ENVIRONMENTAL IMPACT EVALUATION AND MANAGEMENT FOR END-OF-LIFE (EoL) OF MOBILE PHONES IN THAILAND

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for the Degree of Master of Science Program in Environmental Management
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การประเมินผลกระทบสิ่งแวดล้อมและแนวทางการจัดการสำหรับโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งานในประเทศไทย

นายวิชวินท์ แสงประเสริฐ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	ENVIRONMENTAL IMPACTS EVALUATION AND MANAGEMENT FOR END-OF-LIFE (EOL) OF MOBILE PHONES IN THAILAND.
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วิธวินท์ แสงประเสริฐ : การประเมินผลกระทบสิ่งแวดล้อมและแนวทางการจัดการสำหรับโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งานในประเทศไทย (ENVIRONMENTAL IMPACT EVALUATION AND MANAGEMENT FOR END-OF-LIFE (EoL) OF MOBILE PHONES IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.ชนาธิป ผาริโน, 138 หน้า.

เนื่องด้วยเทคโนโลยีในการพัฒนาของโทรศัพท์มือถือเป็นไปอย่างรวดเร็ว ส่งผลให้ผู้บริโภคมีพฤติกรรมในการเปลี่ยนโทรศัพท์มือถือบ่อยขึ้น ดังนั้นจึงทำให้ปริมาณขยะโทรศัพท์มือถือในประเทศไทยมีแนวโน้มที่จะเพิ่มขึ้นทุกปี ซึ่งถ้าในอนาคตยังไม่มีการเตรียมแนวทางแก้ไขปัญหา ก็จะทำให้ปัญหาเกิดการสะสมมากยิ่งขึ้น

การศึกษานี้มีวัตถุประสงค์ คือ เพื่อที่จะประเมินผลกระทบต่อสิ่งแวดล้อมและ ตรวจสอบแนวทางการจัดการที่แตกต่างกันของโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งาน และเพื่อแนะนำแนวทางและยุทธศาสตร์ในการปรับปรุงระบบการจัดการขยะโทรศัพท์มือถือในประเทศไทย ในการวิจัยใช้ซอฟแวร์ Simapro รุ่น 7.3.3 เพื่อประเมินวัฏจักรชีวิตของโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งาน โดยขอบเขตของการประเมินผลจะไม่รวมถึงการขนส่งไปยังระบบการจัดการ การวิจัยจะตรวจสอบและเปรียบเทียบผลกระทบต่อสิ่งแวดล้อมจาก 3 สถานการณ์ : 1) สถานการณ์ที่ 1: "หลุมฝังกลบ 100%", 2) สถานการณ์ที่ 2: "หลุมฝังกลบ 95% และรีไซเคิล 5%" และ (3) สถานการณ์ที่ 3: " หลุมฝังกลบ 80% และ รีไซเคิล 20% " การวิจัยครั้งนี้ยังทำการสำรวจแบบสอบถามเพื่อรวบรวมความคิดเห็นของประชาชนเกี่ยวกับสถานการณ์ตลอดจนความเข้าใจของปัญหาและการแนวทางการแก้ปัญหา เพื่อที่จะเป็นข้อเสนอแนะในการเพิ่มประสิทธิภาพของการจัดการขยะโทรศัพท์มือถือในประเทศไทย

ผลการวิจัยพบว่าโทรศัพท์มือถือเฉลี่ยส่วนใหญ่จะประกอบไปด้วยพลาสติก (43-53%) และอโลหะ(19-29%) โดยชาร์จเจอร์เป็นส่วนที่ทำให้เกิดผลกระทบต่อสิ่งแวดล้อมสูงที่สุดเมื่อเปรียบเทียบกับส่วนอื่นในโทรศัพท์มือถือ จากการวิเคราะห์สถานการณ์การจัดการพบว่าสถานการณ์ที่ 3 ที่มีการรีไซเคิล 20% ทำให้เกิดผลกระทบต่อสิ่งแวดล้อมน้อยที่สุดเมื่อเทียบกับสถานการณ์อื่น ๆ ในการประเมินผลกระทบขั้นปลายของการจัดการโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งานพบว่าจะมีผลกระทบต่อสุขภาพของมนุษย์เป็นสัดส่วนที่สูงที่สุดเมื่อเปรียบเทียบกับผลกระทบอื่น ๆ ซึ่งการจัดการ โดยการรีไซเคิลขยะโทรศัพท์มือถือจะถือได้ว่ามีศักยภาพที่จะช่วยลดผลกระทบต่อสิ่งแวดล้อมในอนาคตได้เป็นอย่างดี นอกจากนี้ผลจากการสำรวจความคิดเห็นจากคนส่วนใหญ่พบว่ามักจะเก็บโทรศัพท์มือถือที่ไม่ได้ใช้งานแล้วไว้ที่บ้าน ส่วนแรงจูงใจที่จะทำให้คนนำโทรศัพท์มือถือที่ไม่ได้ใช้งานแล้วมาเข้าสู่ระบบการรีไซเคิลก็คือการให้ผลประโยชน์หรือส่วนลดในการซื้อของโทรศัพท์เครื่องใหม่

สำหรับข้อเสนอแนะการจัดการโทรศัพท์มือถือในประเทศไทย ในระยะแรกควรที่จะสร้างความตระหนักให้กับประชาชนเกี่ยวกับความรุนแรงของปัญหาที่เกิดขึ้นในอนาคตโดยไม่มีการจัดการที่เหมาะสม ส่วนในระยะกลางควรที่จะมีเงินอุดหนุนจากภาครัฐหรือมีการใช้เครื่องมือทางเศรษฐศาสตร์เข้ามามีส่วนช่วยในการพัฒนาระบบการเก็บรวบรวมและเทคโนโลยีที่ใช้ในการรีไซเคิล ส่วนในระยะยาวควรที่จะมีนโยบายแห่งชาติในการจัดการขยะโทรศัพท์มือถือและมีการตั้งเป้าหมายในการจัดการที่ชัดเจน ซึ่งจะทำให้การพัฒนาเพื่อการแก้ไขปัญหาขยะโทรศัพท์มือถือในประเทศไทยให้เป็นไปได้อย่างมีประสิทธิภาพมากยิ่งขึ้น

สาขาวิชา การจัดการสิ่งแวดล้อม...... ลายมือชื่อนิสิต ....

ปีการศึกษา ...2555........ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

5487585020: MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: Mobile phone / Impact / End of life (EoL) / Landfill / Recycling

WITTHAWIN SANGPRASEART: ENVIRONMENTAL IMPACT EVALUATION AND MANAGEMENT FOR END-OF-LIFE (EOL) OF MOBILE PHONES IN THAILAND. ADVISOR: ASST. PROF. CHANAHIP PHARINO, Ph.D., 138 pp.

Technological of mobile phones speeds up the turn-over rate of mobile phone usages. This impacts consumers' behavior to change mobile phones more often. Consequently, amount of mobile phone wastes are likely to increase every year with no exception for Thailand. In the future, if no solution is prepared to solve a problem of mobile phone wastes, the accumulated problem can increasingly.

This study aims to evaluate the environmental impact and examine End of Life (EoL) of mobile phones from different management approach, and to suggest plans and strategies to improve mobile phone wastes management system in Thailand. The research uses Simapro software version 7.3.3 to evaluate life cycle assessment (LCA) for end of the life (EoL) of mobile phones. The scope of evaluation does not include transportation to the management system. The research examined and compared environmental impacts from 3 scenarios: 1) Scenario 1: "100% landfill": No materials are recycled, 2) Scenario 2: "95% landfill & 5% recycling", and (3) Scenario 3: "80% landfill & 20% recycling". This research conducted questionnaires survey to gather public opinions on situation, understanding the problems and solutions of mobile phone wastes in Thailand to provide suggestions to increase efficiency of mobile phone wastes management in Thailand.

The research found that averaged mobile phone is mainly comprised of plastic (43-53%) and non-ferrous metal (19-29%). Phone charger causes the highest environmental impacts compared to all compartments of the phone. The management scenario analysis found that scenario 3 with 20% recycling generates the least environmental impacts compared to other scenarios. In the end-point analysis, human health impact was found to contribute the highest proportion from the end-of life impact from mobile phone wastes. Therefore, recycling of mobile phone wastes has a good potential to reduce future environmental impacts. Based on the public surveys, most people mainly keep end of life (EoL) of mobile phone at home. To provide incentive for people to bring end of life (EoL) of mobile phone to recycling system is by providing benefits or discount on the purchase of a new phone in return.

The suggestions for mobile phone management in Thailand in the initial term should raise awareness of people about the severity of the problems in the future without proper management. In the medium term, subsidy from the government or financial incentives should be provided to help developing the collecting and recycling technology and system. In long term, national policy on mobile phone waste management and policy target should be set to solve the mobile phone wastes problem in Thailand effectively.

Field of Study Environmental management Student's Signature……………………….

Academic Year …2012…………….. Advisor's Signature ……………………….

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I thank the respondents from both channels are 377 persons (207 persons from hard copy direct survey and 170 persons from online survey) for questionnaires survey. Lastly, I deeply express my sincere appreciation and gratitude, the success of this research to my family for supports and encouragement throughout my research work.

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LIST OF ABBREVIATIONS

1,4-DB eq	1,4-Dichlorobenzeen Equivalent
AEC	ASEAN Economics Community
ARF	Advance Recycling Fee
CO_2	Carbon Dioxide
CO_2 eq	Carbon Dioxide Equivalent
DALY	Disability adjusted life years
DOWA	DOWA ECO-SYSTEM CO., LTD
EHWM	Center of Excellence for Environmental and Hazardous Waste Management
EIP	Ecoindicator'99 points
EoL	End-of-Life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
E-Waste	Electronic Waste
Fe eq	Iron (Fe) Equivalent
ISO	International Standard Organization
LCA	Life cycle assessment
LCD	Liquid crystal display
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NSO	National Statistical office
Oil eq	Oil Equivalent
PCB	Printed Circuit Board
PCD	Pollution Control Department
PE	Person equivalents
Pt	Point
PWB	Print wiring board
S1	Scenario 1
S2	Scenario 2
S3	Scenario 3
TCIJ	Thailand Information Center For Civil Rights And Investigative Journalism
U.S.	United State
WEEE	Waste electric and electronic equipment

CHAPTER I

INTRODUCTION

1.1 Problem Statement

Technological innovation speeds up the rates of introducing new models of mobile phones. This impacts consumers' behavior to change mobile phones more often than a few years ago. The Pollution Control Department (PCD) showed consumption of mobile phones in the country which increased from 47,760,000 units in 2007 to 59,678,000 units in 2010 (PCD, 2012: online). The factors that increase the consumption of mobile phones may cause by 3 factors: (1) Competitive mobile phone market. Producer are trying to increase volume into the consumer market, price of models tend to be decreased in order to increase the market share, people at all levels have also bought and have payment system that creates incentives for consumers, including consumers have low incomes. (2) Rate of mobile phone service charge was down as well as the marketing strategy as a SIM free deal motivating consumers to hold more than one unit. (3) Speeds up the rates of introducing new models of mobile phones of producer, it brings to consumers' behavior to change mobile phones more often (TCIJ, 2013: online).

The Pollution Control Department (PCD) forecasted the mobile phones wastes in Thailand will increase from 8,524,000 units in 2012 to 10,907,000 units in 2016 (PCD, 2012: online). Consequently, amount of wastes of unused or out of date mobile phones are becoming a major problem of modern society. In Thailand, the used mobile phones are distributed in local market and abroad. Thailand has a big second-hand mobile phone market. Most used mobile phones are sold in the market. The results from interview survey, used mobile phones that are not salable in Thailand are exported to neighboring counties such as Myanmar, Laos, Vietnam, Cambodia and Bangladesh. End-of-Life (EoL) mobile phones which are not able to be used are exported to China as the big sources of spare parts. Although, the export of the used mobile phones in Thailand is legal, Thailand has no information on the amount or routes of the exports of used phones. Moreover, used mobile phones have economic values because they contain precious metals such as gold, silver, copper etc. This should be used as incentives or benefits for users who collect used mobile phones effectively (DOWA, 2007: online).

Mobile phone wastes have the potential to generate the environment impact because mobile phones contain toxic and rare substances. The toxic substance of mobile phones can pollute into the air, soil or water. Many of toxic substance can persist in the environment by bio-accumulating through the food chain and pose a risk of causing adverse effects to the environment and human health (Lim and Schoenung, 2010). The toxic substances in mobile phones may not be immediate danger from end of life (EoL) if appropriately treated or managed. If their disposal is not properly treated, it will involve conditions and processes that may lead to the release of toxic substances. Due to the toxic substances are of concern under the conditions of land disposal and incineration. The major problem of mobile phone wastes are incinerated or disposed with domestic wastes in most developing countries due to lack of treatment systems and take back of wastes. Therefore, the disposal of mobile phone wastes needs to be managed to minimize toxic substances which release into the environment and human health (Obanjo and Nnorom, 2008).

Recycling of electronic wastes has potentials solutions for reduction of e-waste and depletion of natural resources from mass production of present modern society. Mobile phone wastes contain precious metals such as gold, silver, copper etc., if these metals are collected and sent proper recycling process, it can minimize environmental impact and save energy from resource extraction. Mobile phone wastes are important sources for urban mining which can be extracted precious metal out of a several-fold higher than natural mine (Baba et al, 2010). A recent life cycle assessment (LCA) study pre-treatment and recovery process of e-wastes by Bigum et al. (2012) reported that the environmental costs of pre-treating the e – waste and recovering the metals are less than the cost of producing virgin metals from mining. Therefore, pretreatment and recovery of metal from e–wastes are cost-effective and environmental friendly.

The major problem of management EoL of mobile phones in Thailand is the lack of efficient collection system of mobile phone wastes. The percentage of distribution EoL of mobile phone in different channels in Thailand from surveying of consumer behavior done by PCD in 2012 found that mobile phones were sold (50.18%), store (31.66%), throw (12.39%) and donate (5.77%). Based on the survey, only a few of EoL mobile phones were sent to the formal management system. Because Thailand has no mobile phone wastes management system so most of EoL mobile phones were sent to informal management system. The Pollution Control Department (PCD) summarized the problems in the management of e-wastes in Thailand before set WEEE strategic plan the problems in 2007 including: 1) management of e-wastes in the country has no plans to link between government, private and public as a framework for long-term operation, 2) limitations in the rules and guidelines for the practice of e-waste management, 3) no charge fees for managing e-wastes effectively, 4) publicity campaign to the public and operators of all levels took part in the e-wastes management remains discontinue, 5) government and private sectors have restrictions and lack of incentive to invest in the e-wastes management (PCD, 2012: online).

To manage e – wastes in Thailand, the collection of quantitative data of end of life (EOL) electronic products is not quite in systematic because lifetime of electronic devices, the type and behavior of the people are different. So it does not have sufficient information to evaluate amount of e – wastes in the country. However, many governmental agencies are trying to determine the quantity and quality of the e-wastes. The results of research projects and measures to restore the ruins of electronic products for Pollution Control Department (PCD, 2004) found that the EoL of the electronics in the country, were about 2 million units, equivalent to 70,000 tons, and there are potentials to recycle about 80 percent. Beside The problem of the lack of proper management by 90 percent of the remains of electronic products is handled together with municipal wastes, as well as its disassembly for recycling. The management system is not designed for controlling the hazardous substance in the electronic product (PCD, 2007)

In Thailand, electronic wastes have increased every year because people are not aware of the dangerous impact to the environment and human health. The general public still does not realize the importance of using environmental friendly products to reduce the environmental impact from products. People lack of incentives for wastes separation, and do not cooperate in sorting out the mobile phone wastes from municipal waste. In the section of business, lack of financial mechanisms and investment to support product management and research remains relevant and need sustainable solutions. Since the data collection and database of mobile phone wastes in Thailand, is not enough to be linked to the plan as a whole to solve the problem effectively. Recycling factory require high capitals for investment, along with information of waste systems to collect are still not efficient enough to create confidence for the investors. In the section of laws and regulations are currently cannot enforce a mechanism to handle the mobile phone wastes effectively, the result is local government has low potential and limited capacity to handle wastes. Currently in Thailand, there are laws to control the issue of electronic waste which is under the responsibility of the Pollution Control Department (PCD). Ministry of Environment and Natural Resources has drafted a strategic plan for the management of electronic wastes, but there has not been declared enforceable in any way to manage this problem (PCD, 2007).

From the above, the existing problems in EoL of mobile phone wastes in Thailand are 1) People do not aware of the environmental impact from hazardous substances, 2) The lack of efficient collection system of mobile phone wastes to bring the proper management system. The contribution of this research contribution is to examine scales of the environmental impacts from managing mobile phone wastes in Thailand based on different management scenarios compared to business as usual approach. The research focuses on improving collection and recycling of mobile phone wastes to reduce the environmental impact. The results will be helpful in developing policy and planning to promote effective collection and recycle system for mobile phone wastes to solve the problem of EoL mobile phones in Thailand.

1.2 Research Objectives

1. To evaluate life cycle environmental impact of mobile phone wastes in Thailand

2. To compare impact from different management scenarios to minimize the impacts of mobile phones wastes in the future

3. To develop recommendations to better improve collection and recycle system for mobile phone wastes in Thailand

1.3 Hypotheses

1. Charger is the main source of environmental impact from EoL mobile phone components if disposed into the environment.

2. Smartphone model has higher environmental impact per unit than the regular phone model.

1.4 Expected Outcomes

1. Understand levels of environment impacts of mobile phone wastes from different management scenarios.

2. Suggest appropriate management strategy to increase the recycle rate and manage the EoL of mobile phones problem in Thailand.

1.5 Scopes of Study

To evaluate the environmental impacts from different management scenarios to minimize the impacts of mobile phones wastes in the future in Thailand. The research uses 6 models (regular phone 3 models and smartphone 3 models) of mobile phones as case studies to find average value in order to represent of mobile phone to evaluate the environment impact for end of life (EoL). The condition of scenarios analysis varied parameters in percentage of landfill and recycling in order to compare impacts from different management scenarios. The impact evaluation does not include the impact from transportation of mobile phones and recent cost from recycling technology in each scenario.

CHAPTER II

BACKGROUND AND LITURATURE REVIEW

To examine environmental impacts and management for end-of-life (EoL) of mobile phones in Thailand, the study reviewed background and literatures in 6 relevant topics including (1) the situation of mobile phone wastes and e-wastes problems in Thailand, (2) material components of mobile phones, (3) environmental impacts of mobile phone wastes, (4) current urban mining and recycling of mobile phone wastes, (5) Life-cycle assessment (LCA) analysis tools and (6) management of e-wastes and mobile phone wastes. Details of these topics are as following;

2.1 The Situation of Mobile Phone Wastes and E-Wastes Problems in Thailand

Technological innovation speeds up the rates of introducing new models of electronic equipment in the consumer markets especially mobile phones. This impacts consumers' behavior to change mobile phones more often than a few years ago consequently amount of wastes of unused or out of date mobile phones are becoming a major problem of modern society. Based on data of the National Statistical office (NSO) in Thailand, percentage of population aged 6 years and over who use mobile phone in the years 2005 – 2011 are likely to increase every year as shown in **Figure 2.1**. In 2011, the statistics showed that mobile phone users about 41.4 million of population or 66.4 percent of population who aged 6 years and over (NSO, 2012: online). The Pollution Control Department (PCD) showed consumption of mobile phones in the country which increased from 47,760,000 units in 2007 to 59,678,000 units in 2010 as shown in **Table 2.1**. **Table 2.2** showed the average lifespan of mobile phone in country which only 3.09 years per unit. Moreover, **Table 2.3** forecasted that the mobile phones wastes will increase from 8,524000 units in 2012 to 10,907,000 units in 2016 (PCD, 2012: online).

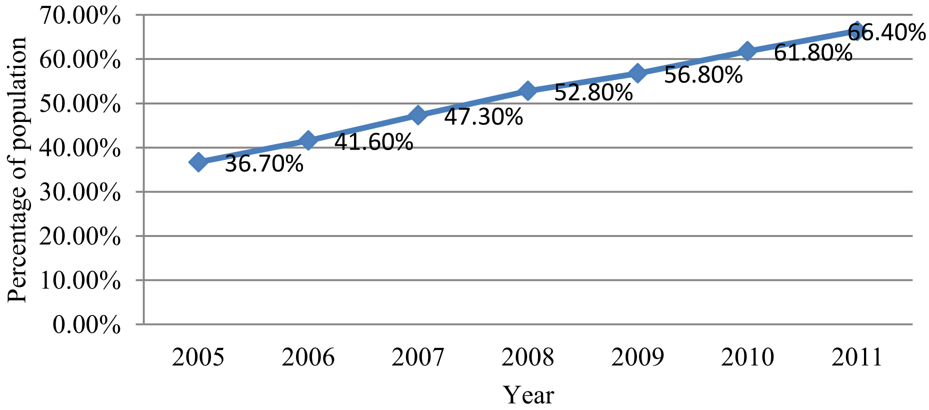


Figure 2.1: Percentage of mobile phone users aged 6 years and over (NSO, 2012: online)

Table 2.1: Consumption of electronic devices in the Thailand (PCD, 2012: online)

Product type	**(1,000 units) in year**			
	2007	**2008**	**2009**	**2010**
TV (CRT, LCD, Plasma)	3,106	2,840	2,500	2,655
Digital camera	9,369	9,863	10,382	10,928
Media player	3,429	3,160	3,800	2,010
Printer	1,724	1,814	1,910	1,748
Mobile phone	47,760	54,130	56,836	59,678
PC	2,726	2,870	3,021	3,180
A/C	1,568	1,650	1,737	1,829
Refrigerator	1,474	1,552	1,634	1,720

Table 2.2: The average lifespan of electronic devices (PCD, 2012: online)

Product type	Life span (Year)
TV (CRT)	6.9
TV (LCD/Plasma)	3.8
Refrigerator	6.87
Mobile phone	3.09
Media player	3.78
PC	3.65
Digital camera	3.13
A/C	5.20
Printer	3.05

Table 2.3: The E-waste generation forecast in Thailand (PCD, 2012: online)

Product type	**Waste generation (1,000 units) in year**				
	2012	**2013**	**2014**	**2015**	**2016**
TV	2,377	2,483	2,587	2,689	2,790
Digital camera	724	785	875	983	1,059
Media player	3,253	3,380	3,476	3,537	3,571
Printer	1,495	1,507	1,520	1,532	1,542
Mobile phone	8,524	9,146	9,750	10,337	10,907
PC	1,789	1,999	2,210	2,421	2,630
A/C	696	717	740	766	796
Refrigerator	822	872	922	972	1,023

In Thailand, the used mobile phones are distributed in local market and abroad according to market principle. Thailand has a big second-hand mobile phone market, and most used mobile phones are sold. The results from interview survey done by DOWA company in 2007 found that used mobile phones which are not sellable in Thailand are exported to neighboring counties such as Myanmar, Laos, Vietnam, Cambodia and Bangladesh. End-of-Life (EoL) mobile phones which are not able to be used anymore, are exported to China as the big sources of spare parts. Although the export of the used mobile phones in Thailand is legal, Thailand has no information about the amounts or routes of the exports of used phones. Moreover, used mobile phones still have economic values because they contain precious metals such as gold, silver, copper etc. It could potentially be used as incentives or benefits to give to users who can collect used mobile phones to return into a proper treatment system (DOWA, 2007: online).

Mobile phone wastes are not only a problem in Thailand, but also a major problem for many countries in the world. Developing countries in the newly industrialized countries such as Singapore, Malaysia and Thailand face difficulties in estimating the actual number of wastes from outside the electronic system, to assess the environmental impact on the import of electronic waste, and to recycle or get rid of them properly. The U.S. data indicated that more than 80 percent of e-wastes were exported to developing countries for disposal or recycling (US EPA, 2008: online).

To manage e – wastes in Thailand, the collection of quantitative data of end of life (EoL) electronic products is not quite in systematic because lifetime of electronic devices, the type and behavior of the people are different. So there is a lack of sufficient information to evaluate e – waste in the country. However, many governmental agencies are trying to determine the quantity and quality of the e-waste. The results of research projects and measures to restore the ruins of electronic products for Pollution Control Department (PCD, 2004) found that the EoL of the electronics in the country, were about 2 million units, equivalent to 70,000 tons. There are potentials to recycle about 80 percent. The major problem of management EoL of mobile phone in Thailand is the lack of efficient collection system of mobile phone wastes. The percentage of distribution EoL of mobile phone in different channels in Thailand from surveying of consumer behavior found that mobile phones were sold (50.18%), store (31.66%) , throw (12.39%) and donate (5.77%) as shown in **Figure 2.2** (PCD, 2012: online).

