01E-04	5.31E-04	2.03E-05	2.49E-04
Power supply	9.85E-03	7.25E-03	2.85E-04	2.32E-03
PC cabinet	1.09E-02	6.17E-03	2.37E-04	4.49E-03
LAN card	1.88E-04	1.19E-04	4.99E-06	6.40E-05
HDD	1.61E-03	9.25E-04	2.23E-05	6.64E-04
GPU	4.10E-04	2.60E-04	1.09E-05	1.40E-04
FDD	1.13E-03	6.16E-04	1.56E-05	4.94E-04
Cooling unit for GPU card	5.92E-05	4.88E-05	1.99E-06	8.35E-06
Cooling unit for CPU	3.71E-03	2.96E-03	1.16E-04	6.35E-04
CPU	1.96E-04	1.27E-04	8.17E-06	6.14E-05
CD/DVD rom	3.64E-03	2.58E-03	9.94E-05	9.63E-04
ATX mainboard	3.88E-03	2.76E-03	1.21E-04	9.94E-04
Total	**3.64E-02**	**2.44E-02**	**9.43E-04**	**1.11E-02**

Appendix F

Surveying question form

โปรดใส่เครื่องหมาย ✓ ในช่อง ☐ ที่ท่านเลือกหรือเติมข้อความให้ตรงกับความเป็นจริงของท่านมากที่สุด

ตอนที่ 1 : ข้อมูลเกี่ยวกับสถานภาพของผู้ตอบแบบสอบถาม

1. เพศ :	☐ ชาย ☐ หญิง			
2. อายุ :	☐ ต่ำกว่า 20 ปี ☐ 20 –30 ปี	☐ 31-40 ปี ☐ 41 – 50 ปี	☐ 51-60 ปี ☐ 60 ปีขึ้นไป	
3. การศึกษาขั้นสูงสุด :	☐ ประถมศึกษา ☐ มัธยมศึกษาตอนต้น	☐ มัธยมศึกษา ตอนปลาย/ปวช. ☐ อนุปริญญา/ปวส.	☐ ปริญญาตรี ☐ ปริญญาโท	☐ ปริญญาเอก ☐ อื่นๆ……….
4. อาชีพ :	☐ นักเรียน/นักศึกษา ☐ รับราชการ/รัฐวิสาหกิจ	☐ พนักงานบริษัทเอกชน ☐ อื่นๆ…...............	☐ ธุรกิจส่วนตัว	
5. รายได้ต่อเดือน	☐ ต่ำกว่า 10,000 บาท ☐ 10,001-20,000 บาท	☐ 30,001-40,000 บาท ☐ 20,001-30,000 บาท	☐ 40,001-50,000 บาท ☐ 50,000 บาทขึ้นไป	

6. **ในครัวเรือนของท่านมีหรือเคยมีอุปกรณ์คอมพิวเตอร์เช่น <u>คอมพิวเตอร์ตั้งโต๊ะ จอคอมพิวเตอร์ CRT หรือ LCD</u> ที่สิ้นอายุการใช้งานแล้วใช่ หรือไม่**

☐ มีอุปกรณ์คอมพิวเตอร์ที่สิ้นสุดอายุการใช้งาน ☐ ไม่มีอุปกรณ์ใดที่สิ้นสุดอายุการใช้งาน **(ข้ามไปทำตอนที่ 3)**

ตอนที่ 2 : ลักษณะพฤติกรรมทั่วไปในการจัดการซากผลิตภัณฑ์ขอผู้ทำแบบสอบถาม

(กรอกข้อมูลเฉพาะอุปกรณ์ที่ท่านมีครอบครองเท่านั้น)

7. ท่านจัดการกับซากคอมพิวเตอร์เหล่านั้นที่ไม่ได้ใช้งานแล้วอย่างไร

☐ 7.1 คอมพิวเตอร์ตั้งโต๊ะ	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติ/มูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง☐ส่วนลดหรือแลกสินค้าใหม่ ☐ ให้เช่า ☐อื่นๆ…………………… ☐ ขายให้ร้านซ่อมคอมพิวเตอร์ตามห้างสรรพสินค้า
☐ 7.2 จอคอมพิวเตอร์แบบ CRT	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติ/มูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง☐ส่วนลดหรือแลกสินค้าใหม่ ☐ ให้เช่า ☐อื่นๆ…………………… ☐ ขายให้ร้านซ่อมคอมพิวเตอร์ตามห้างสรรพสินค้า
☐ 7.3 จอคอมพิวเตอร์แบบ LCD	☐ เก็บไว้ที่บ้านโดยไม่ได้ใช้งาน ☐ บริจาคให้ญาติ/มูลนิธิ/วัด ☐ ขายให้ซาเล้ง	☐ ขายให้ร้านสินค้ามือสอง☐ส่วนลดหรือแลกสินค้าใหม่ ☐ ให้เช่า ☐อื่นๆ…………………… ☐ ขายให้ร้านซ่อมคอมพิวเตอร์ตามห้างสรรพสินค้า

8. สาเหตุหลักใดที่ทำให้ท่านต้องเปลี่ยนอุปกรณ์คอมพิวเตอร์เหล่านี้(โปรดตอบโดยใส่ลำดับที่ตรงกับท่านมากที่สุดโดย 1= น้อย 2= ปานกลาง 3=มาก 4=มากที่สุด)

____ ไม่สามารถใช้งานร่วมกับอุปกรณ์ที่มีเทคโนโลยีที่สูงกว่าได้ เพราะข้อจำกัดทางเทคโนโลยี

_____ อุปกรณ์ภายในชำรุดจนไม่สามารถใช้งานได้

_____ ประสิทธิภาพต่ำ ประมวลผลช้า

_____ เนื่องจากเปลี่ยนไปใช้คอมพิวเตอร์ชนิดอื่น เช่น คอมพิวเตอร์แบบโน้ตบุ๊ก แท็บเล็ต หรือ ออลอินวัน

____ อื่นๆ____

ตอนที่ 3 : สอบถามความรู้ทั่วไปเกี่ยวกับความรู้ความเข้าใจต่อการจัดการซากผลิตภัณฑ์คอมพิวเตอร์

9. ในส่วนประกอบของอุปกรณ์คอมพิวเตอร์ตั้งโต๊ะนั้นมีโลหะ และอโลหะที่มีค่าอยู่มากมายอาทิ เช่น ทอง เงิน ทองแดง เหล็ก แก้ว เป็นต้น ท่านทราบหรือไม่

☐ ทราบมาก่อน ☐ ไม่ทราบมาก่อน

10. ส่วนประกอบของอุปกรณ์คอมพิวเตอร์นั้นมีสารเคมีที่อันตรายเป็นองค์ประกอบอยู่ อาทิเช่น สารประกอบจำพวกโลหะ(ตะกั่ว ใน แก้วของจอ CRT และ แผงวงจรในอุปกรณ์คอมพิวเตอร์ หรือ ปรอทในหลอดไฟของหน้าจอชนิด LCD) ซึ่งสามารถส่งผลเสียต่อสุขภาพและสิ่งแวดล้อม ท่านทราบข้อมูลเหล่านี้มาก่อนหรือไม่

☐ ทราบมาก่อน ☐ ไม่ทราบมาก่อน

11. การรีไซเคิลอุปกรณ์คอมพิวเตอร์โดยวิธีการที่เหมาะสมนั้นเป็นระบบที่จะสามารถจะนำวัตถุมีค่ากลับมาใช้ได้อีกครั้ง ซึ่งจะเป็นประโยชน์กับสิ่งแวดล้อมและทรัพยากรอย่างยั่งยืนท่านทราบข้อมูลเหล่านี้มาก่อนหรือไม่

☐ ทราบมาก่อน ☐ ไม่ทราบมาก่อน

ตอนที่ 4 : นโยบายในการจัดการซากผลิตภัณฑ์อุปกรณ์คอมพิวเตอร์ที่สิ้นสุดการใช้งาน

12. มาตรการใดที่ทำให้ท่านให้ความร่วมมือและลงมือนำขยะคอมพิวเตอร์มารีไซเคิล(โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่องโดย 1=น้อย 2= ปานกลาง 3=มาก)

____	ออกกฎหมายบังคับใน การรีไซเคิลซากผลิตภัณฑ์	___	รับซื้อคืนซาก ผลิตภัณฑ์ ที่ไม่ได้ใช้งานแล้ว	___	การเก็บค่าจัดการซาก ทันทีเมื่อซื้อผลิตภัณฑ์	___	อื่นๆ…… …

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13. สิ่งใดที่ส่งเสริมให้ท่านนำซากผลิตภัณฑ์คอมพิวเตอร์มาเข้าสู่ระบบรีไซเคิล(โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่องโดยเรียงลำดับจากน้อยไปหามาก เช่น 1=น้อยที่สุด 2=น้อย 3=ปานกลาง 4=มาก 5=มากที่สุด)