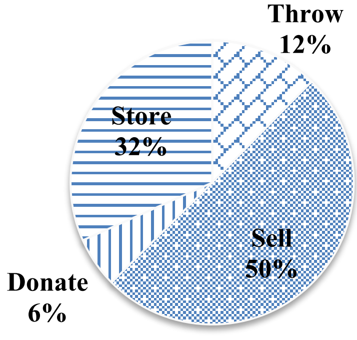


Figure 2.2: The distribution of EoL mobile phones in Thailand (PCD, 2012: online)

From the results of distribution EoL mobile phones in Thailand found that few of EoL mobile phones were sent to the formal management system because the country has no management system for e-waste. Therefore, most of EoL mobile phones were sent to informal management system. Currently, most of mobile phone wastes were regular phone. Most of smartphone were not very much discarded as the wastes. The factors that increase the amount of mobile phone wastes may include 3 factors: (1) Competitive mobile phone market. Manufacturers are trying to increase sales volume into the consumer market all models with price tend to be lessen to increase the market share of many more consumers, including those with low incomes. Nowadays, mobile phones price is as low as 700 Baht per unit, people at all levels can afford and have payment system that creates incentives for consumers to buy new model of mobile phone. (2) Rate of mobile phone service charge was reduced as well as the marketing strategy as a SIM free deal motivating consumers to hold more than one mobile unit. (3) Technological innovation speeds up the rates of introducing new models of mobile phones. It brings to consumers' behavior to change mobile phones more often (TCIJ, 2013: online).

2.2 Material Component of Mobile Phones

There are many models of mobile phone in the world and each model of mobile phone has different material and components. Most of components are made of large variety of substances and materials which made up of metals, plastics, ceramics, and trace other substances. Typical mobile phone consists of the following:

1. ***PWB (Print wiring board)*** containing a digital signal processor, microprocessor, read-only-memory and flash memory chips.
2. ***Antenna***, sometimes contained inside with circuitry
3. ***LCD*** (liquid crystal display) – a screen
4. ***Battery*** – sealed within its own case, the type of battery has 3 types: nickel-cadmium, nickel metal hydride, lithium ion.
5. ***Case*** - plastics, holding the components
6. ***Adapte***r- used for recharging the battery. Adapter is transformer to low-voltage direct current and it consists of wire, plastics, with copper connecting points
7. ***Accessories*** such as earphone or connecting cable

The components of mobile phones are composed of several types of plastics, ferrous and non-ferrous metals, ceramics and other substances (Obanjo and Nnorom, 2008). The composition of a typical mobile phone is shown in **Figure 2.3**.

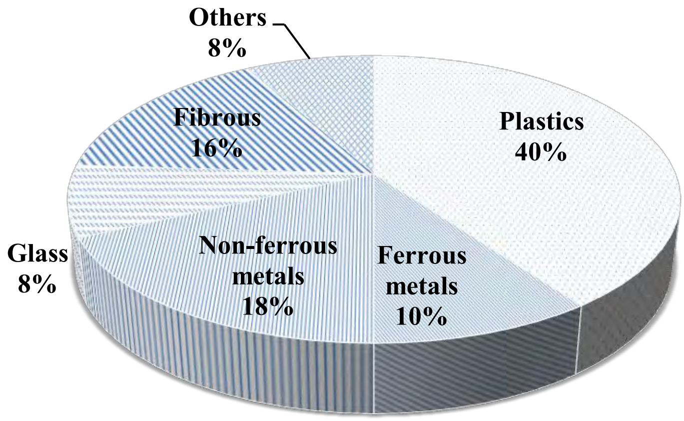


Figure 2.3: The composition of a typical mobile phone (Obanjo and Nnorom , 2008)

The main reason to treat mobile phone wastes is because major content of both, precious metals and hazardous substances in the phone. Hazardous substances have high impact to the environment, if the management is not effective, the hazardous substances can contaminate into the ecosystem through soil, water and air. On the other hand, mobile phone wastes contain precious metals such as gold, silver, copper etc., if these metals are collected and sent proper recycling process, it can minimize environmental impact and save energy from resource extraction. The extracted gold concentration from typical primary gold mines in the world is yield around 5 g/ton of soil. The study by Polák and Drápalová 2012 about extraction of precious metals from mobile phone wastes found that gold can be extracted from up to 300 - 350 g / ton of mobile phone wastes. The composition of the metals in mobile phone produced in the years 2001 and 2005 is shown as in **Table 2.4**. Therefore, mobile phone wastes are important sources for urban mining which can be extracted precious metal out of a several-fold higher than natural mine.

Table 2.4: The materials in mobile phones produced in the years 2001 and 2005 (Polák and Drápalová 2012)

Materials	Mass in mg per unit (2001)	Mass in mg per unit (2005)
Silver	244	150
Aluminum	2914	8166
Gold	38	18
Beryllium	3	2
Bismuth	31	1
Bromine	941	427
Chromium	345	1046
Copper	14,235	9996
Iron	8039	8399

Materials	Mass in mg per unit (2001)	Mass in mg per unit (2005)
Glass	10,594	7501
Nickel	1124	3276
Lead	301	10
Palladium	15	1
Antimony	84	3
Tin	689	911
Zinc	641	655

Printed wiring board (PWB) is the important part of mobile phone to recycle because it has various metals such as copper, iron, tin, nickel, lead, aluminum, gold, silver, etc. The recycling of various metals present in the composition of the PWB is very difficult. On the other hand, the interesting materials for recycling come from the high percentages of precious metals in PWB (Kasper et al., 2011). The percentages of metals present in the PWB as shown in **Table 2.5**. While 52% of PWB contain metals, 48% of PWB mainly contain plastics and others.

Table 2.5 : Percentages of metals present in the PWB (Kasper, Berselli et al. 2011)

Metal	**%**
Copper	37.81
Aluminum	0.61
Lead	1.23
Iron	4.85
Tin	2.55
Nickel	2.54
Zinc	1.82
Sliver	0.05
Gold	0.09
Total	**51.55**

2.3 Environmental Impact of Mobile Phones Waste

The environmental impact of mobile phone wastes for the hazardous substances including lead, cadmium, etc. If the management is not effective, the hazardous substances can contaminate into the environment. Many of these hazardous substances can persist in the environment, accumulate in the food chain, and pose a risk of causing adverse effects to the environment and human health. Osibanjo and Nnorom (2008) studied the environmental impact assessments of mobile phone wastes by Nokia and stakeholders. They found that the printed wiring boards (PWB) and liquid crystal display (LCD) are the components to the highest environmental impact in the life of mobile phones accounted for about 98% (59% and 39% respectively), see **Figure 2.4**.

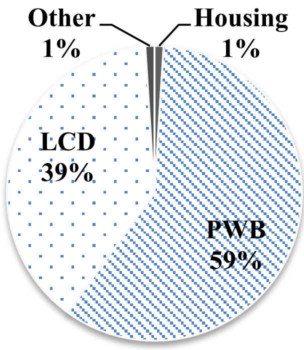


Figure 2.4: Components which have environmental impact (Obanjo and Nnorom, 2008)

The new model of mobile phone is more eco-efficient than the old one, which is not due to a reduction in the type of hazardous elements, but rather due to a significant miniaturization of the package with less weight. According to analysis of materials in mobile phone wastes found that although mobile phones are quite different in model and production year, the type of toxic substances and their relative ratio do not change. In addition, technological innovation speeds up the rates of introducing new models of mobile phones consequences the overall usage of toxic substances in mobile phones is expected to increase substantially (Wu et al., 2008).

Mobile phones have the potential to generate the environment impact because mobile phones contain toxic and rare substances. The toxicity potentials are evaluated by using heavy metal content, respective characterization factor, the pathway and impact model for heavy metals that considers end of life disposal in landfills or incineration. A recent study by Lim and Schoenung (2010) found that cancer potentials from mobile phone wastes are mainly from Pb and As as shown in **Figure 2.5.** Ecotoxicity potentials from mobile phone wastes are mainly from Cu and Hg as shown in **Figure 2.6**. The toxic substance of mobile phones can pollute into the air and water. Many of toxic substance can persist in the environment by bio-accumulating through the food chain. Therefore, it is important to reduce the emissions and control pollution from these wastes. A pathway and impact model for heavy metals in e-wastes as shown in **Figure 2.7**. Heavy metals in e-wastes treated in incineration facilities are distributed into flue gas, fly ash and bottom ash. The heavy metals in the fly and bottom ashes are landfilled for final disposal and that they ultimately leach into water. The heavy metals included in e-wastes have the potential to impact human health and the ecosystem through air and water medium.

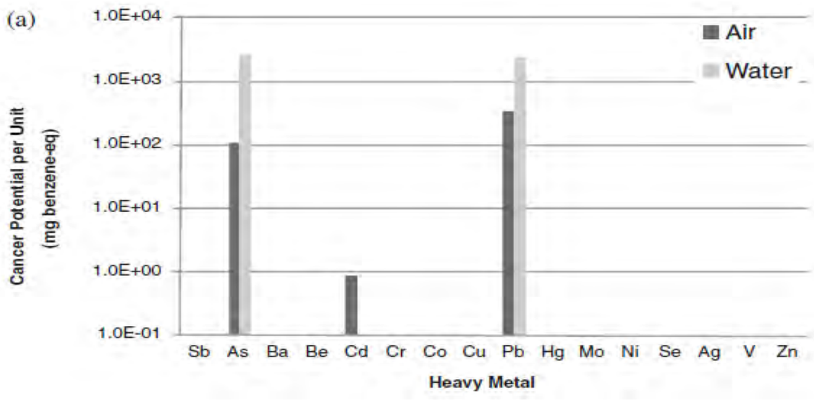


Figure 2.5: Cancer potentials form mobile phone wastes to air and water (Lim and Schoenung, 2010)

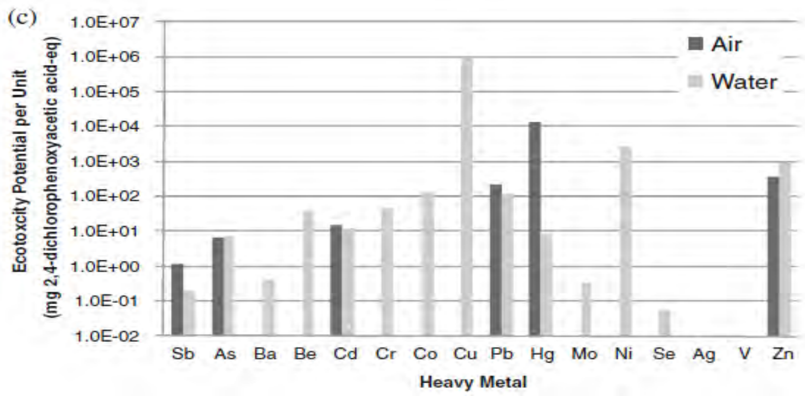


Figure 2.6: Ecotoxicity potentials form mobile phone wastes to air and water (Lim and Schoenung, 2010)

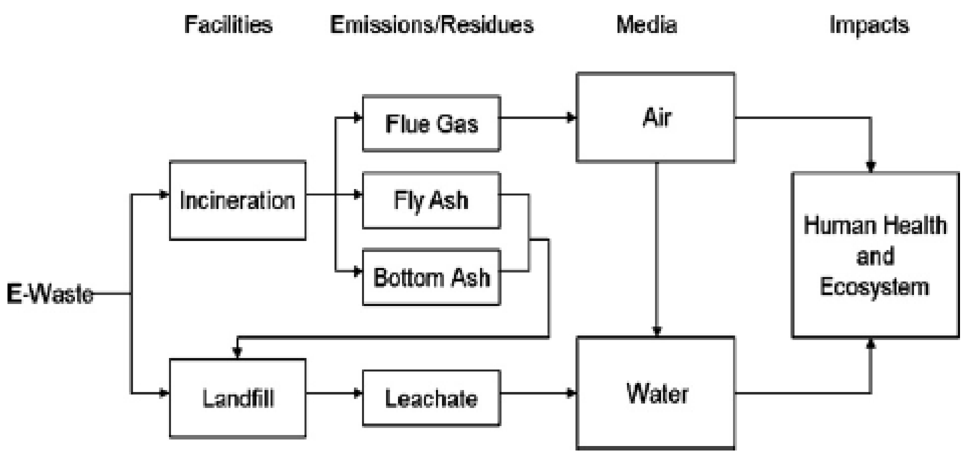


Figure 2.7: Pathway and impact model for heavy metals in e-wastes (Lim and Schoenung, 2010)

The toxic substances in mobile phones may not be immediate danger from end of life (EoL) if appropriately treated or managed. If their disposal is not properly treated, it will involve conditions and processes that may lead to the release of toxic substances. Due to the toxic substances are of concern under the conditions of land disposal and incineration. The major problem of mobile phone wastes are incinerated or disposed with domestic wastes in most developing countries due to lack of treatment systems and take back of wastes. So the disposal of mobile phone wastes needs to be managed in order to minimize toxic substances which release into the environment and human health (Obanjo and Nnorom, 2008).

Life cycle assessment (LCA) is based on systematic examination of the environmental impacts of activities or products, with the goal of revealing the environmental dimension of sustainability. The types of environmental impacts that can be evaluated by the LCA program such as climate change, toxicity and fossil fuel depletion etc. For climate change can result in adverse the affects upon ecosystem health and human health. Climate change is related to emissions of greenhouse gases to air and has effects of natural disasters, only the effects of inland flooding, caused by intensive precipitation, and coastal flooding, driven by sea level rise. Toxicity has affects to environment and human health because it can pollute into the soil, air and water, moreover it can persist in the environment by bio-accumulating through the food chain. For fossil fuel depletion, fossil is unconventional resources which is generally more energy intensive and more costly to produce when compared to conventional fuels. Fossils can be eliminated from the world due to the limited resources available (Goedkoop et al, 2009)

2.4 Current Urban Mining and Recycling of E-Wastes and Mobile Phone Wastes

Urban Mining is actions and technologies that adopted to recover resources from residues produced by municipal, industrial and agriculture waste in terms of secondary raw materials and energy. Krook et al, (2011) argued for urban mining that it has so far primarily dealt with the potential of long-term strategies for managing such urban ores through successive increasing recycling rates of annual discards. Valuable materials in e – wastes, which typically provide the incentive for recycling, include base metals such as copper and precious metals such as gold or palladium (Wäger et al., 2011). For mobile phone wastes contain precious metals such as gold, silver, copper etc., if these metals are collected and sent proper recycling process, it can minimize environmental impact and save energy from resource extraction. The study by Baba et al, 2010 about mobile phone wastes that can extract gold from up to 280 g / ton of mobile phone wastes. The composition of the other precious metals in mobile phone waste is shown as in **Table 2.6** (Baba et al, 2010). Therefore, mobile phone wastes are important sources for urban mining which can be extracted precious metal out of a several-fold higher than natural mine.

Table 2.6: The precious metals recovered 1 ton of mobile phone wastes (Baba et al, 2010).

Recovered Metal	Weight (g/ton)
Gold	280
Palladium	137.1
Copper	140
Aluminum	145.1
Silver	450

The recycling of mobile phone wastes is very attractive because the volume of mobile phone is small and printed wiring board (PWB) containing high contents of precious metals such as gold, palladium, silver, etc. So the key to success recycling of mobile phone wastes hinges on efficient technologies and economical for recovery valuable metals from PWB. **Figure 2.8** shows the methods of recycling processes developed in Korea. The first method (process I) is shredding of PWB wastes and send to a copper smelter. The second method (process II) is comprised of shredding, incineration, melting into copper alloy containing precious metals and refining processes including leaching, separation and recovery have been employed for the recovery of valuable metals (Lee, Song et al. 2007).

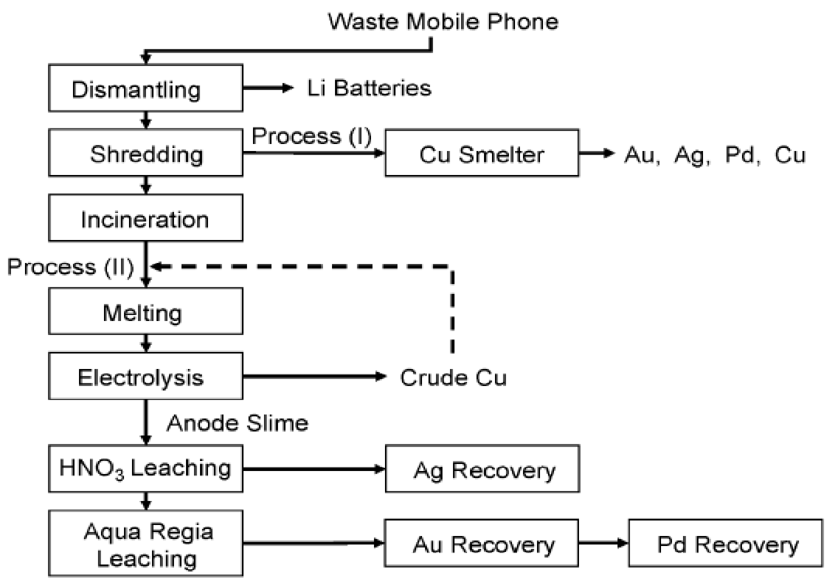


Figure 2.8: Flow chart for the recycling of metal values from mobile phone wastes (Lee, Song et al. 2007).

Recycling is emerging as potentials solutions for reduction of waste and depletion of natural resources from mass production and mass consumption of present highly civilized social system (Kim et al., 2009). A recent LCA study by Bigum et al, (2012) reported that the metal content of high-grade e-waste and the recovery rates for pre-treatment, recovery process and overall as shown in **Table 2.7**. The function unit of the study is recovery of gold, iron, nickel, aluminum, copper, palladium and silver from 1 tons of high-grade e-wastes (the assessment is attribution using average data for the energy substitution). The environmental costs of pre-treating the e – waste and recovering the metals are less than the cost of producing similar amount of metals from virgin ore. In recycling e –wastes, it should aware importance a cost-effective and environmental friendly recycling system. Process in recycling of e – wastes: disassembly and mechanical/physical processing is based on the characterization of e–wastes such as screening, magnetic, eddy current, electrostatic, etc.

Table 2.7: The metals content of e-waste and the recovery rates (Bigum et al, 2012)

Metal	**Metal content high-grade e-waste**		**Recovered [%]**		
	Value	**Unit**	**Pre treatment**	**Recovery process**	**Overall**
Palladium	7	g/ton	26	98	25
Gold	22	g/ton	26	98	25
Sliver	313	g/ton	12	97	12
Nickel	3	Kg/ton	100	90	90
Aluminum	33	Kg/ton	86	79	68
Copper	44	Kg/ton	60	95	57
Iron	204	Kg/ton	96	100	96

Recycling of e-waste is important for recovery aspect of valuable materials, savings in energy, saving in virgin materials and reduction wastes. The US Environmental Protection Agency (EPA) has identified major benefits when using scrap iron and steel instead of virgin materials as shown in **Table 2.8.** Using recycled materials in place of virgin materials results in significant energy savings as shown in **Table 2.9**. (Cui and Forssberg, 2003)

Table 2.8: Benefits of using scrap iron and steel instead of virgin materials (Cui and Forssberg, 2003)

Benefits	Percentage
Savings in energy	74
Savings in virgin materials use	90
Reduction in air pollution	86
Reduction in water use	40
Reduction in water pollution	76
Reduction in mining wastes	97
Reduction in consumer wastes generated	105

Table 2.9: Recycled materials energy savings over virgin materials (Cui and Forssberg, 2003)

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

The results from life cycle assessment (LCA) of the recovery of metals from 1 ton of high grade WEEE are shown in **Table 2.10**. This table allocates the environmental loads and benefit from mass flows and economic of the mass flows. The results of person equivalents (PE) found that the environmental impacts show negative values, it means that the environmental costs for recovery of metals are less than the cost of producing metals from virgin minerals. Therefore pretreatment and recovery of metal form WEEE is significant to reduce resource consumption and environmental impacts (Bigum et al, 2012).

Table 2.10: Environmental impact assessment of recovery of metal per ton high-grade WEEE. (Bigum et al, 2012).

Impacts **Environmental Impact categories**	**Mass** Person equivalents (PE)	**Economics** Person equivalents (PE)
Acidification	-0.25	-0.27
Ecotoxicity in soil	-1.13×10^{-3}	-1.10×10^{-3}
Ecotoxicity in water (chronic)	-7.83	-4.41
Global warming 100 years	-0.25	-0.38
Human toxicity via air	-0.98	-1.00
Human toxicity via soil	-0.26	-0.50
Human toxicity via water	-0.48	-0.25
Nutrient enrichment	-0.05	-0.07
Photochemical ozone formation	-0.02	-0.04
Stratopheric Ozone depletion	-1.01×10^{-4}	-2.16×10^{-3}

Resource consumption	**Mass** Person equivalents (PE)	**Economics** Person equivalents (PE)
Aluminum	-5.07	-5.07
Brown coal(lignite)	-0.41	-2.18
Copper	-11.0	-11.0
Crude oil	-0.21	-0.49
Gold	-14.6	-14.6
Hard coal	-0.62	-0.91
Iron	-3.93	-3.94
Lead	-2.50×10^{-4}	-5.21×10^{-3}
Manganese	-1.44	-1.44
Nature gas	-0.18	-0.43
Nickel	-12.3	-12.3
Palladium	-63.0	-63.0
Sliver	-11.7	-11.7
Uranium	-0.20	-0.03
Zinc	-0.04	-0.01

2.5 LCA-analysis-tools

Life-cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from- cradle-to-grave. LCA is environmental assessment tool standardized by International Standard Organization (ISO) that provides quantitative environmental impact (Kim et al., 2009). LCA’s can help avoid a narrow outlook on environmental concerns by: inventory of relevant materials and energy inputs and evaluating the potential impacts associated with identified inputs and releases. Apisitpuvakul et al. (2008) mentioned that LCA is an appropriate tool in evaluate these benefits of each end of life (EoL) product handling, as it examines the environmental burden generated by a product or process for its entire life. It will be taken materials, energy, and pollutants or waste into account.

Kasper et al. (2011) mentioned that the electro- electronics industry has used tool such as life cycle assessment (LCA), eco-design to improve its environmental performance.

LCA study of a Chinese desktop personal computer by Simapro software version7.0, expressed with the Eco-indicator'99 method, ecoinvent 1.3 database shows the result of Ecoindicator'99 points (EIP) from Single score, found that the manufacture and use phase generate with about 41 EIP and 43 EIP respectively. The use of such devices is the highest environmental impact because the used are dominated by the fossil resource consumption. The distribution step contributes very few to the impacts. During the EOL step assuming a state-of-the-art recycling, substantial environmental benefits value of about 22 EIP equals. In the manufacturing of such devices, the desktop personal computer is part contributing most to the impacts, while keyboard and mouse are of minor impact (Duan et al., 2009).

LCA study on TV in China by Simapro software version7.2, expressed with the Eco-indicator'99 method, ecoinvent 2.2 database shows that the use stage of such devices has the highest environment impact, has Ecoindicator'99 points from Single score about 63.43 Pt. More than 99% is attributable to electricity consumption, followed by the manufacturing stage has about 30.68 Pt, about 42% is due to the consumption of fossil resources and minerals. In this stage the CRT and the Printed Circuit Board (PCB) are those components contributing the most environmental impacts. The distribution stage has very little impact, because the energy consumption of transportation is the only input. The EoL stage sets in four management options: 1.Sanitary Landfill, 2.Hazardous waste incineration, 3.Recycling treatment by the formal dismantling enterprises in China and 4.Recycling treatment in the EU. The result found that the incineration of TV has the highest environment impacts due to high emissions into water, air and soil in the incineration process, followed by the environmental impacts from the sanitary landfill scenario. In recycling treatment by the formal dismantling enterprises in China scenario has the highest net environmental benefits because of the recovery of valuable materials followed by the environmental benefits from EU recycling treatment scenario (Song, et al., 2012).

The environmental impacts of Swiss WEEE collection and recovery systems in 2009 and of landfilling and incineration scenarios usingthe Eco-indicator'99 (H/A), Ecoinvent v. 2.01 database, shows that environmental impacts of Swiss WEEE recovery scenario are the lowest impacts followed by incineration and landfilling respectively. Because recycled in case of the Swiss WEEE recovery scenario can avoid environmental impacts from the primary production of materials. The results of three Ecoindicator'99 damages categories ecosystem quality, resources and human health, the ecosystem quality dominates the environmental impacts in case of incineration and landfilling scenario as shown in **Figure 2.9**. Main contributors to the environmental impacts of the Swiss recovery scenario come from the metals treatment and recovery (i.e. the secondary production of copper, aluminum and steel out of the fractions resulting from WEEE pre-processing), followed by CRT devices treatment and plastics treatment (incineration and recovery, respectively) (Wäger et al., 2011).

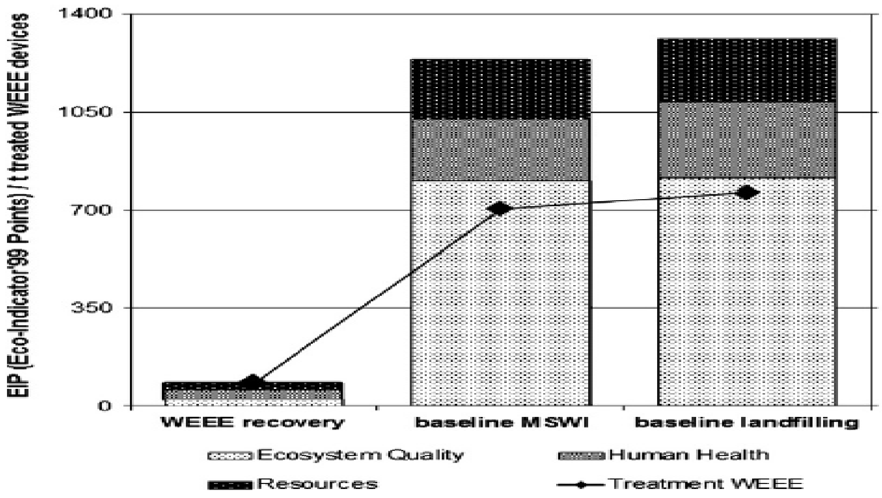


Figure 2.9: Environmental impacts of the Swiss WEEE recovery scenario 2009 compared landfilling and incineration scenarios (Wäger et al., 2011)

From LCA study on mobile phone using IMPACT 2002+ method, the environmental impacts relevance of the three life cycle phases: production phase, use phase and end of life (EoL) phase is shown in **Figure 2.10**. The results found that the environmental impacts of use phase are higher than impacts on resource depletion from other phases over the entire life cycle of mobile phone. The impacts of production phase are primarily attributable to energy intensive manufacturing of printed wiring board (PWB). The EoL phase dominates the environmental impacts on ecosystems quality because long-term emissions of heavy metals have critical effects. The EoL phase shows that recycling of materials leads to reduce of environmental impacts by avoided primary production of materials. The increased recycling of secondary precious and rare materials leads to significant reduction in the environmental impacts on human health (Scharnhorst et al., 2005).

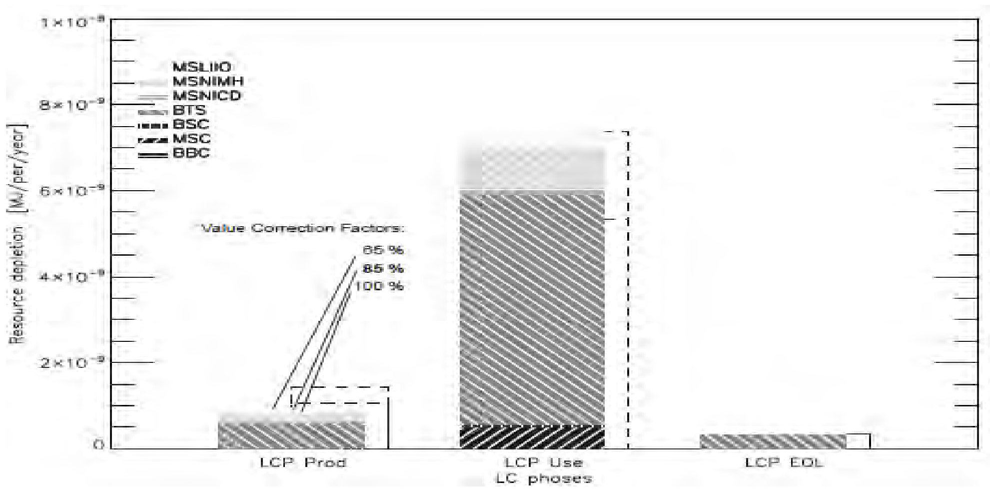


Figure 2.10: Environmental impacts of the three life cycle phases: production phase, use phase and EOL phase (Scharnhorst et al., 2005)

2.6 Management of E-Wastes and Mobile Phone Wastes

In Thailand, the separation and storage of e – wastes is not efficient. The problem of electronic management remains a major problem and need to be corrected urgently such as the lack of capital to build and operate the system, shortage of personnel and expertise, finding a place to set up a management center and implement the appropriate treatment technology. Pollution Control Department (PCD) concluded the problems in the management of e-wastes in Thailand before set WEEE strategic plan the problems in 2007: including (1) management of e-wastes in the country has no plans to link between government, private and public as a framework for long-term operation, (2) limitations in the rules and guidelines for the practice of e-waste management, (3) no charge fees for managing e-wastes effectively, (4) publicity campaign to the public and operators of all levels took part in the e-wastes management remains discontinue, and (5) government and private sectors have restrictions and lack of incentive to invest in the e-wastes management (PCD, 2012: online).

In 2007, The Pollution Control Department (PCD) set WEEE Strategic Plan in order to solve the electronic wastes problem in the country. *Strategy 1* is technology development & best available practice: development in technology and the proper way to handle e - waste. The production of electrical and electronic equipment must be environmental friendly. *Strategy 2* is capacity building & empowerment: to Enhancing the learning process and the participation of all sectors in management problem of e - waste. *Strategy 3* is law enforcement & development: enhancing the efficiency of law enforcement and legal systems that facilitate the management of e - waste. *Strategy 4* is financial & investment system: using financial measures to promote investment to support the production of electrical and electronic equipment environmental friendly as well as managing e - waste. *Strategy 5* is management scheme & organization development: management system e - waste in an efficient and comprehensive, including the establishment of environmental responsibility (PCD, 2007).

In 2011, Nokia, TES-AMM (Singapore) and the Center of Excellence for Environmental and Hazardous Waste Management (EHWM), Chulalongkorn University have worked together to promote and raise awareness of consumer regarding mobile phone recycling. They set take-back campaign in name “Chula Loves the Earth 2011”. The objectives in this campaign are (1) to raise awareness of students and the public about the importance of mobile phone recycling, (2) to take back unused mobile phones for recycling and (3) to raise funds for Chaipattana Foundation. This campaign project was initiated under the Pollution Control Department’s WEEE CAN DO to celebrate His Majesty’s 84^{th} Birthday. Those who join by returning their unused phone devices, Nokia will donate US$2 of every phone drop to Chaipattana Foundation (His Majesty’s Foundation). This project continued within Chulalongkorn University and neighborhood (communities and schools) by promoting the campaign by various media and collecting dropped-off mobile phones and accessories from all recycling bins every month (EHWM, 2012).

Nnorom and Osibjoan (2008) mentioned that in European union, the objective of the WEEE Directive are to shift e-waste from incineration and landfill to environmentally sound recycling and reuse, to preserve resources and energy. The financing for recycling and responsibility for organizing collection of WEEE has to be taken over by the producers of electrical and electronics. The Directive as the following : 1) Design and production of electrical and electronics should facilitate dismantling and recycling, 2) WEEE should be collected separately from other waste, and the collection should be free of charge, 3) Best available recovery, recycling and treatment techniques should be used to protect human health and environment, 4) Producers are responsible for financing the management and take back of WEEE, 5) Information should be provided to users and to treatment facilities. Switzerland is the first country in the world to develop and implement the well organized and formal E-waste management system for collection, transportation, recycling, treatment and disposal of e-waste. The legal and operation frame work of the system is based on the Extended Producer Responsibility (EPR) model and places the physical and financial responsibilities for the environmentally sound handling, recycling and disposal of the e-waste on the manufacturer/ producer and exporter of these products. Financial system is generated from visible Advance Recycling Fee (ARF), collected from all the purchaser of the new electronic appliance at the time of purchase. End consumer pays the recycling fee, which is equivalent to the difference between the total system cost and the total recovered value from the e-waste. Switzerland, have established and implemented a formal E-waste management system and has recycled 11 kg /capita of WEEE against the target of 4 kg /capita set by EU (Wath et al., 2010)

Kojima (2005) discussed the involved in developing recycling industry and apply EPR in developing countries may be difficult because of the following: (1) Countries with rural communities which have low household appliance rates and it difficult to collect EOL equipment, (2) Recycling is undertaken by the informal sector so collecting used e-waste would be no easy task, (3) Difficult to establish where the responsibility lies for used products that have been modified or repaired and smuggled products lies with9 importer or producer, (4) There are no figure on the number of importing agents and 5) There are products that have been brought in as private imports and it is difficult to identify which product was imported by whom. E-wastes are dumped in developing countries and Eastern Europe from USA, Japan, Canada and Western European countries. Exporting e-wastes to developing countries exposes to toxics and hazardous substances and these countries have no appropriate technology for waste management. The reasons which present informal and ineffective of e-wastes management in developing countries includes; (1) Unwillingness of consumer to pay for the disposal of e-wastes or handout their EOL products, (2) Lack of awareness among collectors, consumer and recycles of the potential hazards of e-wastes, (3) Lack of funds and investment to finance improvements in recycling, (4) Lack appropriate management and infrastructure for recycling of e-wastes, (5) Lack effective take-back programs for EOL electronic devices, (6) Lack of legislation dealing with e-waste and ineffective implementation of existing regulations on the trans-boundary of e-wastes (Nnorom and Osibjoan, 2008)

For mobile phone wastes are a type of e-waste, has impacts to every country in the world. For example in Korea, the average 14.5 million mobile phones have been retied annually over the period of analysis (2000 – 2007) Most end of life mobile phones have been stored at home waiting for disposal. The methods and infrastructure for recycling have not yet been well-established. More active collection activities and system for end of life are still needed, establish more collection points where consumers can drop off end of life mobile phones. Producers, consumers and local government should consider promote the collection and recycling schemes. So to achieve effective management of mobile phones waste, there has to be in place a well-coordinated network for collection. The quantity collected will however determine the EOL approach to be adopted. Economics and environmental performance will have to be considered in choosing combinations of the management option (Jang and Kim, 2010).

Osibanjo and Nnorom (2008) studied how to reduce impacts of the EoL mobile phone in developing countries from mobile phones usage and manufacturing. They had recommendation for relevant stakeholders as following: for manufacturers (1) Redesign of mobile phones to reuse of component, this is important to recycling business, (2) Encourage product life extension through remanufacturing by training labor in repairs and remanufacturing of mobile phones, (3) Implement EPR (voluntary) and take responsibility in management of their EoL products. For governments in developing countries, the researchers recommend to (1) Introduce EPR mandating producers to be stimulate in the EoL management of products, this requires legislation dealing with e-wastes management, (2) Encourage the introduction of formal recycling for electronic waste, technology necessary for recovery materials from EoL mobile phones and ban the disposal of e-wastes with municipal wastes, (3) Promote e-wastes management for example exchange of knowledge on e-wastes management, discuss strategies towards promoting management options for e-wastes, (4) Adopt strategies to prevent the dumping of mobile phone waste. To achieve effective management of e-wastes, there has to be in place a well-coordinated network for collection of the EoL mobile phones. Environmental performance and Economics will have to be considered to choose management option. In developing countries, the introduction of mandated producer responsibility has become necessary.

Lim and Schoenung (2010) suggest that Government, corporate and consumer responsibilities are required for effective mobile phone wastes management by; (1) Government responsibility implements and establishes wastes management system, educates environmentally responsibility and coordinate all stakeholders with mobile phones, (2) Corporate responsibility, manufactures develop environmentally responsible mobile phones in the context of design for environment and take-back EoL electronic devices in order to increase recycling and (3) Consumer responsibility, consumers have behavior to prevent excessive consumption of resources and toxicity potential associated with mobile phone and return of EoL mobile phones to the take-back system which is link with treatment and recycling facilities. **Figure 2.11** shows triple bottom line for effective mobile phone wastes management by Lim and Schoenung (2010).

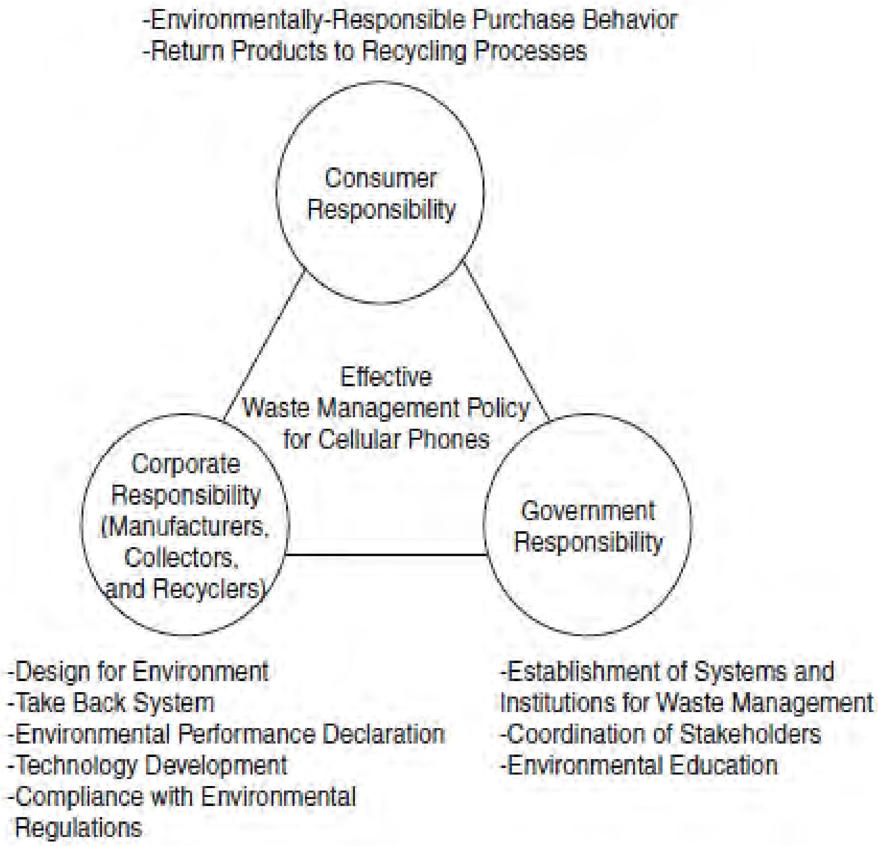


Figure 2.11: Triple bottom line for effective mobile phone wastes management (Lim and Schoenung 2010).

CHAPTER III

METHODOLOGIES

The methodologies of this research are divided in 3 steps (1) Preliminary study phase, (2) LCA phase and (3) Development of recommendation phase. For preliminary study phase, the aims are to review all relevant theories, data, publication and etc. to support the experimental design, to select the model of mobile phone representatives in case study, and to examine components for the phones in preparation for the next step of analysis. In the LCA phase, it examined details about LCA framework, set a scope of the study, describe research scenarios and LCIA, data collection and treatment and analysis tool. In the development of recommendation phase, it explains about steps to compare impacts from different management scenarios, to survey public opinions about mobile phone wastes management, and to uses all analyzed results for develop strategies for improve efficiency of the management. The details of each step are described below:

3.1 Preliminary study phase

3.1.1 Relevant data is reviewed to support in this research design and experiment including;

- Review report and data about the situation of mobile phone wastes and e-wastes problems in Thailand from Pollution Control Department (PCD), Electrical and Electronics Institute, and National Statistical Office (NSO).
- Review journal articles about environmental impact of mobile phones wastes, life cycle assessment (LCA), urban mining and recycling of mobile phone wastes, policy and management of e-wastes and mobile phone wastes.
- Study the manual life cycle assessment software (Simapro) to be used in this research.

3.1.2 Select the model of mobile phone representatives in case study

There are 6 models chosen to be studied in the research (regular phone 3 models and smartphone 3 models). The models that are selected for used in this research have been popular in the past (2004-2007) (Thaimobilecenter, 2012: online).

Regular phone model: It is basic cell phone. This phone has no camera, memory storage and no operating system. It cannot link internet (Thaimobilecenter, 2012: online).

Smart phone model: It has camera, memory and application in basic sets. It can link internet (Thaimobilecenter, 2012: online).

3.1.3 Study compartments of mobile phone model

Data collecting in the part of component and weight from mobile phone components was done by disassembling 6 models to collect the data in the part of component, and dividing the disassembles into 4 parts (mobile phone casing, charger casing, charger, battery) (Tan, 2005)

3.2 LCA Phase

3.2.1 Life cycle assessment framework

This research focused on assessment of environmental impact for End of life (EoL) of mobile phone according to life cycle assessment (LCA). The LCA includes four phases according to ISO 14040 and 14044 (ISO 14040, 2006; ISO 14044, 2006) as shown in **Figure 3.1.**

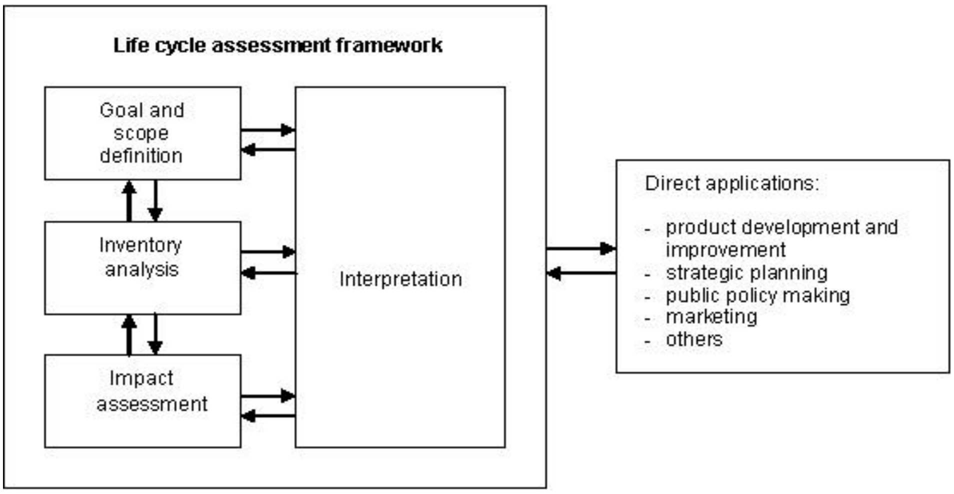


Figure 3.1: Four phases of LCA (Obtained from ISO 14040, 2006)

The details of each phase as following:

I. Definition of Goal and scope

In this phase, purpose of the study was identified. Scope including scenario description, system boundary, functional units, cut-off criteria, calculate system of recycling and benefits value from recycling of mobile phone per unit, life cycle impact assessment (LCIA), data collection and treatment, and analysis tool.

II. Life cycle inventory

In this phase, the data inventories were established. Life cycle inventory (LCI) was calculation the quantity of Inputs/Outputs flows into and outs of the system. The data to collect for life cycle inventory connected relevant process throughout the end of life of mobile phone in landfill and recycling management system, not include the transportation as shown in **Figure 3.2**. For each process, the inputs were materials, Energy, Chemicals, Others. The outputs were products, wastes, emissions to soil, emission to air, emission to water.

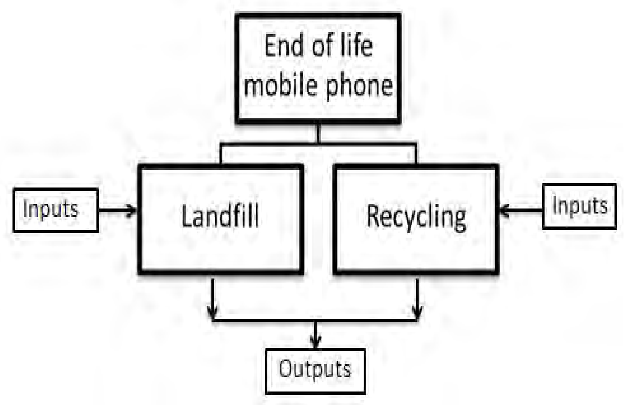


Figure 3.2: Flow inventory diagram of the end of life mobile phone management

III. Life cycle impact assessment (LCIA)

In this phase, studying the significance of potential environmental impacts from end of life mobile phone management system, using data compiled in the inventory. Elements of this phase contain impacts at the midpoint level and impacts at endpoint level.

IV. Interpretation

In this phase, after assessing the environmental impacts based on the inventory from database, the results from evaluation will be used to compare impacts from different management scenarios to develop policy.

3.2.2 Purpose of the study

The main objectives of this study are evaluating life cycle environmental impacts of mobile phone wastes in Thailand, comparing impacts from different landfill and recycling management scenarios to minimize the impacts of mobile phones wastes in the future, and developing recommendations to better improve collection and recycling system for mobile phone wastes in Thailand.

3.2.3 Scenario description

Various scenarios were set up based on end of life (EoL) of mobile phone management and each scenario was analyzed for amounts of environmental impact value. The condition of scenarios analysis is compare landfill and recycling management system of mobile phone wastes. There are 3 scenarios in the study as the following:

I. Scenario 1 (S1)

Baseline scenario or S1 is “100% landfill”: No materials are recycled. This scenario set for mobile phone wastes situation in Thailand currently (2012) which has no management system except landfill. In this step, evaluated environmental impacts value per unit of mobile phone that if 100 % of mobile phone wastes were directly sent to landfill for disposal and there were no recycling. After that environmental impacts per unit would be multiplied by the quantity of wastes that occur in 2012 (baseline scenario) and in 2020 as shown in **Figure 3.3** to evaluate environment impacts value in the future, if Thailand does not have to manage mobile phone wastes.

II. Scenario 2 (S2)

Scenario 2 or S2 is “95% landfill & 5% recycling”. This scenario set from the target of PCD in 2016 to collection e-wastes to recycling in municipalities of Bangkok and Pattaya (PCD, 2012: online). In this step, evaluated environmental impacts value per unit of mobile phone that if 5% of mobile phone wastes were taken to the recycling process and 95% of mobile phone wastes were taken to the landfill. After that environmental impacts per unit would be multiplied by the quantity of waste that forecast in 2020 to evaluate environments impacts value in the future.

III. Scenario 3 (S3)

Scenario 3 or S3 is “80% landfill & 20% recycling”. This scenario set from the recycling rate of municipal wastes in Thailand currently which 22% of wastes to recycle (PCD, 2009). This scenario set target 20% of mobile phone wastes to recycle, it is approximate recycling rate of municipal wastes in Thailand. In this step, evaluated environmental impacts value per unit of mobile phone that if 20% of mobile phone wastes were taken to the recycling process and 80% of mobile phone wastes were taken to the landfill. After that environmental impacts per unit would be multiplied by the quantity of waste that forecast in 2020 to evaluate environments impacts value in the future.