___ เงินค่าตอบแทนจากการนำซากผลิตภัณฑ์ขายคืน _____ ส่วนลดในการซื้ออุปกรณ์คอมพิวเตอร์ใหม่

___ เป็นการสร้างภาพต่อสังคม _____ ได้รับสิทธิในการลดหย่อนภาษี

___ การรณรงค์ประชาสัมพันธ์เกี่ยวกับประโยชน์ของการรีไซเคิลอย่างกว้างขวาง

___ ความสะดวกสบายในการนำซากผลิตภัณฑ์ไปจัดการอย่างเหมาะสม

___ ได้บุญจากการทำความดี หรือ รู้สึกว่าพิทักษ์สิ่งแวดล้อมและใช้ทรัพยากรได้อย่างยั่งยืน

___ อื่นๆ____

14. ถ้าหากมีการจัดตั้งศูนย์รวบรวมซากผลิตภัณฑ์เพื่อทำการรีไซเคิลท่านคิดว่าใครควรจะเป็นผู้ดำเนินการ

☐ รัฐบาล ☐ เอกชน ☐ ตัวแทนชุมชน ☐ อื่นๆ ________________________

15. ถ้าจะมีศูนย์รวบรวมซากคอมพิวเตอร์ แนวทางหรือวิธีใด ท่านเห็นว่าสะดวกสุดในการนำขยะเข้าสู่ระบบการจัดการที่เหมาะสม

(โปรดตอบโดยใส่ลำดับที่ท่านพอใจลงในช่องโดย 1=น้อยที่สุด 2= น้อย 3=ปานกลาง 4=มาก 5= มากที่สุด)

_____ นำมาส่งยังรวบรวมซากคอมพิวเตอร์ด้วยตนเองโดยตรง

_____ พนักงานศูนย์รวบรวมซากคอมพิวเตอร์มารับคืนบริเวณชุมชนใกล้เคียง

_____ พนักงานศูนย์รวบรวมซากคอมพิวเตอร์มารับคืนบริเวณหน้าบ้าน

_____ นำอุปกรณ์คอมพิวเตอร์ที่สิ้นสุดอายุการใช้งานไปคืนยังร้านซ่อมคอมพิวเตอร์ที่ได้รับการรับรองอย่างถูกกฎหมาย

_____ นำอุปกรณ์คอมพิวเตอร์ที่สิ้นสุดอายุการใช้งานไปคืนยังศูนย์รวบรวมซากคอมพิวเตอร์ในห้างสรรพสินค้าหรือบริเวณใกล้เคียง

_____ อื่นๆ____________________________________

16. ท่านคิดเห็นว่าอะไรจะเป็นอุปสรรคสำคัญในการรวบรวมขยะคอมพิวเตอร์ และการนำเข้าสู่กระบวนการจัดการของเสียที่เหมาะสม (สามารถตอบตอบได้มากกว่าหนึ่งคำตอบ)

☐ การขนส่งซากอุปกรณ์ไปยังศูนย์รวบรวมที่ไม่เหมาะสม

☐ การนำเข้าซากผลิตภัณฑ์อย่างผิดกฎหมายจากต่างประเทศ

☐ อื่นๆ________________________

☐ การแข่งขันกับภาคเอกชนที่ประกอบอาชีพคัดแยกขยะ

☐ เงินสนับสนุนไม่เพียงพอกับค่าใช้จ่ายทั้งหมดในการรวบรวมขยะ

17. ท่านมีข้อคิดเห็นหรือเสนอแนะเพิ่มเติม ที่คิดว่าจะเป็นการส่งเสริมให้มีระบบการจัดการขยะคอมพิวเตอร์ให้เกิดขึ้นได้เป็นรูปธรรมหรือดำเนินการได้อย่างแพร่หลาย อย่างไรบ้าง

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ขอบคุณครับที่กรุณาให้ความร่วมมือในการกรอกแบบสอบถาม

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Presentation: Tatthap Veeratat and Chanathip Pharino, Environmental Impact Evaluating of CRT and LCD Computer Screens Management between Landfilling and Recycling Approaches, International Conference Environmental and Hazardous Substance Management towards a Green Economy, vol.(2013), 65-66.

Tatthap Veeratat and Chanathip Pharino, Environmental Impact Evaluating of Computer Waste Management in Thailand: Recycling VS. Landfilling, Proceedings of Asian Conference on Civil, Material and Environmental Sciences (2012), 375-382