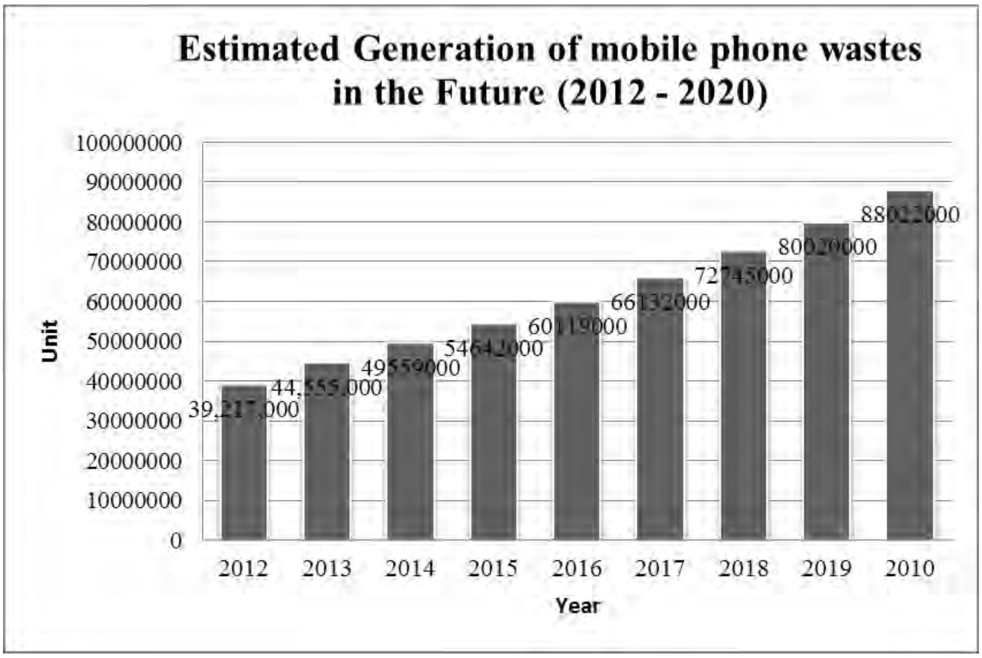


Figure 3.3: The mobile phone waste generation forecast in Thailand (Electrical and Electronics Institute, 2007)

3.2.4 System boundary, functional units and cut-off criteria

System boundaries: It is defined in the end of life (Disposal to Landfill /Recycling), does not include the transportation to landfill or recycling plant. Scope of analysis for EoL mobile phone using expanded system approached (avoided primary) (Ligthart and Ansems, 2012).

Functional unit: 1) mobile phone one unit (average from regular phone and smartphone) in end of life (disposal to landfill and recycling depend on condition of scenario), 2) regular phone model and smartphone model per unit in order to compare the environment impacts in the end of life (disposal to 100% landfill), 3) components of mobile phone (mobile phone casing, charger casing, charger and battery) in order to compare the environment impacts in the end of life (disposal to 100% landfill).

Cut-off criteria: No cut-off criteria (0%) in environmental impacts evaluation of this study.

3.2.5 Calculate system of recycling and benefit values from recycling mobile phone per unit

- Calculate system of recycling mobile phone one unit in order to find the quantity of material recovery from one mobile phone. The process of recycling based on the current treatment rules in Switzerland (Swico Environmemtal Commission, 2006). The first step of recycling is manual step that takes off those components of electronic wastes for further treatment. In case of mobile phone waste separate materials into parts in order to send in further treatment as shown in **Table 3.1**. Transfer coefficient values in the mechanical treatment of WEEE can be seen in the ecoinvent report No.18 / Part V page 19 (Hischier and Gallen, 2007)

Table 3.1: The components and further treatment of WEEE (Hischier and Gallen, 2007)

Components / Parts Amount	**further treatment**
[i] Housing / Support	
- metal parts, outside	Scrap, for metal production
	to shredder process
- metal parts, inside	to shredder process
- plastic parts, outside	plastics, to incineration
	to shredder process
- plastic parts, inside	to shredder process
[ii] Slide-in Modules	to shredder process
[iii] Printed Wiring Boards	
- high quality, mounted	PWB, for further treatment
	to shredder process
- low quality, mounted	to shredder process
[iv] Cables	
- cable (power, w/o plugs)	Cable, for further treatment
- plugs (power cable)	PWB, for further treatment
- cable (others, with plugs)	to shredder process
[v] Hazardous Components	
- Batteries	Batteries, for further treatment
- Capacitors (big)	Capacitors, to special disposal
- Capacitors (small)	to shredder process
[vi] Special components / modules	
- toner	Incineration
- LCD module, dismantled	LCD module, to incineration
- LCD, backlight (CCFL)	backlight lamp, to further treatment
- CRT tube, without gun	CRT glass treatment

Next step for further treatment of mobile phone waste has five treatments (1) Shedder process, (2) PWB, for further treatment, (3) Batteries, for further treatment, (4) Scrap, for metal production, (5) Incineration, each treatment has process to implement in detail as following:

I. Shedder process

In this process has a variety of different technologies. The result from this process ends up in four different fractions .The description of the shedder process together with its subsequent separation techniques Huisman (2003) can be seen in **Figure 3.4.**

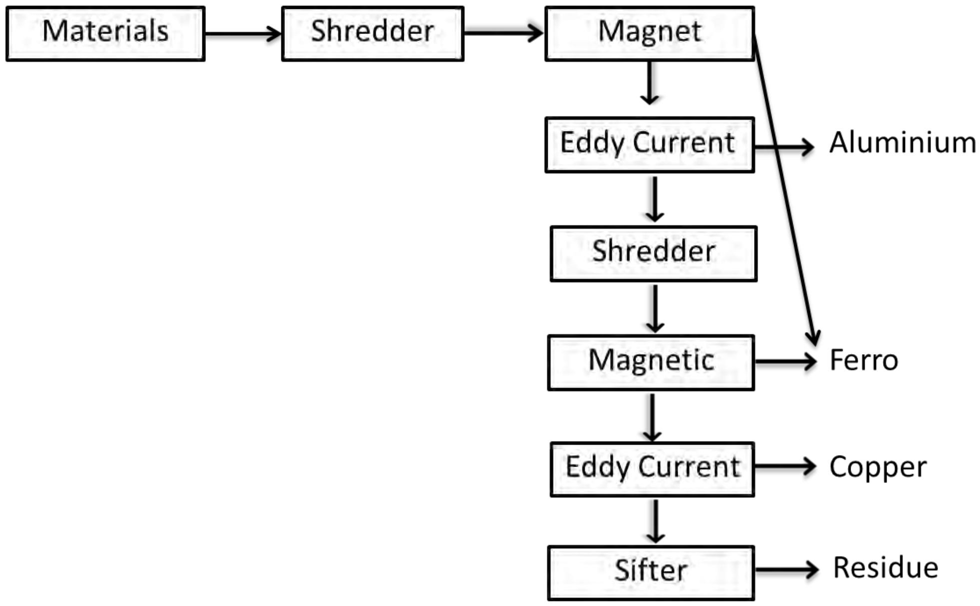


Figure 3.4: Shredder process and subsequent separation techniques of electronic wastes (Huisman, 2003)

Transfer coefficients for the materials flows in shedder process based on literature that it contacts with German and Dutch recycling companies can be seen in the ecoinvent report No.18 / Part V page 21 (Hischier and Gallen, 2007).

II. PWB Recycling

In this process, print wiring board (PWB) is treated in order to recovery metal. The process of recovery metal has 3 steps (1) secondary metal conversion, (2) secondary metal refining and (3) secondary precious metal refining. The metal from recovery of each step has details as following:

a. Secondary metal conversion
   Lead, secondary
   Metal values send to next step
b. Secondary metal refining
   Metals (Al, Fe), at refinery
   Copper, secondary, at refinery
   Nickel, secondary, at refinery
   Precious metals send to next step
c. Secondary precious metal refining
   Sliver, secondary, at precious metal refinery
   Gold, secondary, at precious metal refinery
   Palladium, secondary, at precious metal refinery

The percentage of materials flow balance in recycling process can be seen in the ecoinvent v2.1 report No.10/ Part IX page 84 (Classen et al, 2009).

III. Batteries Recycling

The type battery of mobile phone that used in this research is Lithium-ion battery. The treatment technology to recycle Lithium-ion Batteries has mixed technology between Pyromentellurgical treatment (50%) and Hydrometallurgical treatment (50%).The metals are recycled from battery by pyromentellurgical treatment are steel, cobalt, non-ferrous metals and MnO_2. The metals are recycled from battery by hydrometallurgical treatment are Cobalt, Li salt, Iron and steel, and non-ferrous metals. The percentage of materials recovery in recycling process can be seen in ecoinvent report No.18 / Part V page 86-93 (Hischier and Gallen, 2007).

IV. Scrap, for metal production

In the metal parts, outside of mobile phone waste has scrap in order to produce secondary metal. The calculation of scrap to secondary metal adapted from ecoinvent 2.1 database, Simapro software (Classen et al, 2009).

V. Incineration

Wastes from recycling process cannot be recycled which sent to incineration process. In case of mobile phone wastes for this recycling system, plastics and liquid crystal display (LCD) module which are sent to incineration can be seen in the ecoinvent report No.18 / Part V page 19 (Hischier and Gallen, 2007)

From calculated recycling system got the quantity of materials recovery from one mobile phone.

- Benefit values from recycling mobile phone per unit

The quantity of metal recovery from recycling of one mobile phone was multiplied by the price of each metal as shown in **Table 3.2** and **Table 3.3** to evaluate benefit values from recycling of mobile phone per unit. The assumption for analyze benefit values in this study is price does not include operating and recycling cost when setting recycling plant which based on recycling technology.

Table 3.2: The purchase prices each type of metal from recycling.

Metal	Price (Bath/Kilogram)
Palladium	306,450
Sliver	15,890
Cobalt	851.25
Steel	30
Copper	197
Gold	1,201,000
Aluminum	64
Ferro	7

Source: Price of the metal recycling at August 13, 2009 (PCD, 2010)

Table 3.3: The purchase prices each type of metal from mining

Metal	Price (Bath/Kilogram)
Lead	12.946
Sliver	21,860
Tin	617
Copper	246.84
Gold	1,347,000
Ferro	2.7

Source: Price of metal from mining at May 17, 2013 (DPIM, 2013)

3.2.6 Life cycle impact assessment (LCIA)

The method using in this study was ReCiPe (H) version 1.06, ecoinvent 2.1 database. This research used Perspective H because it is based on balance between short term and long term which approached proper policy that can avoid many problems (Goedkood et al, 2010). The details of fully ReCiPe method can be seen in ReCiPe 2008 – a life cycle impact assessment method (Goedkood et al, 2009). ReCiPe 2008 comprises two sets of impact categories with associated sets of characterization factors, structure of ReCiPe method as shown in **Figure 3.5.**

At the midpoint level, 18 impact categories are addressed. At the endpoint level, most of these midpoint impact categories are further converted and aggregated into the following three endpoint categories: Human health, Ecosystems and Resource (Goedkood et al, 2010). The detail of midpoint and endpoint categories can be seen in **Appendix D**.

Characterization: The substances that contribute to an impact category are multiplied with a characterization factor that expresses the relative contribution of the substance (Goedkood et al, 2010).

Single score: In the single score step, the weight values (three endpoint categories: Human health, Ecosystems and Resource) are added together and presented as a single number change (Goedkood et al, 2010).

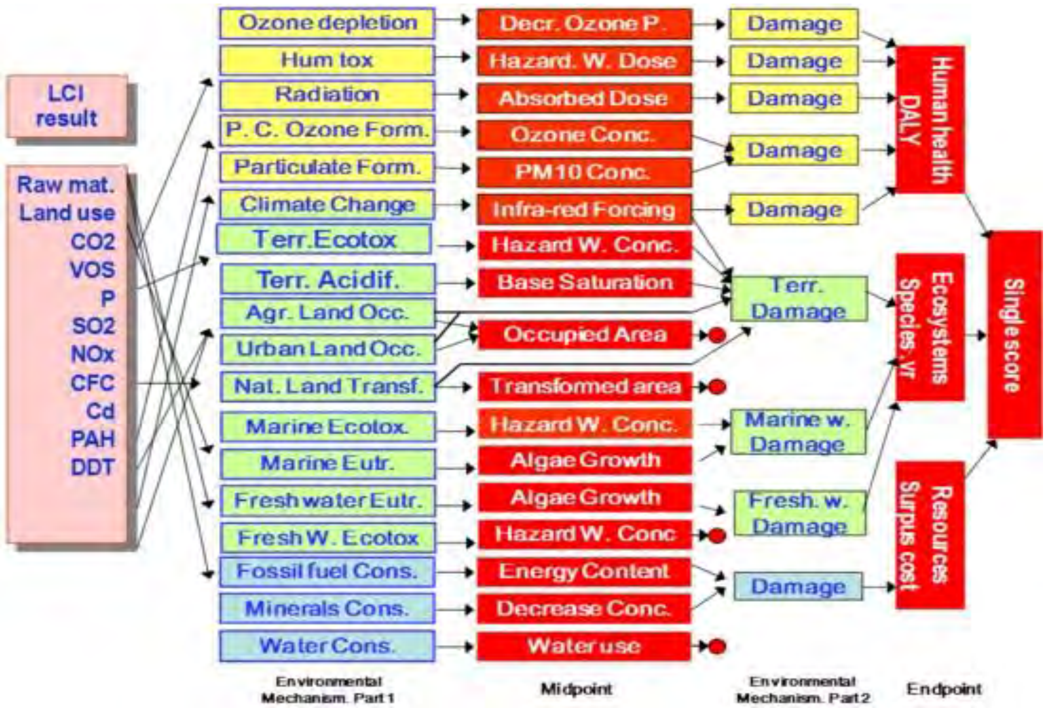


Figure 3.5: Structure of ReCiPe method (Obtained from Goedkood et al, 2009)

In this study selected impact at midpoint level to present in study 5 impact categories (1) Human toxicity, (2) Climate change human health, (3) Fresh water ecotoxicity, (4) Minerals depletion and (5) Fossil fuel depletion. Because this research studied environmental impact of mobile phone wastes which containing hazardous and precious metals. Hazardous substances have high impact to the environment, if the management is not effective, the hazardous substances can contaminate into the ecosystem through soil, water and air. Many of these hazardous substances can persist in the environment, accumulate in the food chain, and pose a risk of causing adverse effects to the environment and human health (Lim and Schoenung, 2010). So evaluation the impacts in Human toxicity, Climate change human health and Fresh water ecotoxicity showed impacts from mobile phones wastes to human health and environment. For evaluation impacts in Minerals depletion and Fossil fuel depletion because mobile phones wastes containing precious metals, if these metals are collected and sent to proper recycling process, it can minimize environmental impact and save resource from extraction (Bigum et al, 2012).

3.2.7 Data collection and treatment

I. Data types: data used in this study was primary data collected from disassembly the model of mobile phones and weight the component and secondary data from database of ecoinvent 2.1. to support the emissions from raw material extraction and other important processes.

II. Demands to data quality: disassembly 6 models to collect data in the part of component as shown in **Figure 3.6**, divided to disassembly in 4 parts (mobile phone casing, charger casing, charger, battery), list of material from model of mobile phone which will measure the weight as shown in **Table 3.4.**

Figure 3.6: The picture disassembly the model of mobile phone

Table 3.4: Lists of material from disassembly the model of mobile phone which will measure the weight.

Model of mobile phone	
Component	**Component**
1. Mobile phone Casing	**3. Charger**
1.1 Plastic	3.1 Liquid crystal display (LCD)
1.2 Rubber	3.2 Metal (Aluminum)
1.3 Screws	3.3 Print wiring board (PWB)
1.4 Metal (Iron)	3.4 Plastic
2.Charger Casing	3.5 Metal (Iron)
2.1 Plastic	**4. Battery**
2.2 Metal (Gold plating)	4.1 Plastic
2.3 Metal (Stainless)	4.2 Metal (Tin)
2.4 Paper (Carbon)	4.3 Print wiring board (PWB)
2.5 Rubber	4.4 Battery Pack
2.6 Metal (Copper)	4.5 Rubber
2.7 Metal (Iron)	

After disassembly 6 models to divide in 4 parts (mobile phone casing, charger casing, charger, battery), finding average value from 3 regular phone models and 3 smartphone models in order to represent of regular phone model and smartphone model in order to compare the environment impacts between regular phone and smart phone. **Figure 3.7** shows step of average mobile phone.

Next find average value between representative regular phone model and representative of smartphone model to represent of mobile phone model, in order to find whether any part that has the most environmental impacts.

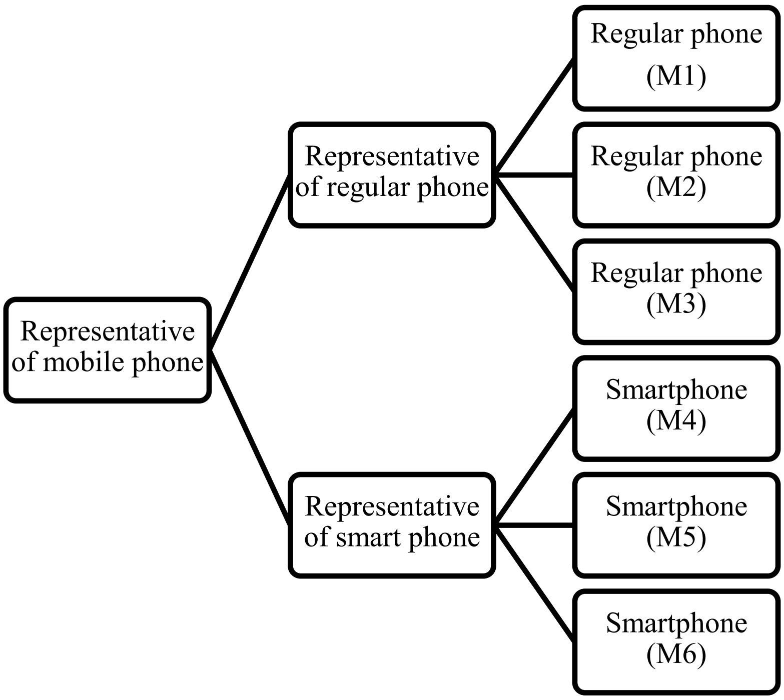


Figure 3.7: Step of average mobile phone

III. Strategy for data collection: the models that are selected for using in this research have been popular in the past (2004-2007) (Thaimobilecenter, 2012: online). Because the popular models of mobile phone in the past are become wastes in the present.

IV. Plans for verification of results: Verification of results by sensitivity analysis for each scenario, varied parameters in measurement of materials by trial and errors at 5% of weighting materials per unit of mobile phone. To exam percentage changing of environmental impacts value in each scenario from error measurement of materials which has effect to reliability of the results.

3.2.8 Analysis tool

In this research evaluated levels of environmental impacts of mobile phone using LCA software SimaPro Version7.3.3 and expressed with the ReCiPe (H) method version 1.06, ecoinvent 2.1 database. The detail of fully analysis steps in this study can be seen in **Appendix D**.

3.3 Development of recommendation phase.

3.3.1 Compare impacts from different management scenarios

Comparison of environmental impacts among various management scenarios in is done to understand the different impact that will occur in the future. By setting different target of recycling mobile phone wastes brings reduction of impacts and benefit from recovery of materials when compare management situation of business as usual (100% landfill). The study analyzed if Thailand did nothing about mobile phones wastes management, how the future environmental impact (in 2020) will be. Impacts evaluation of scenario analysis does not include the impact from transportation of mobile phones and not compare recent cost from recycling technology in each scenario.

3.3.2 Survey public opinions about mobile phone wastes management

The objective of survey public opinions is to develop recommendations on how to better improve collection system for mobile phone wastes in Thailand. Public survey in this study focuses on issue of collection system in order to bring mobile phone wastes to recycle because collection of wastes is the key factor of the waste management. The cause of problem e-wastes recycling in Thailand comes from the volume of wastes from collection that are not sufficient for the investment to make profits (PCD, 2007). Moreover survey conducted to examine the public opinion on mobile phone waste situation to understand problem and potential solutions of mobile phone wastes in Thailand by using questionnaires. Conducting Surveys divide in 2 channels as follows: (1) Hard copy direct survey and (2) online survey.

3.3.3 Develop strategies for improve efficiency of the management

Strategies for improve efficiency of the management will be examined to suggest recommendation for future mobile phone wastes management. It will be developed based on the results from scenarios analysis for End-of-life (EoL) of mobile phones in (2012-2020) and surveying results about from citizens on management mobile phone wastes in Thailand by questionnaire.

CHARPTER IV

RESULTS AND DISCUSSIONS

There are 3 main parts in this chapter: 1) Life cycle inventory (LCI) part, 2) Life cycle impact assessment (LCIA) and interpretation part and 3) Surveying of public opinions part. Life cycle inventory (LCI) part explained about components from disassembly of mobile phone models selected as cases studies, percentage of material composition of each model, average material of mobile phones which were used as data for LCIA analysis, recycling process of mobile phone per unit and the potential benefit from recycling mobile phone per unit. Life cycle impact assessment (LCIA) and interpretation part presented and discussed about environmental impacts evaluation of mobile phone and also based on components of representative mobile phone, scenarios analysis for end of life management of mobile phone and sensitivity analysis of each scenario. In the survey of public opinions part, the result analyzed opinions of citizens about mobile phone wastes management which were used to develop suggestion in the final sections. The details of each part are as following:

Part I: **Life cycle inventory (LCI) part**

4. 1 Components from disassembly the case study model of mobile phones

In this research, there are 6 models chosen to be used as case studies (3 regular phone models and 3 smartphone models). By disassembling each model of mobile phone into compartments, the components were classified into 4 groups (mobile phone casing, charger casing, charger, battery). The each component from disassembly 6 models of mobile phones is shown in **Figure 4.1- 4.6**, separating into parts (a) Mobile phone casing, (b) Charger casing, (c) Charger and (d) Battery.

4.1.1 Components from disassembly 3 regular phone models are shown in **Figure 4.1-4.3**.

(a) (b) (c) (d)

Figure 4.1: Components of regular phone model (Model 1)

(a) (b) (c) (d)

Figure 4.2: Components of regular phone model (Model 2)

(a) (b) (c) (d)

Figure 4.3: Components of regular phone model (Model 3)

4.1.2 Components from disassembly 3 smartphone models are shown in **Figure 4.4-4.6.**

(a) (b) (c) (d)

Figure 4.4: Components of smartphone model (Model 4)

(a) (b) (c) (d)

Figure 4.5: Components of smartphone model (Model 5)

(a) (b) (c) (d)

Figure 4.6: Components of smartphone model (Model 6)

From disassembling all models, type of materials from components of all 6 models of mobile phone are quite similar. Lists of material of mobile phones components which are mostly found in the mobile phone are shown in **Table 4.1.**

Table 4.1: Types of materials from components mostly found in all 6 models

Mobile phone disassembly	
1. Mobile phone Casing	**3. Charger**
1.1 Plastic	3.1 Liquid crystal display (LCD)
1.2 Rubber	3.2 Metal (Aluminum)
1.3 Screws	3.3 Print wiring board (PWB)
1.4 Metal (Iron)	3.4 Plastic
2.Charger Casing	3.5 Metal (Iron)
2.1 Plastic	**4. Battery**
2.2 Metal (Gold plating)	4.1 Plastic
2.3 Metal (Stainless)	4.2 Metal (Tin)
2.4 Paper (Carbon)	4.3 Print wiring board (PWB)
2.5 Rubber	4.4 Battery Pack
2.6 Metal (Copper)	4.5 Rubber
2.7 Metal (Iron)	

Table 4.1 summarized the main materials found as components in mobile phones which are plastic (acrylonitrile-butadiene-styrene and polycarbonate)(Bhatti, 2010) and metal. Bill of materials of PWB, LCD and Battery are applied from database ecoinvent 2.1, different quantity of substance in PWB, LCD and Battery of each model depend on weighting of components from different model, summarized is in **Appendix A**.

4.2 Percentage of material composition of each model

All components from disassembly of each model will be weighted and separated based on types of materials. Averaged value of types of material in each model will be used as data to analyze by LCA software SimaPro Version7.3.3.

4.2.1 Percentage of material composition of 3 regular phone models.

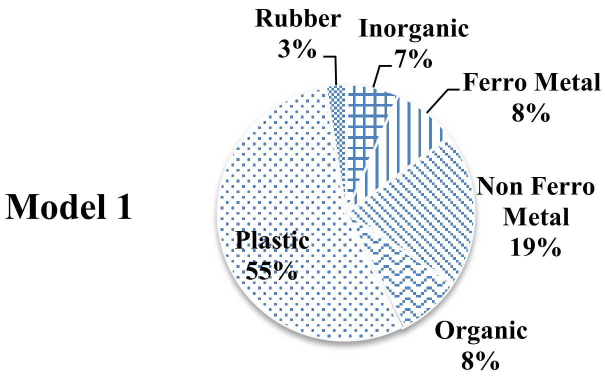


Figure 4.7: Percentage of material composition of regular phone (model 1)

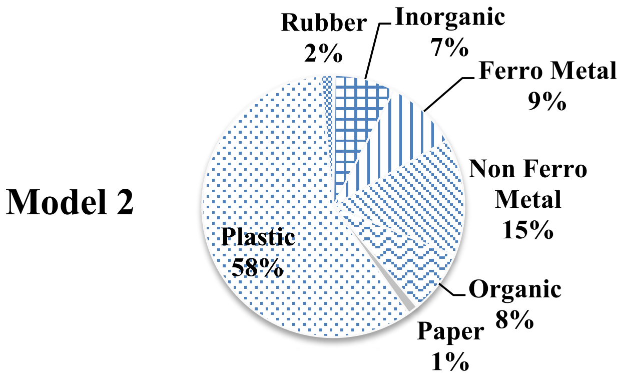


Figure 4.8: Percentage of material composition of regular phone (model 2)

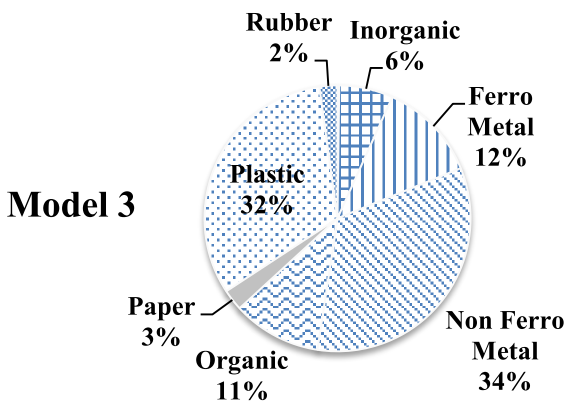


Figure 4.9: Percentage of material composition of regular phone (model 3)

The results show that the materials in component of regular phone are plastic, ferrous metal, non-ferrous metal, inorganic, organic, paper, rubber and glass. The main materials in component of regular phone are plastic (32-58%), non-ferrous metal (15-34%) and ferrous metal (8-12%). The percentage of plastic in model 1 and model 2 has much higher than non-ferrous metal. It is opposite in model 3, the percentage of plastic has slightly lower than non-ferrous metal.

4.2.2 Percentage of material composition of 3 smartphone models.

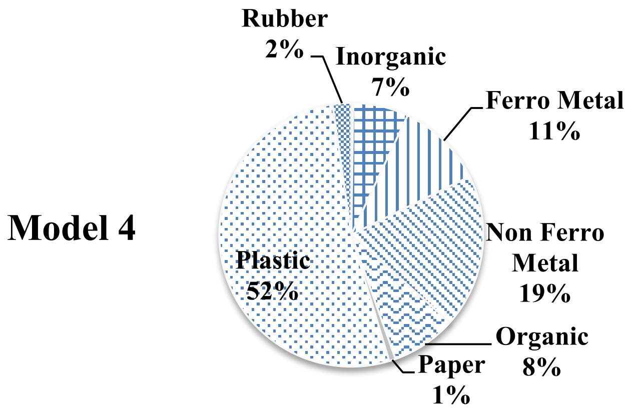


Figure 4.10: Percentage of material composition of smartphone (model 4)

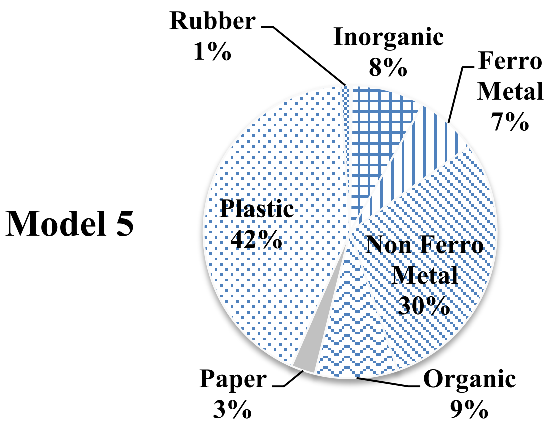


Figure 4.11: Percentage of material composition of smartphone (model 5)

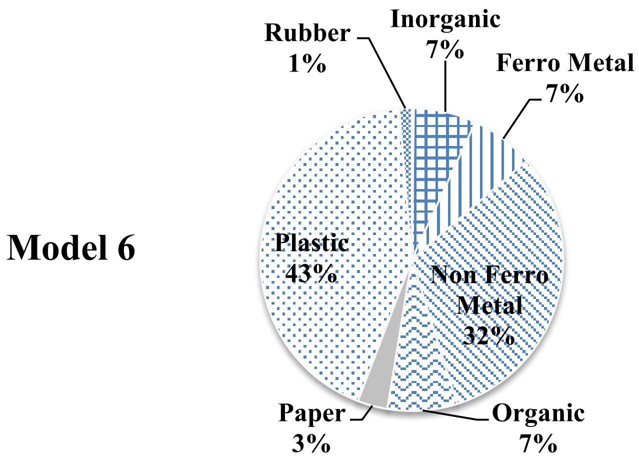


Figure 4.12: Percentage of material composition of smartphone (model6)

The results show that the materials in component of smartphone are plastic, ferrous metal, non-ferrous metal, inorganic, organic, paper, rubber and glass. The main materials in component of smartphone are plastic (42-52%), non-ferrous metal (19-32%) and ferrous metal (7-11%). Percentage of material composition in model 5 and model 6 has proportion quite similar. It is quite different in model 4, percentage of plastic is a lot higher than that in model 5 and model 6.

4.3 The average material of mobile phones as representative data for LCIA analysis

Material from 3 regular phone models and 3 smartphone models were averaged in order to represent single value of regular phone model and smartphone model to assess and compare the environment impacts between regular phone and smart phone. The next step is to calculate average material between representative regular phone model and smartphone model to represent as single mobile phone model to analysis EoL environmental impacts.

The average material of mobile phones is shown in **Table 4.2**. This table shows materials each component of mobile phone. In component of mobile phone casing, the main material is plastic, metal (Iron, Aluminum) and rubber. In component of charger casing, the main material is plastic, metal, rubber and paper. In component of charger and battery, the main material is chemicals (inorganic), metal, chemicals (organic), plastic, rubber and paper. The metal found in each component is ferrous metal and non-ferrous metal. The precious metal and toxic metal found in component of charger and battery.

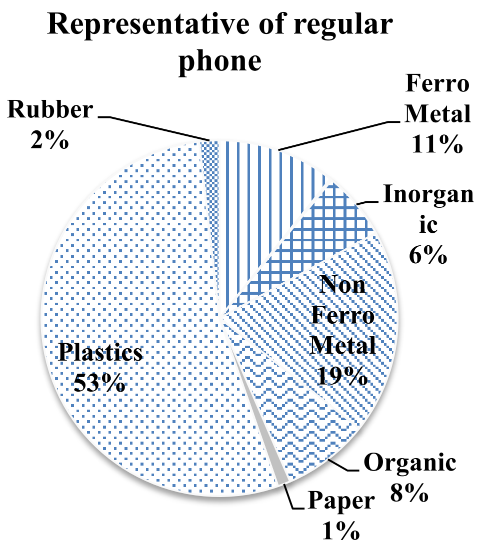
Table 4.2: The result of average material of mobile phones

Material/ Model	Representative of regular phone (g)	Representative of smartphone (g)	Representative of mobile phone* (g)	Type of Material
1 Mobile phone Casing				
1.1 Plastic	3.0926E+01	2.0121E+01	2.5524E+01	Plastics
1.2 Aluminum	3.5743E-01	1.3001E+00	8.2874E-01	Non ferrous
1.3 Iron	1.0056E+00	6.9605E-01	8.5081E-01	Ferrous
1.4 Rubber	1.5917E+00	8.6620E-01	1.2289E+00	Rubber
2.Charger Casing				
2.1 Iron	2.5190E+00	5.6933E-01	1.5442E+00	Ferrous
2.2 Copper	7.8667E-03	1.7833E-02	1.2850E-02	Non ferrous
2.3 Aluminum	0.0000E+00	1.9156E+00	9.5778E-01	Non ferrous
2.3 Gold	1.0000E-03	0.0000E+00	5.0000E-04	Non ferrous
2.4 Zinc	8.8350E-02	0.0000E+00	4.4175E-02	Non ferrous
2.5 Plastic	8.1696E+00	9.6293E+00	8.8994E+00	Plastics
2.6 Rubber	2.1393E-01	2.9193E-01	2.5293E-01	Rubber
2.7 Paper	1.9583E-01	2.2940E-01	2.1262E-01	Paper
3. Charger				
3.1 Chemicals (inorganic)	2.7588E+00	4.4773E+00	3.6180E+00	Inorganic
3.2 Copper	1.8191E+00	1.7066E+00	1.7629E+00	Non ferrous
3.3 Glass	1.5579E-01	2.4997E-01	2.0288E-01	Glass
3.4 Nickel	4.5646E-01	4.2335E-01	4.3990E-01	Non ferrous
3.5 Palladium	3.9649E-03	4.7991E-03	4.3820E-03	Non ferrous
3.6 Silver	1.5514E-01	1.8835E-01	1.7174E-01	Non ferrous
3.7 Tin	9.6937E-01	1.3966E+00	1.1830E+00	Non ferrous
3.8 Bass	2.5438E-01	2.5438E-01	2.5438E-01	Non ferrous
3.9 Gold	1.3708E-01	1.6168E-01	1.4938E-01	Non ferrous
3.10 Plastic	1.1360E+01	1.2440E+01	1.1900E+01	Plastics
3.11 Aluminum	6.0469E+00	1.1242E+01	8.6447E+00	Non ferrous
3.12 Chemicals (organic)	5.6093E+00	6.7030E+00	6.1561E+00	Organic
3.13 Lead	3.5186E-01	4.1164E-01	3.8175E-01	Non ferrous
3.14 Molybdenum	4.2073E-02	1.3067E-01	8.6373E-02	Non ferrous
3.15 Zinc	8.8575E-02	1.1049E+00	5.9674E-01	Non ferrous
3.16 Iron	4.7456E+00	2.0015E+00	3.3736E+00	Ferrous
3.17 Chromium	6.2542E-01	2.7627E-01	4.5085E-01	Non ferrous
3.18 Rubber	3.4369E-02	5.9783E-01	3.1610E-01	Rubber
3.19 Paper	5.6410E-01	2.6401E+00	1.6021E+00	Paper

Material/ Model	Representative of regular phone (g)	Representative of smartphone (g)	Representative of mobile phone* (g)	Type of Material
4. Battery				
4.1Chemicals(inorganic)	3.5301E+00	3.9634E+00	3.7468E+00	Inorganic
4.2 Copper	2.5589E+00	3.6790E+00	3.1190E+00	Non ferrous
4.3 Glass	2.4393E-03	2.6740E-03	2.5566E-03	Glass
4.4 Nickel	9.0170E-03	2.8106E-02	1.8562E-02	Non ferrous
4.5 Palladium	1.0229E-04	1.1006E-04	1.0618E-04	Non ferrous
4.6 Sliver	3.8729E-03	4.2979E-03	4.0854E-03	Non ferrous
4.7 Tin	1.9974E-02	2.2777E-02	2.1375E-02	Non ferrous
4.8 Bass	6.0940E-03	6.9494E-03	6.5217E-03	Non ferrous
4.9 Gold	3.2264E-03	3.6792E-03	3.4528E-03	Non ferrous
4.10 Plastic	3.6362E+00	1.8477E+00	2.7420E+00	Plastics
4.11 Aluminum	4.7829E+00	5.3122E+00	5.0475E+00	Non ferrous
4.12 Chemicals (organic)	2.3416E+00	2.9663E+00	2.6540E+00	Organic
4.13 Lead	1.1120E-02	1.2807E-02	1.1963E-02	Non ferrous
4.14 Molybdenum	1.0080E-03	1.1495E-03	1.0787E-03	Non ferrous
4.15 Zinc	2.0817E-03	2.3739E-03	2.2278E-03	Non ferrous
4.16 Iron	2.5360E+00	3.2313E+00	2.8836E+00	Ferrous
4.17 Chromium	4.6218E-05	4.7116E-05	4.6667E-05	Non ferrous
4.18 Rubber	1.2933E-02	0.0000E+00	6.4667E-03	Rubber
4.19 Paper	4.2210E-01	6.4380E-01	5.3295E-01	Paper
Total	101.1343554	103.7770256	102.4556905	

Representative of mobile phone* averaged from representative of regular phone and representative of smartphone

Figure 4.13 shows percentage of each material used to produce representative of regular phone and representative of smartphone. The main composition of regular phone is plastic (53%) and non-ferrous metal (19%). The main composition of smartphone is plastic (43%) and non-ferrous metal (29%). **Figure 4.14** shows percentage of each material used to produce representative of mobile phone. The main composition of mobile phone is plastic (48%) and non-ferrous metal (24%). High proportion of metal and plastic from the mobile phone has a potential to be recycled after disposal instead of left in the landfill, if appropriately collected.



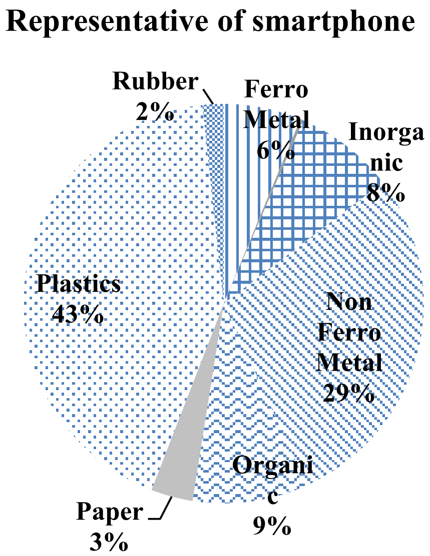


Figure 4.13: Percentage of material composition of representative of regular phone and smartphone

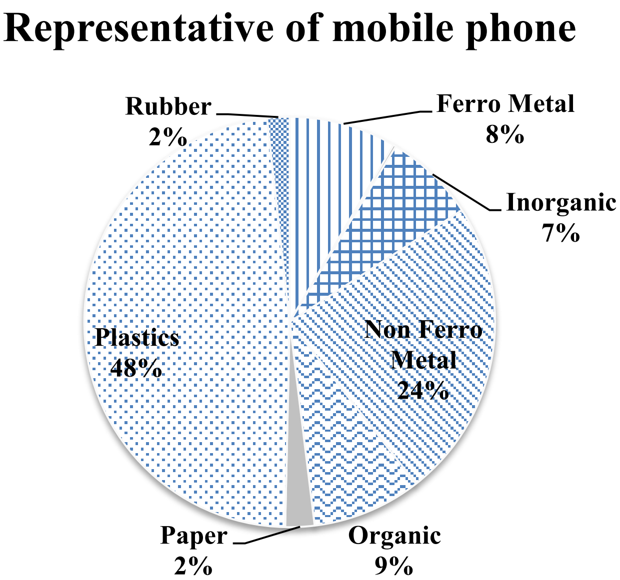


Figure 4.14: Percentage of material composition of representative of mobile phone

4.4 Recycling process of mobile phone per unit

This part analyzed system of recycling mobile phone per unit to evaluate the quantity of materials recovery from one mobile phone. The process of recycling based on the treatment rules in Switzerland (Swico Environmemtal Commission (2006)). The first step of recycling is manual step that takes off mobile phone wastes into parts. There are 7 parts in separation to send for further treatment: (1) metal parts, outside, (2) metal parts, inside, (3) plastic parts, outside, (4) plastic parts, inside, (5) high quality, mounted, (6) Batteries and (7) LCD module, dismantled. **Table 4.3** shows the weights after manual separation step that takes off mobile phone wastes per unit into 7 parts and then sent for further treatment. Further treatments of mobile phone waste have five treatments (1) Shedder process, (2) PWB recycling, (3) Batteries recycling, (4) Scrap, for metal production and (5) Incineration. **Table 4.4** shows the results from separation 7 parts of mobile phone waste for further treatment.

Table 4.3: Results from manual step that separated one mobile phone into 7 parts.

Part	**Amount (g)**
1. metal parts, outside	1.6796E+00
2. metal parts, inside	1.2550E+01
3. plastic parts, outside	2.6753E+01
4. plastic parts, inside	1.6015E+01
5. high quality, mounted	1.8588E+01
6. Batteries	1.8735E+01
7. LCD module, dismantled	8.7284E+00
Total	1.0246E+02

Table 4.4: Results from separation parts of one mobile phone for further treatment.

Part	**Amount (g)**	**Further treatment**	**Net (g)**
1. Metal parts, outside	1.6796E+00	Scrap, for metal production	8.3978E-01
		Shredder process	8.3978E-01
2. Metal parts, inside	1.2550E+01	Shredder process	1.2550E+01
3. Plastic parts, outside	2.6753E+01	plastics, to incineration	1.3376E+01
		Shredder process	1.3376E+01
4. Plastic parts, inside	1.6015E+01	Shredder process	1.6015E+01
5. PWB	1.8588E+01	PWB recycling	9.2942E+00
		Shredder process	9.2942E+00
6. Batteries	1.8735E+01	Batteries recycling	1.8735E+01
7. LCD module, dismantled	8.7284E+00	LCD module, to incineration	8.7284E+00

Each treatment has process to implement in detail as following:

4.4.1 Shredder process

The material is sent into the shredder process that come from the parts of mobile phone waste: 1.metal parts outside , 2. metal parts inside , 3. plastic parts outside, 4. plastic parts inside, 5. plastic parts inside, and 6. PWB part. **Table 4.5** shows material weight from all parts of mobile phone waste which are sent into shedder process. The material which is sent in shredder process is aluminum, copper, iron, glass, plastics, silver, gold, lead and others. The main material is plastics and aluminum.

Table 4.5: Summary material inputs from parts of mobile phone to shredder process

Material	**Weight (g)**
Aluminum	9.2054E+00
Copper	5.4718E-01
Iron	4.0939E+00
Glass	5.3851E-02
Plastics	3.2000E+01
Silver	8.7313E-02
Gold	7.6047E-02
Lead	1.9032E-01
Others	5.8213E+00

Procedure for the shredder process calculation of output amounts and output composition is in **Appendix B**. **Table 4.6** shows the outputs from shredder process. The material output is iron, aluminum, copper and residue. The main material is residue which is sent to landfill. For iron, aluminum and copper are produced products replace primary resource.

Table 4.6: Summary material outputs from shredder process

Material	Weight (g)
Iron	4.3720E+00
Aluminum	7.8733E+00
Copper	6.4687E+00
Residue	3.3361E+01

4.4.2 PWB recycling

The materials are sent into the PWB recycling process that come from the parts of PWB which found in the component of charger and battery. **Table 4.7** shows the weighting of PWB from charger and battery. The weighting of PWB from charger is 9.0688 g and the weighting of PWB from battery is 0.2254 g. Most of weight of PWB comes from charger. The total weight of PWB is 9.2942 g.

Table 4.7: Weighting of PWB from charger and battery

Material	Weight (g)
PWB (charger)	9.0688E+00
PWB (battery)	2.2539E-01

Procedure for the PWB recycling calculation of output amounts and output composition is in **Appendix B**. **Table 4.8** shows the outputs from PWB recycling. The material output is lead, aluminum, iron, tin, nickel, copper, palladium, silver and gold. The main material is copper and aluminum. Metal from recycling are produced products replacing primary resource.

Table 4.8: Summary material outputs from PWB recycling

Material	Weight (g)
Lead	1.4871E-01
Aluminum	4.4752E-01
Iron	6.7554E-02
Tin	3.2607E-01
Nickel	3.1040E-01
Copper	2.2171E+00
Palladium	2.8877E-03
Silver	5.2149E-02
Gold	1.5854E-03

4.4.3 Batteries recycling

Battery is sent in this recycling process which is Lithium-ion battery. The total weight of battery is 18.7350 g. The treatment technology to recycle Li-on Batteries has mixed technology between pyrometallurgical treatment (50%) and hydrometallurgical treatment (50%). So the total weight of battery to pyrometallurgical treatment is 9.3675 g and hydrometallurgical treatment is 9.3675 g. Procedure for the Battery recycling calculation of output amounts and output composition is in **Appendix B**. **Table 4.9** shows material recovery from pyrometallurgical treatment, the material is steel, cobalt, Non-Ferrous (aluminum, copper) and MnO_2. The main material recovery is steel and non-ferrous. **Table 4.10** shows material recovery from hydrometallurgical treatment, the material is cobalt, lithium salt, ferrous and non-Ferrous (aluminum, copper). The main material recovery is cobalt and lithium salt.

Table 4.9: Material recovery from pyrometallurgical treatment

Metal	Amount (g)
Steel	2.5292E+00
Cobalt	1.7986E+00
Aluminum	1.4315E+00
Copper	8.1668E-01
MnO_2	9.3675E-02

Table 4.10: Material recovery from hydrometallurgical treatment

Metal	Amount (g)
Co	3.1850E+00
Lithium salt	1.8548E+00
Steel	1.5456E+00
Aluminum	8.9470E-01
Copper	3.1850E+00

4.4.4 Scrap, for metal production

In the metal parts outside of mobile phone waste has scrap in order to produce secondary metal production. The calculation from scrap metal to secondary metal production adapted from ecoinvent 2.1 database, Simapro software. **Table 4.11** shows the secondary metal production from scrap metal. The metal parts, outside from **Table 4.4** is 0.8397 g (Aluminum (0.4144 g) and Iron (0.4254 g)) when change in to secondary metal production is Aluminum (0.4023 g) and Steel (0.38498 g)

Table 4.11: The materials of secondary metal production from scrap metal

Metal	Secondary metal (g)
Aluminum	4.0230E-01
Steel	3.8498E-01

4.4.5 Incineration

In parts of plastic outside and LCD module are sent into the incineration. **Table 4.12** shows the material which is sent to incineration, the material is plastic, rubber and LCD module. The main material to incineration is plastic and LCD module.

Table 4.12: The amount of materials which is sent to incineration

Material	Amount (g)
Plastic	1.2762E+01
Rubber	6.1447E-01
LCD module	8.7284E+00

After finishing the calculation of five treatment process, it obtains material from recycling of mobile phone per unit. **Table 4.13** shows material from recycling of mobile phone per unit. The material from recycling is Iron, Steel, Lead, Aluminum, Tin, Nickel, Copper, Palladium, Silver, Gold, Cobalt, MnO_2 and Lithium salt. The main material is Aluminum, Copper and ferrous metal (Iron, Steel). High proportion of metal embedded in mobile phone waste has a potential to be recycled if appropriately collected.

Table 4.13: Summary materials from recycling of mobile phone per unit

Material	**Amount (g)**
Iron	4.4395E+00
Steel	4.4599E+00
Lead	1.4871E-01
Al	1.1049E+01
Tin	3.2607E-01
Nickel	3.1040E-01
Copper	1.0013E+01
Palladium	2.8877E-03
Sliver	5.2149E-02
Gold	1.5854E-03
Co	4.9835E+00
MnO_2	9.3675E-02
Li salt	1.8548E+00
Total	3.7735E+01

4.5 Evaluating the potential benefit from recycling mobile phone per unit

From the calculation of benefit from recycling of metal (Ferro and non-Ferro) from mobile phone per unit found that the prices of the quantity of metals from recovery one mobile phone was 10.704 – 11.930 bath as shown in **Table 4.14**. Recycling of mobile phone wastes can potentially be generated significant amounts of money but this approximate benefit does not include operating and recycling cost. Because when include operate cost, the net benefit from materials recovery maybe lower or hardly be estimated in term of the net benefits. Importantly, recycling can generate not only direct benefits (market values) but also indirect benefit in term of protecting human health, ecosystem and natural resource from depletion.

Unfortunately, values for protection of environmental related impacts are hardly recognized in the price of goods or in this case from recycling system. Therefore, the total benefits of recycling mobile phone is still underestimated if only focus on direct benefits from material recovery. When compared to the total costs of establishing and operating recycling system, recycling of mobile phone may still be low in profit or generate no profit.

Table 4.14: Calculation price of metal recycling from mobile phone per unit

Material	Amount (g)	Price[1] (Bath/Kg)	Total Price[1] (Bath)	Price[2] (Bath/Kg)	Total Price[2] (Bath/Kg)
Iron	4.4395E+00	7.0000E+00	3.1077E-02	2.7000E+00	1.1987E-02
Steel	4.4599E+00	3.0000E+01	1.3380E-01	3.0000E+01	1.3380E-01
Lead	1.4871E-01	1.2946E+01	1.9252E-03	1.2946E+01	1.9252E-03
Aluminum	1.1049E+01	6.4000E+01	7.0714E-01	6.4000E+01	7.0714E-01
Tin	3.2607E-01	6.1700E+02	2.0118E-01	6.1700E+02	2.0118E-01
Nickel	3.1040E-01	n/a	0.0000E+00	n/a	0.0000E+00
Copper	1.0013E+01	1.9700E+02	1.9726E+00	2.4684E+02	2.4716E+00
Palladium	2.8877E-03	3.0645E+05	8.8494E-01	3.0645E+05	8.8494E-01
Sliver	5.2149E-02	1.5890E+04	8.2865E-01	2.1860E+04	1.1400E+00
Gold	1.5854E-03	1.2010E+06	1.9041E+00	1.3470E+06	2.1355E+00
Cobalt	4.9835E+00	8.5125E+02	4.2422E+00	8.5125E+02	4.2422E+00
MnO2	9.3675E-02	n/a	0.0000E+00	n/a	0.0000E+00
Lithium salt	1.8548E+00	n/a	0.0000E+00	n/a	0.0000E+00
Total	3.7735E+01		1.0907E+01		1.1930E+01

[1]Price of the metal recycling at August 13, 2009 (PCD, 2010)

[2]Price of metal from mining at May 17, 2013 (DPIM, 2013)

Part II: Life cycle impact assessment (LCIA) and interpretation part

4.6 Environmental impacts evaluation of mobile phone if treated by landfill 100%

In this research evaluated levels of life cycle environmental impacts of mobile phone using LCA software SimaPro Version7.3.3 and expressed with the ReCiPe (H) version 1.06, Ecoinvent 2.1 database. **Figure 4.15** shows the result from the mid-point analysis comparing between representative regular phone model and representative smartphone model per unit in 100% landfill. The impact categories analyzed for case studies including Climate change human health, Human toxicity, Freshwater ecotoxicity, Metal depletion and Fossil depletion, compared impact from each impact categories in figure. The result found that the impact from Climate change of smartphone has 73% higher than regular phone, impact from Human toxicity of regular phone has 1% higher than smartphone, impact from Freshwater ecotoxicity of regular phone has 11% higher than smartphone, impact from Metal depletion of smartphone has 13% higher than regular phone, and impact from Fossil depletion of smartphone has 13% higher than regular phone.

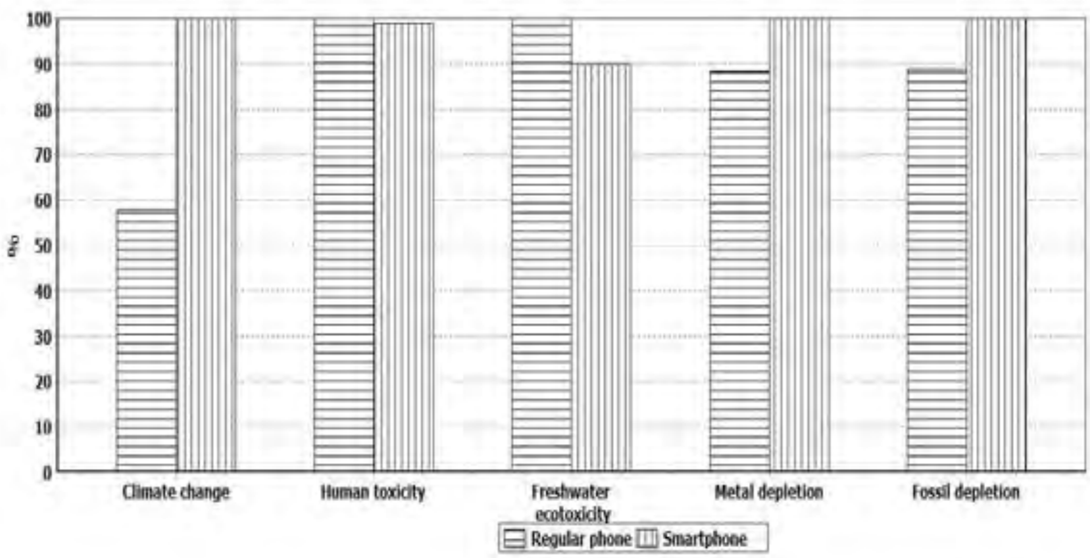


Figure 4.15: Characterization comparison between regular phone and smartphone model per unit in 100% landfill.

Table 4.15 shows the result of environmental impacts value (mid-point) compared between representative regular phone model and representative smartphone model per unit by Simapro software. In Climate change human health category, regular phone has the impact 4.412E-03 kg CO_2 eq and smartphone has the impact 7.599E-03 kg CO_2 eq. In Human toxicity category, regular phone has the impact 4.737E-03 kg 1,4 -DB eq and smartphone has the impact 4.692E-03 kg 1,4-DB eq. In Freshwater ecotoxicity, regular phone has the impact 2.836E-04 kg 1,4-DB eq and smartphone has the impact 2.553E-04 kg 1,4-DB eq. In Metal depletion, regular phone has the impact 7.342E-05 kg Fe eq and smartphone has the impact 8.299E-05 kg Fe eq. In Fossil depletion, regular phone has the impact 8.342E-04 kg oil eq and smartphone has the impact 9.392E-04 kg oil eq. So a regular phone model causes higher impact for Human toxicity and Freshwater ecotoxicity than that from a smartphone. However, a smartphone has higher impact from Climate change Human Health, Metal depletion and Fossil depletion than that of regular phone.

From the results found that regular phone has much less impacts in Climate change Human Health than smartphone when compared other impact categories. Due to main substances (CO_2 (in air) and methane (in air)) and main processes contribution (burned diesel (in building machine) and disposal plastic (to sanitary landfill)) of smartphone is much higher than regular phone. However, a smartphone has less impact in freshwater ecotoxicity than that from regular phone when compared other impact categories. Because main substances (cobalt (in water) and zinc, ion (in water)) and main process contribution (disposal plastic (to sanitary landfill)) of smartphone is much lower than regular phone.

Table 4.15: Results of the characterization per unit of regular phone and smartphone in 100% landfill

Impact category	Unit	Regular phone	Smartphone
Climate change Human health	kg CO_2 eq	4.412E-03	7.599E-03
Human toxicity	kg 1,4-DB eq	4.737E-03	4.692E-03
Freshwater ecotoxicity	kg 1,4-DB eq	2.836E-04	2.553E-04
Metal depletion	kg Fe eq	7.342E-05	8.299E-05
Fossil depletion	kg oil eq	8.342E-04	9.392E-04

The various environmental impacts were examined with the end-point approach which was analyzed in three damage categories: human health, ecosystems and resources. The single score are then performed at this damage level as shown in **Figure 4.16**. The result found that the single score of smartphone has 32% higher than that of regular phone. In human health category, smartphone has impact 44% higher than that of regular phone. In ecosystems category, smartphone has impact 76% higher than that of regular phone. In resources category, smartphone has impact 13% than that of regular phone.

Table 4.16 shows the total ReCiPe point (Pt) from single score per phone found that regular phone has 4.339E-04 Pt and smartphone has 5.718E-04 Pt. In human health category, regular phone has 2.364E-04 Pt and smartphone has 3.395E-04 Pt. In ecosystems category, regular phone has 1.561E-05 Pt and smartphone has 2.753E-05 Pt. In resources category, regular phone has 1.818E-04 Pt and smartphone has 2.047E-04 Pt. So impact from human health of regular phone and smartphone has higher impacts than other damage categories, followed by resources category and ecosystems category respectively.

From the results, smartphone has higher environmental impacts with the end-point approach than regular phone. Because main substances (crude oil (in raw), CO_2 (in air) and methane (in air)) and main process contribution (crude oil (at production) and disposal plastic (to sanitary landfill)) of smartphone is much higher than regular phone. Size of Human health impact of smartphone has higher than regular phone when compared other impact categories because main substances (CO_2 (in air), methane (in air) and arsenic, ion (in water)) and main process contribution (disposal plastic (to sanitary landfill)) of smartphone is much higher than regular phone.

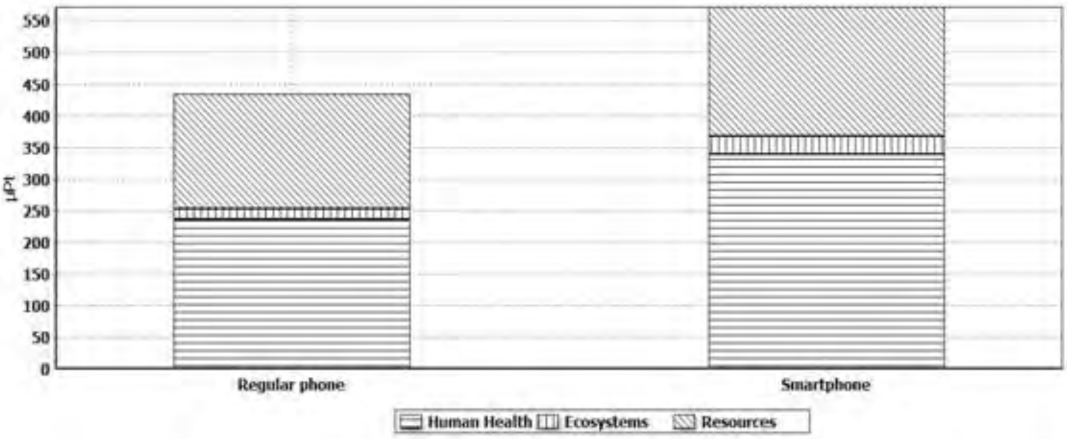


Figure 4.16: Single score between regular phone and smartphone per unit in 100% landfill

Table 4.16: The results of single score per unit of regular phone and smartphone in 100% landfill

Damage category	Unit	Regular phone	Smartphone
Total	Pt	4.339E-04	5.718E-04
Human Health	Pt	2.364E-04	3.395E-04
Ecosystems	Pt	1.561E-05	2.753E-05
Resources	Pt	1.818E-04	2.047E-04

4.7 Environmental impacts based on components of representative mobile phone if treated by landfill 100%

This part was done to identify which components in mobile phone that has the most environmental impact in 100% landfill. The result from the mid-point analysis based on characterization, charger has higher environmental impacts than other components, followed by mobile phone casing, battery and charger casing. Detailed data was also presented in **Table 4.17**.

Charger has higher environmental impacts than other components. For example, impacts on human toxicity of charger have higher other components because main substances (arsenic, ion (in water) and lead (in water)) and main process contribution (disposal plastics (to sanitary landfill)) of charger is much higher than other components. Impacts on metal depletion of charger have higher than that of other components because main substances (chromium (in raw), iron (in raw) and nickel (in raw)) and main process contribution (chromite ore (at mine), iron ore (at mine) and ferronickel (at plant)) of charger is much higher than other components.

Table 4.17: The result of characterization per unit based on components of mobile phone in 100% landfill

Impact category	Unit	Mobile phone casing	Charger casing	Charger	Battery
Climate change Human health	kg CO_2 eq	1.713E-03	7.180E-04	2.487E-03	1.209E-03
Human toxicity	kg 1,4-DB eq	1.322E-03	5.540E-04	1.919E-03	9.330E-04
Freshwater ecotoxicity	kg 1,4-DB eq	7.520E-05	3.150E-05	1.090E-04	5.310E-05
Metal depletion	kg Fe eq	2.230E-05	9.350E-06	3.240E-05	1.570E-05
Fossil depletion	kg oil eq	2.500E-04	1.050E-04	3.630E-04	1.760E-04

The environmental impacts are examined with the end-point approach which is analyzed in three damage categories: human health, ecosystems and resources. The single score are then performed at this damage level as shown in **Figure 4.18**. The result of single score found that human health has higher environmental impacts when compared to the other damage categories, followed by resource depletion and ecosystems. **Table 4.18** shows the total ReCiPe point (Pt) from single score found that mobile phone casing has 1.423E-04 Pt, charger casing has 5.966E-05 Pt, charger has 2.066E-04 Pt, and battery has 1.005E-04 Pt. So Charger has the highest impacts compared to other components, followed by mobile phone casing, battery and charger casing respectively

Charger has higher environmental impacts with the end-point approach than that from other components. Single score from charger has higher than other components because main substance (CO_2 (in air), methane (in air) and crude oil (in raw) and main processes contribution (clinker of metal (at plant) and disposal plastic (to sanitary landfill)) of charger is much higher than other components. For impacts on ecosystems of charger has higher than other components because main substance (CO_2 (in air) and methane (in air)) and main processes contribution (disposal plastic (to sanitary landfill)) of charger is much higher than other components

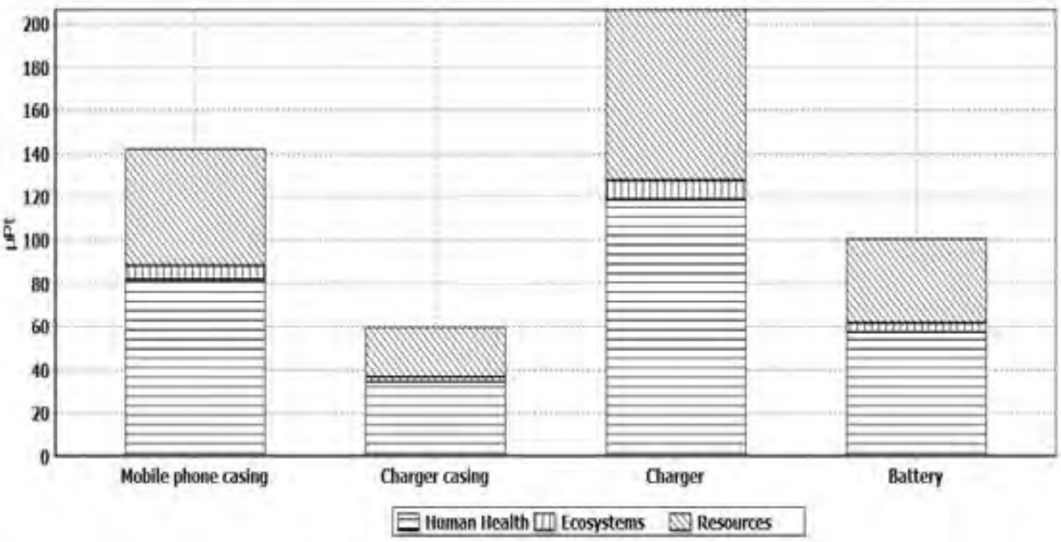


Figure 4.17: Single score based on components of mobile phone per unit in 100% landfill

Table 4.18: The results of single score per unit based on components of mobile phone in 100% landfill

Damage category	Unit	Mobile phone casing	Charger casing	Charger	Battery
Total	Pt	1.423E-04	5.966E-05	2.066E-04	1.005E-04
Human Health	Pt	8.169E-05	3.425E-05	1.186E-04	5.766E-05
Ecosystems	Pt	6.180E-06	2.591E-06	8.973E-06	4.362E-06
Resources	Pt	5.444E-05	2.282E-05	7.903E-05	3.842E-05

4.8 Scenarios analysis for end of life of mobile phone

Various scenarios were set up based on end of life of mobile phone to landfill or recycling. Each scenario was analyzed for amounts of environmental impact value. The condition of scenarios analysis is to compare among various percentage of landfill and recycling of mobile phone wastes. There are 3 scenarios in the study as the following:

I. Scenario 1 is "100% landfill": No materials are recycled.

II. Scenario 2 is "95% landfill & 5% recycling": 95% of wastes to landfill and 5% of wastes to recycling.

III. Scenario 3 is "80% landfill & 20% recycling": 80% of wastes to landfill and 20% of wastes to recycling.

Figure 4.18 shows the results from the mid-point analysis when compared of 3 scenarios of mobile phone per unit. Based on the results of characterization, scenario 3 reduced the most environmental impacts when compare with the other scenario. **Table 4.19** shows the result of characterization of 3 scenarios for end of life of mobile phone per unit. Scenario 1 has higher impact compare to Scenario 2 and 3 on every category. Scenario 2 and 3 has net negative impact (reduce impact in all categories).

From the results of scenario 1, impacts on Climate change human Health has higher than other scenarios because main substances (CO_2 (in air) and methane (in air)) and main processes contribution (clinker of metal (at plant) and disposal plastics (to sanitary landfill)) of scenario 1 is much higher than other scenarios. Impacts on Metal depletion has higher than other scenarios because main substances (copper (in raw) and molybdenum (in raw)) and main process contribution (chromite ore (at mine) and iron ore (at mine), ferronickel (at plant)) of scenario 1 is much higher than other scenarios.

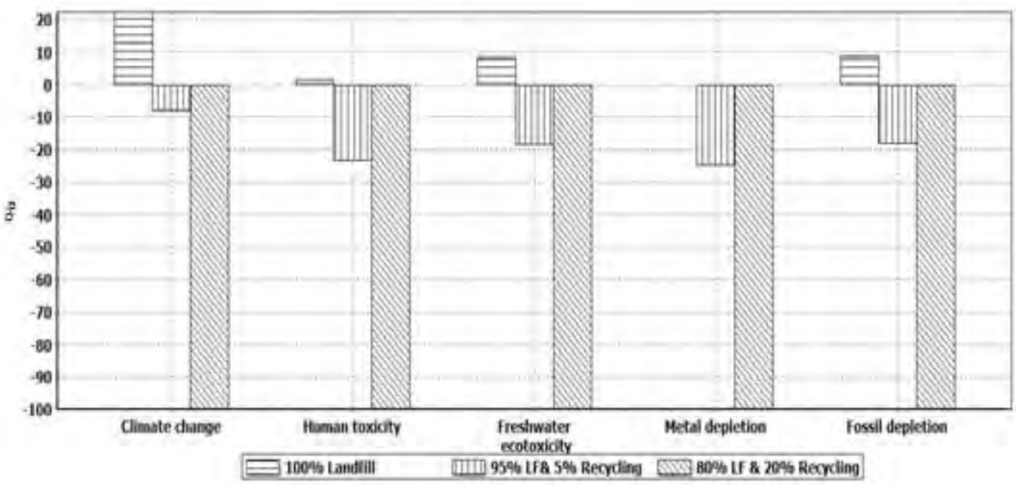


Figure 4.18: Charecterization of all 3 scenarios of mobile phone per unit

Table 4.19: Result of charecterization of 3 scenarios of mobile phone per unit

Impact category	Unit	100% Landfill	95% LF& 5% Recycling	80% LF & 20% Recycling
Climate change Human health	kg CO_2 eq	6.127E-03	-2.280E-03	-2.749E-02
Human toxicity	kg 1,4-DB eq	4.729E-03	-7.518E-02	-3.149E-01
Freshwater ecotoxicity	kg 1,4-DB eq	2.690E-04	-5.900E-04	-3.170E-03
Metal depletion	kg Fe eq	7.980E-05	-3.515E-02	-1.408E-01
Fossil depletion	kg oil eq	8.930E-04	-1.910E-03	-1.033E-02

The various environmental impacts are examined with the end-point approach which is considered in three damage categories: human health, ecosystems and resources. The single score are then evaluated as shown in **Figure 4.19**. The result of single score found that scenario 3 reduced the highest environmental impacts when compare with the other scenarios. By comparing the environmental impacts reduction from scenario 1 (100% landfill), scenario 2 can reduce impact for 7.60 times and scenario 3 can reduce impacts for 30 times from scenario 1 estimated impacts. **Table 4.20** shows the total ReCiPe point (Pt) from single score found that scenario 1 has 5.0904E-04 Pt, scenario 2 has-3.3612E-03 Pt and scenario 3 has -1.4972E-02 Pt. In scenario 2 & 3, human health impact is reduced from scenario 1 at higher proportion than other damage categories, followed by resource depletion and ecosystems respectively.

Scenario 1 has higher environmental impacts with the end-point approach than other scenarios. Due to single score from scenario 1 has higher than other scenarios because main substance (manganese (in water) and sulfur dioxide (in water)) and main processes contribution (clinker of metal (at plant) and disposal plastic (to sanitary landfill)) of scenario 1 is much higher than other scenarios. For impacts on resource of scenario 1 has higher than other scenarios because main substance (coal (in raw), natural gas (in raw) and crude oil (in raw)) and main processes contribution (crude oil (at production)) of scenario 1 is much higher than other scenarios

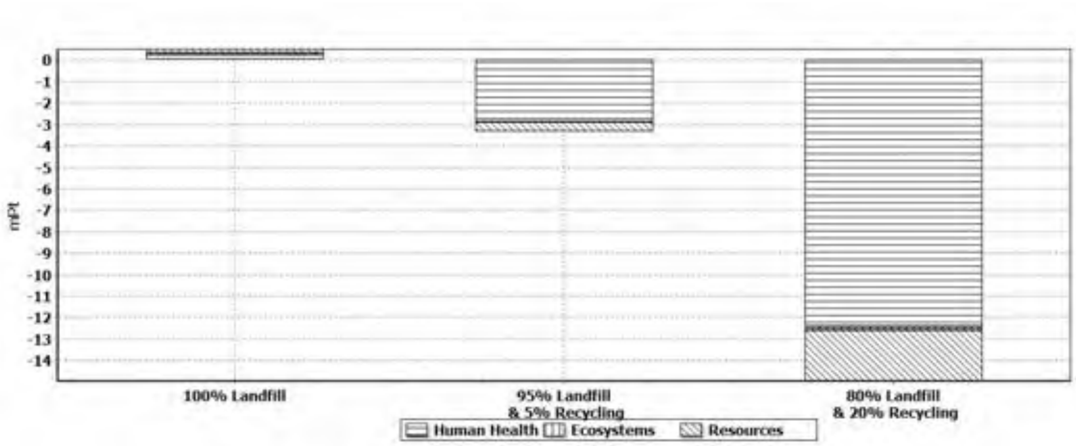


Figure 4.19: Single score of 3 scenarios of EOL mobile phone per unit

Table 4.20: Results of single score 3 scenario of mobile phone per unit

Damage category	Unit	100% Landfill (scenario 1)	95% Landfill & 5% Recycling (scenario 2)	80% Landfill & 20% Recycling (scenario 3)
Total	Pt	5.0904E-04	-3.3612E-03	-1.4972E-02
Human Health	Pt	2.9221E-04	-2.8911E-03	-1.2441E-02
Ecosystems	Pt	2.2106E-05	-1.8856E-05	-1.4174E-04
Resources	Pt	1.9472E-04	-4.5123E-04	-2.3891E-03

Electrical and Electronics Institute in Thailand estimated generation of mobile phone wastes in the future (2012-2020) (Electrical and Electronics Institute, 2007**).** Mobile phone wastes will increase from 39,217,000 units in 2012 to 88,022,000 units in 2020. **Table 4.21** shows comparing single score of environmental impacts compare each scenario between the present period and the future. In 2012 (baseline), the single score of environmental impacts for management of mobile phone wastes by 100% Landfill is 1.9963E+04 Pt. The single score in 2020, scenario 1 ("100% landfill") is 4.4807E+04 Pt. , scenario 2 ("95% landfill & 5% recycling) is -2.9586E+05 Pt, scenario 3 ("80% landfill & 20% recycling") is -1.3179E+06 Pt. The percentage change of impact different of each scenario between current period (2012) and future period (2020), scenario 1 the impact has increased 2.24 times, scenario 2 the impact has decreased 14.82 times and scenario 3 the impact has decreased 66.02 times. So scenario 3 reduced highest environmental impacts if compare with the other scenario but scenario 1 increased environmental impacts. Therefore increasing recycling rate can reduce environmenmental impact. Collection of used mobile phone out of the waste stream and develop programs that keep used mobile phone out of the wastes stream by collecting, is a necessary step to solve the mobile phone problem in the future.

Table 4.21: Comparing single score of environrmmetal impacts compare each scenario

Scenario	Single score of environmental impacts in 2012 (Pt)	Single score of environmental impacts in 2020 (Pt)	Ratio change of impacts (times)
Scenario 1	1.9963E+04	4.4807E+04	2.2445E+00
Scenario 2	-	-2.9586E+05	1.4820E+01
Scenario 3	-	-1.3179E+06	6.6017E+01

4.9 Sensitivity analysis of each scenario

Sensitivity analysis in this study is conducted in order to exam percentage changes of environmental impacts in each scenario whether error measurement of materials which have effect to reliability of the results. Sensitivity analysis varied parameters in measurement of materials of mobile phone in order to examine percentage changing of environmental impacts values in each scenario by trial and errors at 5% of weighting materials per unit of mobile phone.

4.9.1 Sensitivity analysis (100 % landfill)

Figure 4.21 and **Table 4.22** show the result from sentivity analysis in scenario 100% landfill. **Table 4.23** shows percentage changing by trial and errors at 5% of weighting materials. Total Single score in the scenario is 5.090E-04 Pt, while at -5% errors, total score is 4.788E-04 Pt and when calculate percentage changing is - 0.059%.While at +5% errors, total score is 5.095E-04 Pt and when calculate percentage changing is + 0.001%. In all type of impacts, percentage change from errors falls in to the similar magnitude of change. Such as for Human health impact score is 2.922E-04 Pt, at -5% errors an impact is 2.749E-04 Pt when calculate percentage changing is -0.059% and at +5% errors, impact score is 2.925E-04 Pt when calculate percentage changing is + 0.001%.

Sensitivity analysis from case 100% landfill, the results found that when varied parameters in measurement of materials by trial and errors at 5% of weighting materials, the different percentage changing of environmental impacts value (single score) from the results is intervel between -0.059% to +0.001%. The varied parameters in measurement of materials by trial and errors at 5% of weighting materials has minimal effect to reliability of the results.

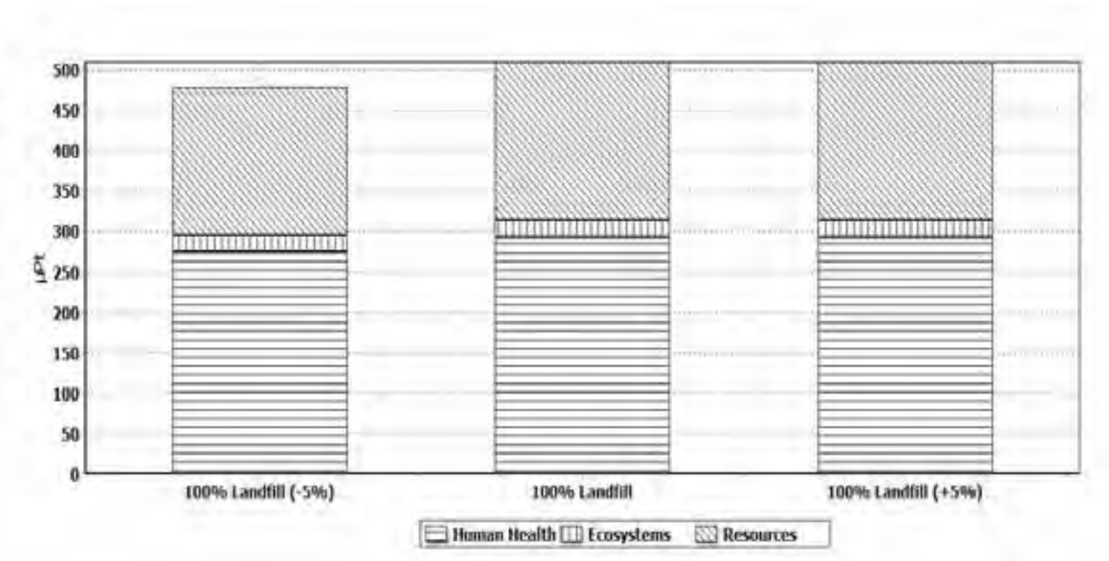


Figure 4.20: Sentivity analysis in scenario 100% landfill

Table 4.22: Results of sentivity analysis in scenario 100% landfill

Damage category	Unit	100% Landfill (-5%)	100% Landfill	100% Landfill (+5%)
Total	Pt	4.788E-04	5.090E-04	5.095E-04
Human Health	Pt	2.749E-04	2.922E-04	2.925E-04
Ecosystems	Pt	2.079E-05	2.211E-05	2.213E-05
Resources	Pt	1.832E-04	1.947E-04	1.949E-04

Table 4.23: Percentage changing by trial and errors at 5% of weighting materials in scenario 100% landfill

Damage category	100% Landfill (-5%)	100% Landfill (+5%)
Total	-0.059%	+0.001%
Human Health	-0.059%	+0.001%
Ecosystems	-0.060%	+0.001%
Resources	-0.059%	+0.001%

4.9.2 Sensitivity analysis (95% landfill and 5% Recycling)

Figure 4.21 and **Table 4.24** show the result from sentivity analysis in scenario 95% landfill and 5% Recycling. **Table 4.25** shows percentage changing by trial and errors at 5% of weighting materials. Total Single score of the scenario is -3.361E-03 Pt, while at -5% errors, single score is -3.162E-03 Pt when calculate percentage changing is -0.059%. While at +5% errors, single score is -3.365E-03 Pt when calculate percentage changing is + 0.001%. In all type of impacts, percentage change from the errors falls in to the similar magnitude of change. Such as for ecosystems impact score is -1.886E-05 Pt, while at -5% errors, impact score is -1.774E-05 Pt when calculate percentage changing is -0.060%. And at +5% errors, impact score is -1.887E-05 Pt when calculate percentage changing is + 0.001%.

Sensitity analysis from case 95% landfill and 5% Recycling, the results found that when varied parameters in measurement of materials by trial and errors at 5% of weighting materials, the different percentage changing of environmental impacts value from the results is intervel between -0.059% to +0.001%. The varied parameters in measurement of materials by trial and errors at 5% of weighting materials has very minimal effect to reliability of the results.

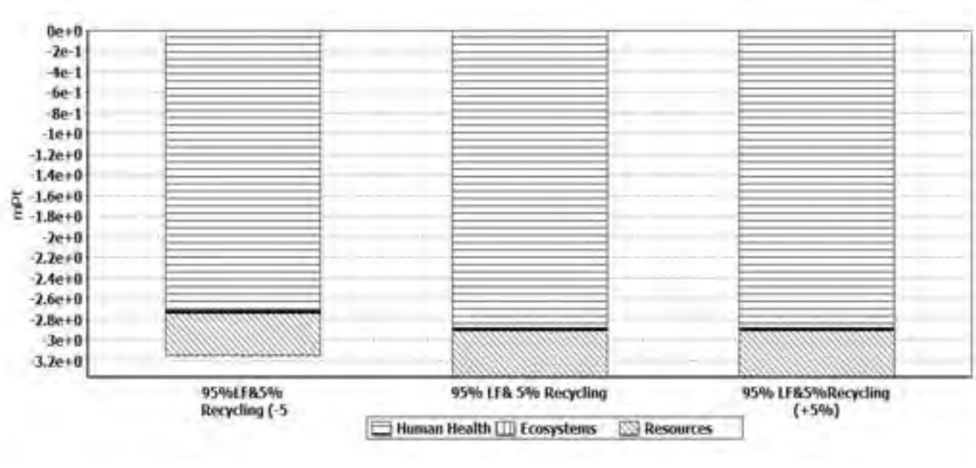


Figure 4.21: Sentivity analysis in scenario 95% landfill and 5% Recycling

Table 4.24: Results of sentivity analysis in scenario 95% landfill and 5% Recycling

Damage category	Unit	95% Landfill & 5% Recycling (-5%)	95% Landfill & 5% Recycling	95% Landfill & 5% Recycling (+5%)
Total	Pt	-3.162E-03	-3.361E-03	-3.365E-03
Human Health	Pt	-2.719E-03	-2.891E-03	-2.894E-03
Ecosystems	Pt	-1.774E-05	-1.886E-05	-1.887E-05
Resources	Pt	-4.244E-04	-4.512E-04	-4.517E-04

Table 4.25: Percentage changing by trial and errors at 5% of weighting materials in scenario 95% landfill and 5% Recycling

Damage category	95% Landfill & 5% Recycling (-5%)	95% Landfill & 5% Recycling (+5%)
Total	-0.059%	+0.001%
Human Health	-0.059%	+0.001%
Ecosystems	-0.060%	+0.001%
Resources	-0.059%	+0.001%

4.9.3 Sensitivity analysis (80% Landfill & 20% Recycling)

Figure 4.22 and **Table 4.26** show the result from sentivity analysis in scenario 80% Landfill & 20% Recycling. **Table 4.27** shows percentage changing by trial and errors at 5% of weighting materials. Total Single score for this scenarion is -1.497E-02 Pt, while at -5% errors, the single score is -1.408E-02 Pt when calculate percentage changing is -0.059%. At +5% errors, the single score is -1.499E-02 Pt when calculate percentage changing is + 0.001%. In all type of impacts, percentage change from the errors falls in to the similar magnitude of change. Such as for resources single score is -2.389E-03 Pt, while at -5% errors, the score is -2.247E-03Pt when calculate percentage changing is -0.059%. And at +5% errors, the score is -2.391E-03 Pt when calculate percentage changing is + 0.001%.

Sensitity analysis from case 80% Landfill & 20% Recycling, the results found that when varied parameters in measurement of materials by trial and errors at 5% of weighting materials, the different percentage changing of environmental impacts value (single score) from the results is intervel between -0.059% to +0.001%. The varied parameters in measurement of materials by trial and errors at 5% of weighting materials has very minimal effect to reliability of the results.

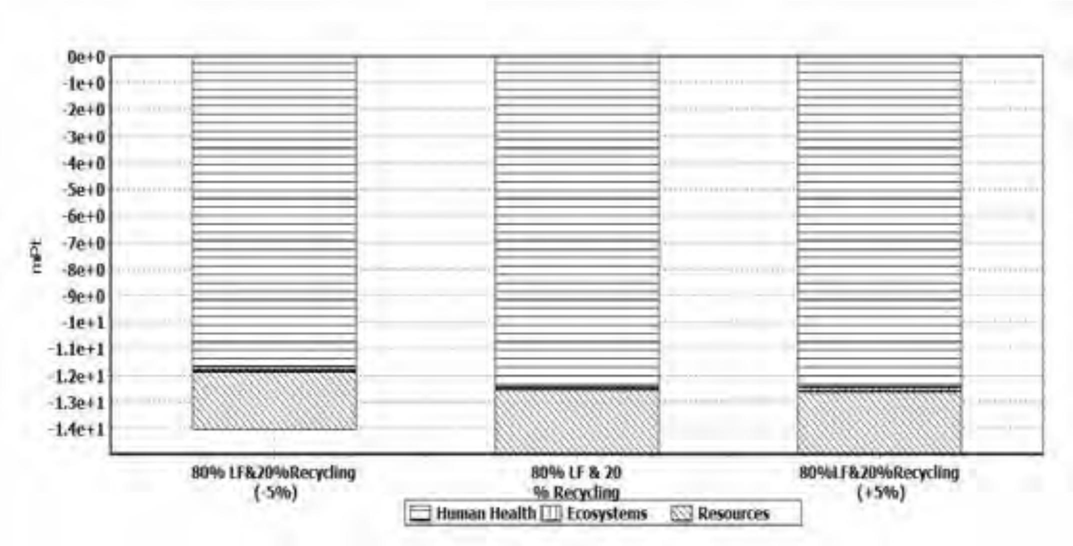


Figure 4.22: Sentivity analysis in scenario 80% landfill and 20% Recycling

Table 4.26: Results of sentivity analysis in scenario 80% landfill and 20% Recycling

Damage category	Unit	80% Landfill & 20% Recycling (-5%)	80% Landfill & 20% Recycling	80% Landfill & 20% Recycling (+5%)
Total	Pt	-1.408E-02	-1.497E-02	-1.499E-02
Human Health	Pt	-1.170E-02	-1.244E-02	-1.245E-02
Ecosystems	Pt	-1.333E-04	-1.417E-04	-1.419E-04
Resources	Pt	-2.247E-03	-2.389E-03	-2.391E-03

Table 4.27: Percentage changing by trial and errors at 5% of weighting materials in scenario 80% landfill and 20% Recycling

Damage category	80% Landfill & 20% Recycling (-5%)	80% Landfill & 20% Recycling (+5%)
Total	-0.059%	+0.001%
Human Health	-0.059%	+0.001%
Ecosystems	-0.059%	+0.001%
Resources	-0.059%	+0.001%

Part III: Surveying of public opinions part

4.10 Surveying opinions of citizens about mobile phone wastes management

Questionnaires survey were conducted to examine the public opinions about mobile phone waste situation to understand problem and potential solutions of mobile phone wastes in Thailand. In this research, the surveys were conducted by 2 approaches : (1) hard copy direct survey , (2) online survey. The total number of respondents in both channels are 377 persons (207 persons from hard copy survey and 170 persons from online survey). The limiation of this survey was distribution of data collection which was mainly from urban area (Bangkok and Nakhonpathom). The questionnaire was divided into 5 sections as follows: (1) General information of the respondents, (2) Behavior for end of life of mobile phone management, (3) Awareness on mobile phone wastes problem, (4) Opinions about mobile phone waste management, and (5) Suggestions for future mobile phone waste management. The results from surveying of each section can be described and discussed as the following:

4.10.1 General information of the respondents

Regarding the demographic background of questionnair respondents, **Figure 4.23** showed the proportion of female (56%) is slightly higher than males (44%). Most respondents were aged between 20-30 years (51%) followed by 31-40 years of age (23%) as shown in **Figure 4.24**. The education background of respondents were in undergraduate (53%) and graduate (32%) as shown in **Figure 4.25**. Levels of income each month of respondents were about 10,000 to 30,000 baht (44%) followed by less than 10,000 bath (39%) (**Figure 4.26**). The career of most questionnair respondents were students (54%) and employees of private companies (27%) as shown in **Figure 4.27**.

Since the method of survey was conducted by online-method, majority of respondents were aged between 20-30 years. It is probably because this group of people (20-30 years) commonly use intertnet. For the hard copy survey, most of the interview were at universities and private companies. Therefore, most respondents were students and employees of private companies.

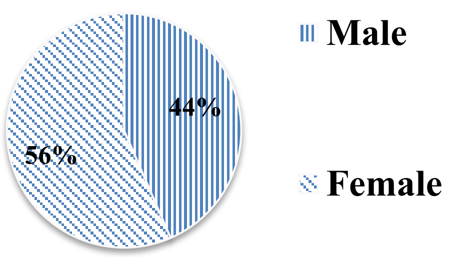


Figure 4.23: Sex of respondents

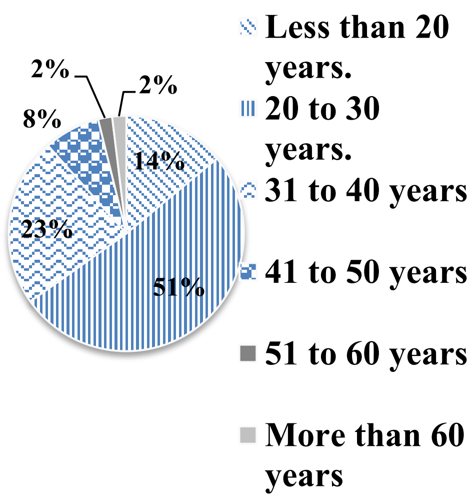


Figure 4.24: Age of respondents

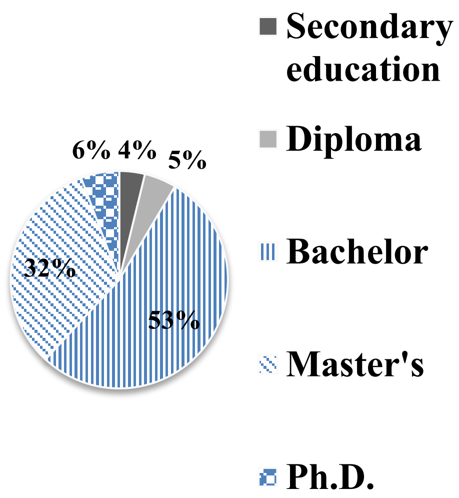


Figure 4.25: Education of respondents

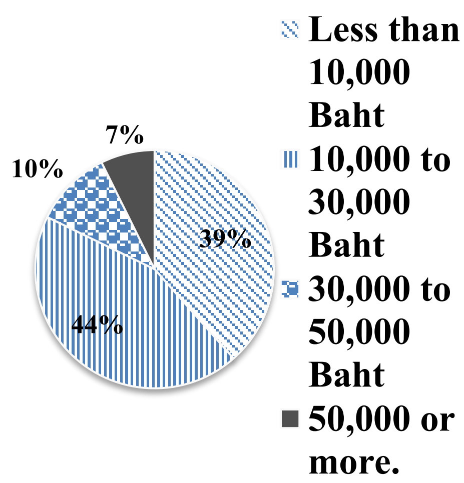


Figure 4.26: Income per month of respondent

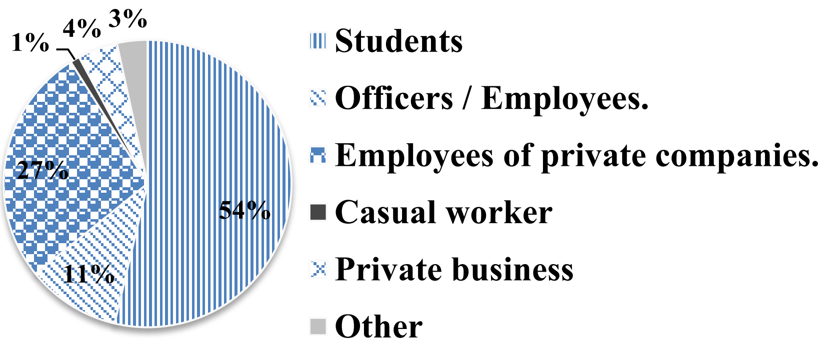


Figure 4.27: Career of respondent

4.10.2 Behavior for end of life of mobile phone management

Most respondents own one unit of mobile phone (74%) followed by 2 units (23%) (**Figure 4.28**). **Figure 4.29** shows the frequency to change to new mobile phone model. The rate of changing to new a mobile phone is every 2 years (31%) and to every 3 years (28%). The main reason to change mobile phone or buy a new phone is because the phone was damaged and could not be repaired (**Figure 4.30**). In term of management for end of life of mobile phone, the discarded phone is mainly kept at home (69%) followed by bringing it to re-sell at mobile phone shop (21%) (**Figure 4.31**).

Based on the survey, the reasons that Thai people usually keep mobile phone wastes at home are as following: (1) people do not aware of the environmental impact from hazardous substances from mobile phone wastes. If the management is not effective, the hazardous substances can potentially contaminate into the environment, (2) the lack of efficient collection system of mobile phone wastes to bring the wastes to proper management system. Thai people are not aware to recycle mobile phone wastes. Therefore, recycling is emerging as potentials solutions for reduction of wastes and depletion of natural resources.

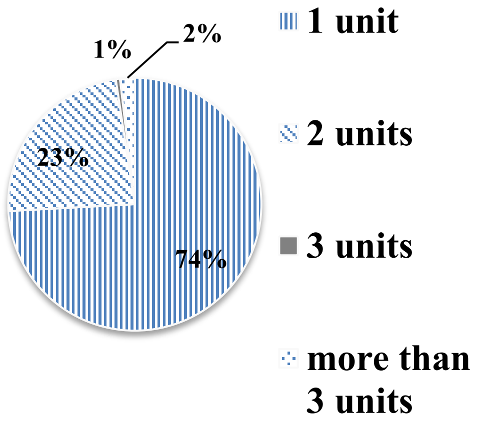


Figure 4.28: Number of mobile phones

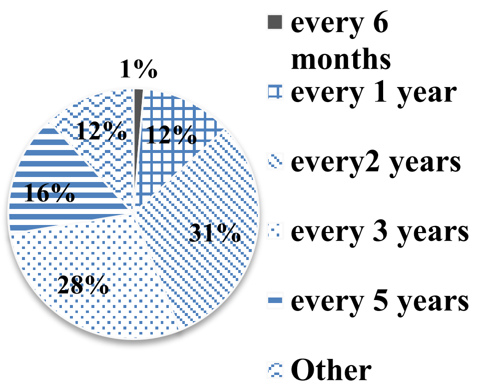


Figure 4.29: Frequency to change phone.

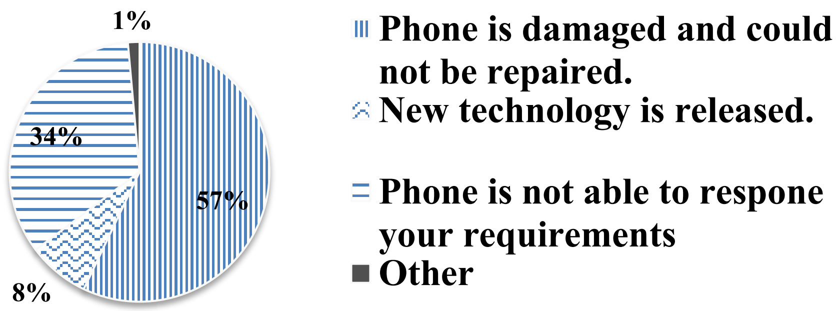


Figure 4.30: Reason for changing mobile phone or buying a new phone.

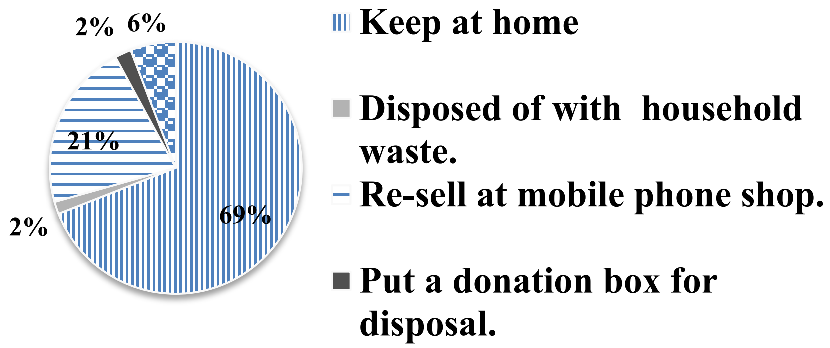


Figure 4.31: Management for end of life of mobile phone.

4.10.3 Level of understanding of the mobile phone waste problems

Figure 4.32 shows understanding of respondents about mobile phone wastes that amount of wastes increase every year and average lifespan of mobile phone tended to decline steadily. The respondents knew (77%) and did not know (23%) about this information. The ratios of respondents who understand about the environmental risk from mismanagement of mobile phone wastes, there are 92% of respondents know that mobile phone wastes are contained with hazardous substances including lead, mercury. If the hazardous substances did not properly handle, they can contaminate into the environment and pose a risk to human health and ecosystems.

From the results, most people understand problems of mobile phone wastes but did not give priority to manage problems seriously. Due to most people are not aware of the problems that will occur in the future, especially with serious environmental problems. Hazardous substances can contaminate into the ecosystem through soil, water and air if manage improperly. Many of these hazardous substances can persist in the environment, accumulate in the food chain, and pose a risk of causing adverse effects to the environment and human health. It is important to increase levels of public awareness on mobile phone wastes management and promote knowledge about hazardous substances in the mobile phone wastes, if people do not manage problem seriously, it will impact public health and environmental quality.

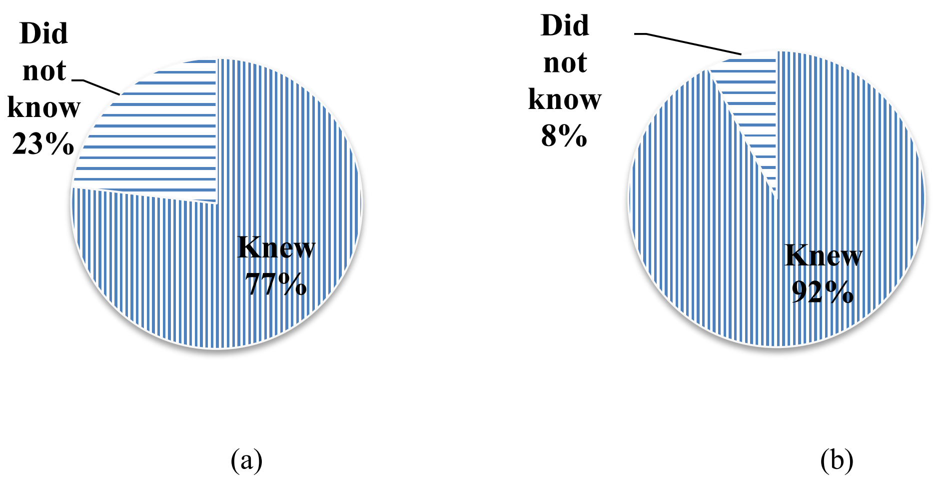


Figure 4.32: understanding of the mobile phone waste problems

(a) Understanding mobile phone wastes increase every year
(b) Understanding mobile phone wastes have hazardous substances

Figure 4.33 shows understanding of respondents about mobile phone wastes contained precious metal such as gold silver and copper etc. About 64% of the respondents know about this information and 36% did not know. From the surveys, most people lack of awareness on recycling mobile phone wastes due to some people do not recognize that mobile phone wastes are contained with precious metals such as gold, silver and copper which proper recycling processes could recovery to gain profits.

Therefore, knowledge about Urban Mining is essential to make people aware of the recycling benefits. Currently population of the world increases rapidly consequences using a lot of resources on a daily life. Amount of mineral from mining in the world has limit and decline rapidly every day. In contrast, mobile phone wastes which are potential source for urban mining and likely to increase every day. So recycling of mobile phones is emerging as potentials solutions for reduction of waste and depletion of natural resources. It can minimize environmental impact and save energy from resource extraction.

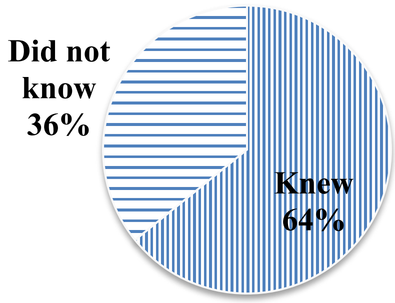


Figure 4.33: Understanding mobile phone wastes contained precious metals

Regarding the situation on mobile phone waste management as shown in **Figure 4.34**, about 47% realized that there is no management at all (44%), 47% did not know any information about the management system while 4% understand that the wastes were managed in systematic way. From the answer of respondents, most people do not know about management mobile phone in the country and think there is no management system for this type of waste. This is major reason why most of Thai people keep mobile phone at home. Potential improvement solution is to distribute the information about appropriate management of mobile phone wastes to the people to increase awareness and bring mobile phone wastes to the appropriate management. And also in the near term, the formal system for e-waste collection needs to be established in the country.

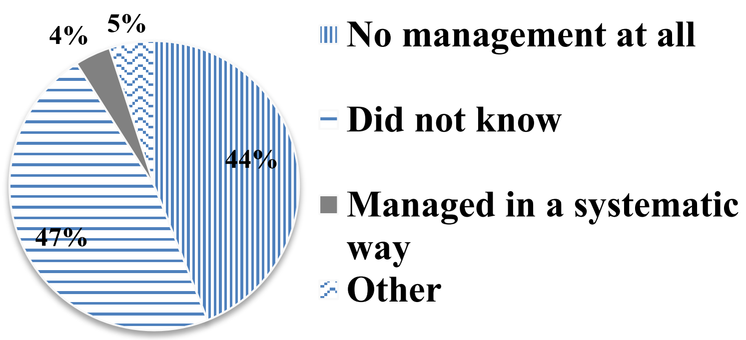


Figure 4.34: Understanding the situation of mobile phone wastes management in Thailand.

4.10.4 Opinion about mobile phone waste management

Figure 4.35 shows the results of the questions about the major motivations for the public to recycle of mobile phone wastes. Number presented in the pile chart is the number of responses voting for each option. There are 6 options that respondents rank from the most preferred to least options: (1) Increase the understanding of mobile phone wastes, (2) Set up laws and regulations to mandate recycle e-wastes, (3) Obtaining money or benefits from recycling, (4) Increase public awareness on environmental value, (5) Convenience of the location for drop off and (6) Others [Respondents can give suggestions in addition to the provided options]. **Figure 4.36** shows percentage of the first rank that respondents prefer: (1) Obtaining money or benefits from recycling (27%), (2) Increase the understanding of mobile phone wastes (25%), (3) Set up laws and regulations to mandate recycle e-wastes (22%), (4) Convenience of the location for drop off (16%) and (5) Increase public awareness on environmental value (10%).

From the results, the major motivation to recycle mobile phone wastes is to obtain money or benefit from recycling because money is still an important factor in daily life, so it makes most people interested in participating recycling activity when compared with other options. The next option which people prefer is to increase the level of understanding about the problems of wastes. So the dissemination of knowledge about mobile phone wastes problem is considered extremely important in order to raise awareness to manage problem. The next option that people prefer is to set up laws and regulations for recycling. The advantage of the laws and regulations can put a mandate for people to comply, but it should be reasonable and equitable to all parties in order to make people practice eventually.

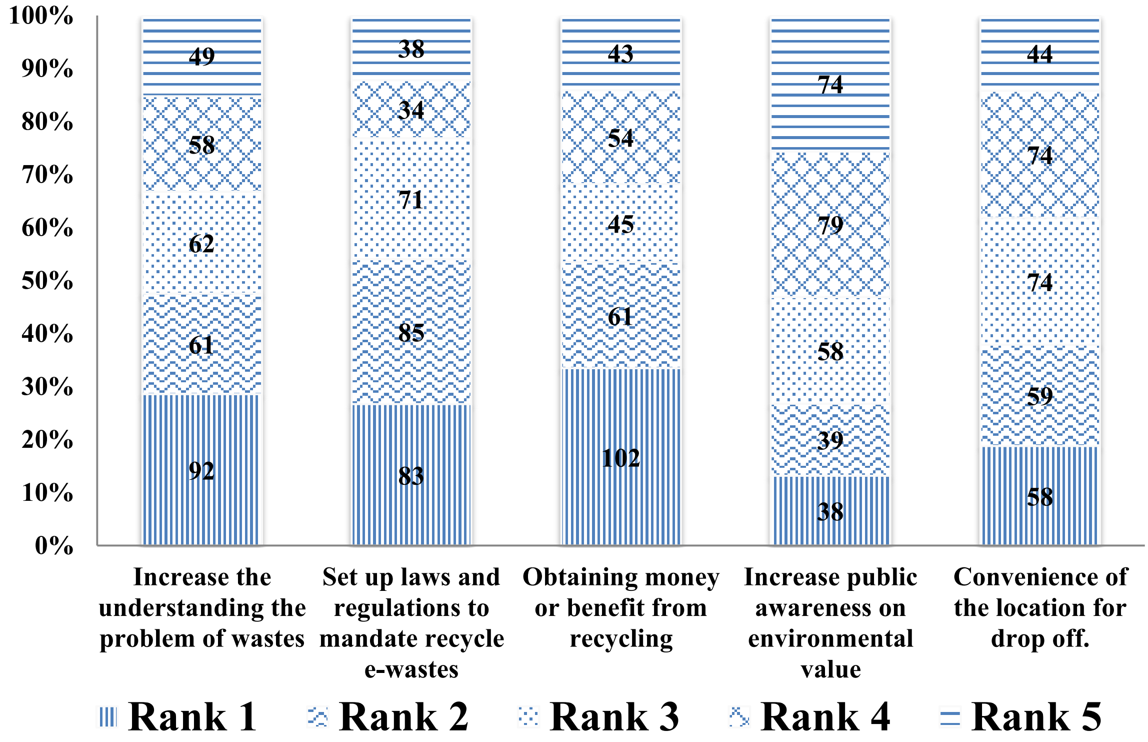


Figure 4.35: The Major motivation of respondents to recycle of mobile phone wastes

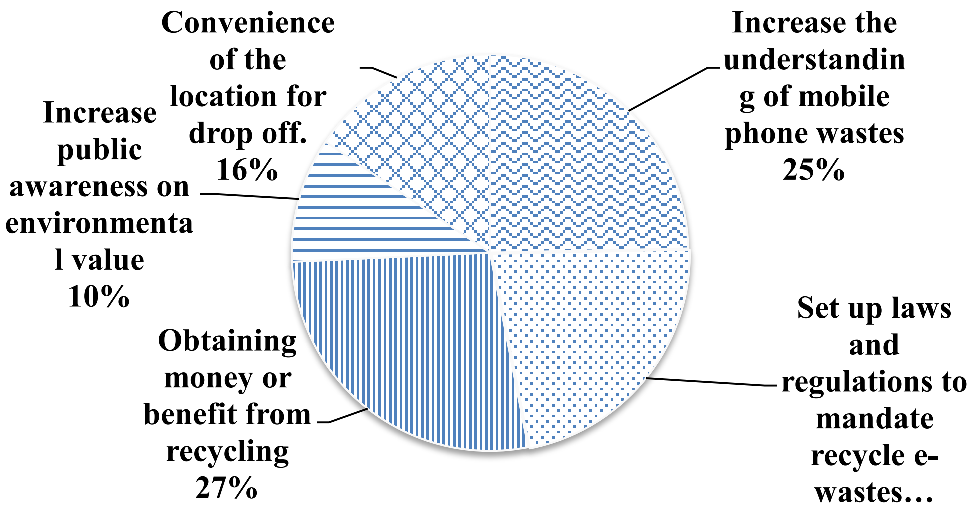


Figure 4.36: The major motivation to recycle that respondents prefer the most (as 1st rank in the questionnaire)

Figure 4.37 shows the results of the question where is the place you think to bring mobile phone wastes to send in recycling. There are 7 options that respondents rank from most preferred to least: (1) Department store, (2) At home, (3) Mobile phone shop/ Repair shop, (4) Convenience store, (5) Government agency, (6) Public transport station and (7) Others. **Figure 4.38** shows the result from first rank that respondents prefer: (1) Convenience store (27%), (2) Departments store (21%), (3) At home (19%), (4) Mobile phone shop/ repair shop (16%), (5) Public transport station (5%) and (6) Government agency (5%).

Based on the results, appropriate place to bring mobile phone wastes to send in recycling is convenience store and department store. Because most people are familiar with this place to purchase items for use in daily life and this places open every day. So convenience stores and department store are appropriate place to set up as a collecting point for bring mobile phone wastes to recycle. Next the option that people prefer is to pick up at home. Due to the answer from interview, most of Thai people keep end of life mobile phone at home. If collection at home, people do not waste time and transportation costs to bring mobile phones to recycle. The disadvantage of the collection at home is a high collection cost since only a few of volume can potentially be collected when compared to a convenience store or department stores. The investment to collect at home can be extremely high because of transportation costs when compared to a convenience store or department stores.

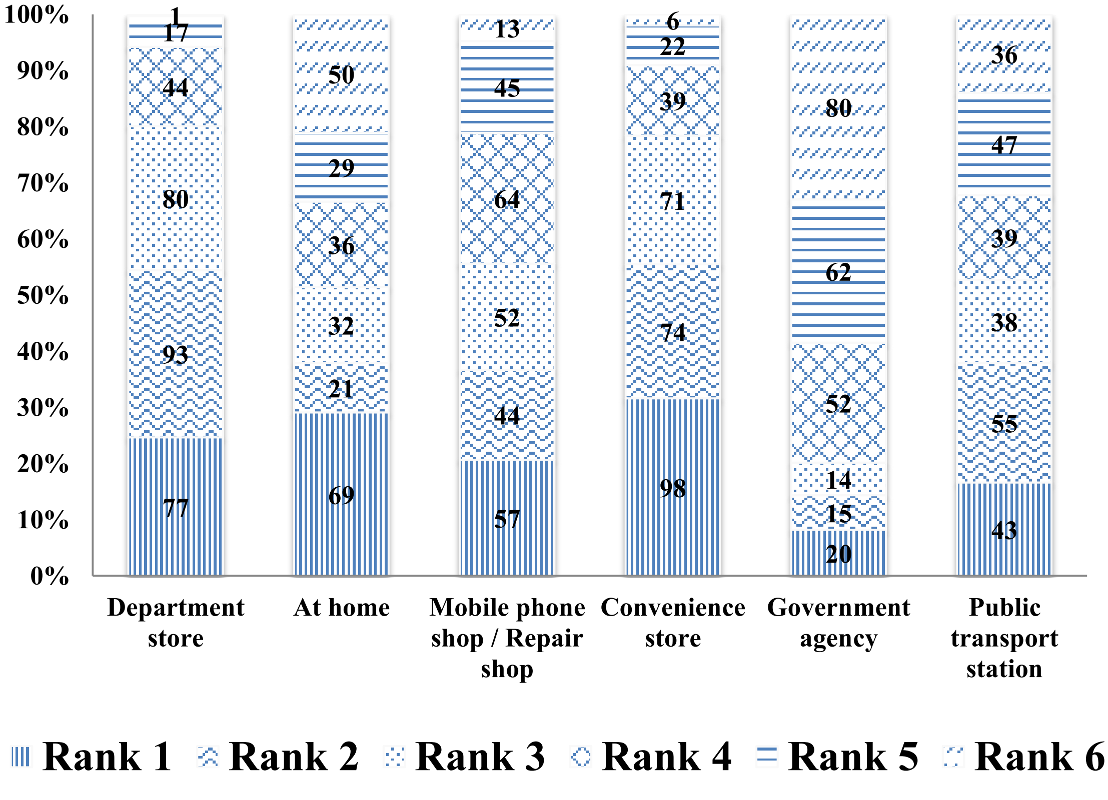


Figure 4.37: Place to bring mobile phone wastes for drop off to recycling

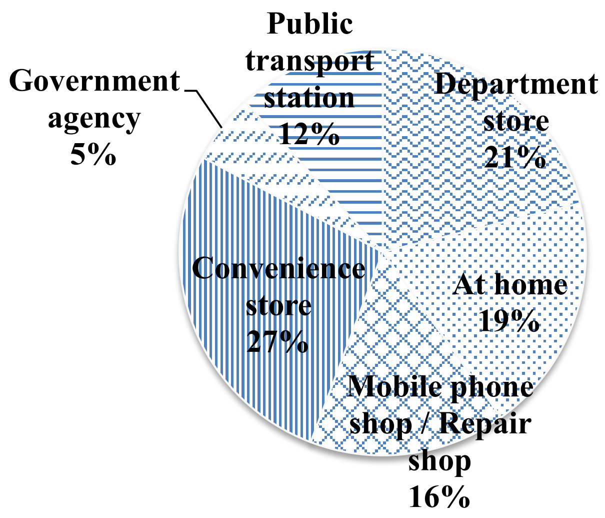


Figure 4.38: Place to bring mobile phone wastes for drop off to recycling that respondents prefer the most (as 1st rank in the questionnaire)

Regarding the public policy that are most interested for managing mobile phone waste, there are 6 options that respondents rank from most preferred to least: (1) Charge recycling fee by including in the cost of products, (2) Paying for mobile phone waste management when disposal, (3) Provide a discount on the purchase for a new mobile phone in return, (4) Donation to government agency to recycling, (5) Law and regulations and (6) Others. Analyzed results are shown in **Figure 4.39**. **Figure 4.40** shows the result from first rank that respondents prefer: (1) Provide a discount on the purchase for a new mobile phone in return (69%), (2) Law and regulations (10%), (3) charge recycling fee by including in the cost of products (8%), (4) Donation to government agency to recycling (7%) and paying for mobile phone waste management when disposal (6%).

From the result most people prefer policy that receiving a discount on the purchase of a new mobile phone or receive money in return when brings the old model back as high as 69% because this policy can offer benefits to people. There are several issues of concerns with this policy, especially how to set up a financial operating system to operate and provide refund to the recycler. The rule and rate for compensation is difficult to be set at first since each model of mobile phone have different technology and different price of model so this policy must be consider a set of standard discount value on the purchase for a new mobile phone to ensure fairness to all parties.

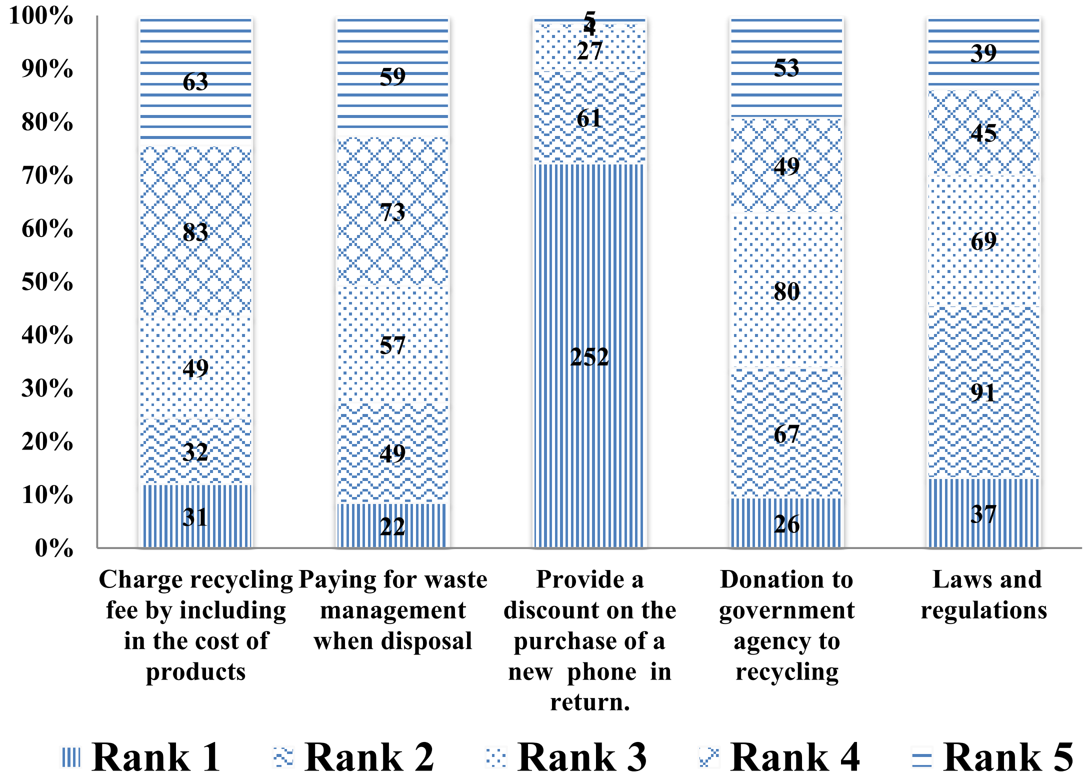


Figure 4.39: Policy that respondents are most interested if government set management system

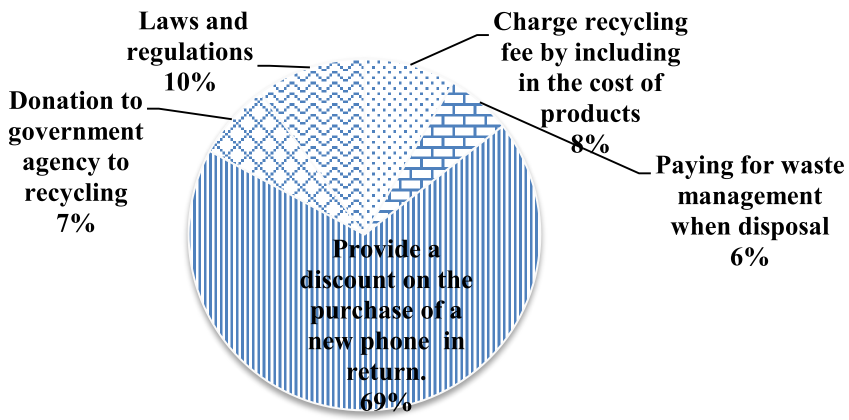


Figure 4.40: Policy to manage mobile phone wastes that respondents prefer the most (as 1st rank in the questionnaire)

The result analysis about the opinions on the government actions to generate public incentive to take mobile phone wastes to collection center summarized in **Figure 4.41**. There are 4 options that respondents rank from the most preferred to the least: (1) Voluntary, (2) Laws and regulations, (3) Obtaining money or benefit, (4) others. **Figure 4.42** shows the results from first rank that people prefer: (1) obtaining money or benefit (42%), (2) Voluntary (35%), (3) laws and regulations (23%).

From the result, most people like policy that obtaining money or benefit which coincided with a voluntary policy. Voluntary from people will happen when they are aware of the problem. Potential policy is to distribute more knowledge and increase public accurate understanding on why we have to manage the mobile phone wastes. Regarding to law and regular policy, most people chose as the least favorite because it is the compulsive act, which may be contrary to the character of Thai people.

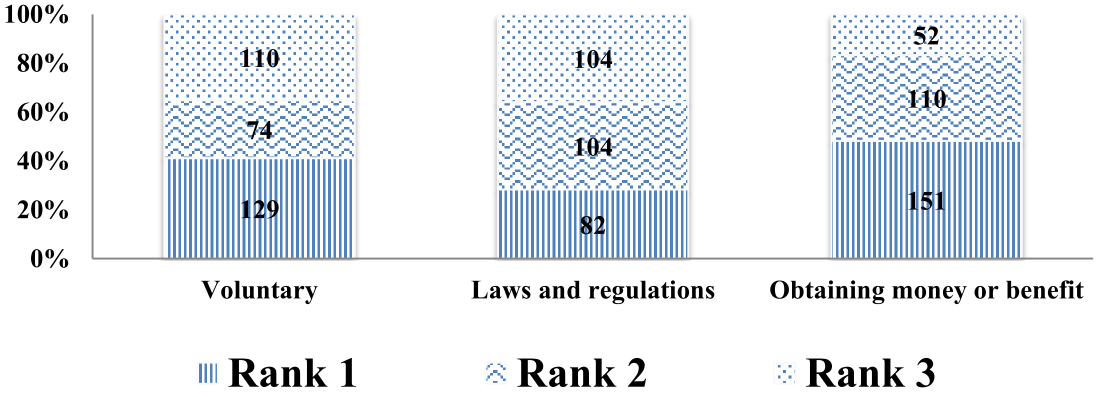


Figure 4.41: Results of the question what the government should do to establish collection center

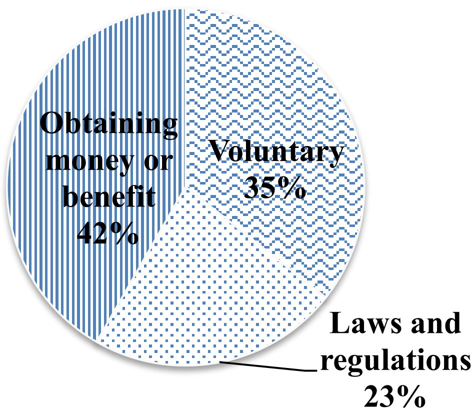


Figure 4.42: Government should do to when establish collection center that respondents prefer the most (as 1st rank in the questionnaire)

4.10.5 Suggestions about mobile phone waste management

This part of the questionnaire asked opinions from the respondents to give suggestion how to improve management of mobile phone wastes in the future. The results analysis can be categorized into 4 main groups of suggestions: (1) Financial incentive, (2) Law and regulations, (3) Practicality: convenience location for bring mobile phone waste to recycle and (4) Social element, the detail of answer as shown in **Table 4.28**.

I. Financial Incentive

The detail of suggestions in financial incentives has 2 main issues (1) Benefits : provide discount rate when you bring old mobile phone to buy new phone or discount rate for utility expense such as water or electricity and (2) Tax : charge fee includes the cost of products or collect tax from the manufacturer or supplier.

From the result, financial incentive is a measure to motivate people to take old mobile phone back to the recycling system. If Thailand government decides to charge environmental tax from manufacturers and supplier of mobile phone, it would be appropriate and more feasible in practice, rather than having consumer to pay for management of mobile phone wastes. Tax from manufacturers and supplier should bring to set up the fund and used as a subsidy and offer benefit incentives for consumers to take back mobile phone wastes into the system. Financial instrument will change the behavior of public to manage problem of mobile phone wastes more seriously.

II. Laws and regulation

There are 2 major issues in Law and regulations suggestions. (1) Disposer should be charged when dispose mobile phone wastes mixed household waste. (2) Government should stringently promote laws about mobile phone wastes management and has a place for collection mobile phone wastes.

Laws and regulation is highly important to manage the problems such as in European Union has set a directive on waste electric and electronic equipment (WEEE) in order to manage electronic wastes problem. For Thailand, there is currently no laws and regulation to manage electronic wastes. The result follows no obligation link between government, private and the public sector so the management of mobile phone waste is very inefficient.

III. Practicality : convenience location for drop off mobile phone wastes to recycle

The suggestion from the survey on this part is to increase collection stations/locations and inform about collection places to people. The problems of collection mobile wastes in Thailand do not have system to collect mobile phone wastes as a result the private sector has no incentive to invest in a recycling plant.

Additionally, the collection of mobile phone wastes in to system can reduce the problem of informal recycling. For example o informal recycling sorting copper from wire by burning, people who sort and separate precious metal from the wastes did not use appropriate recycling technology and did not ware protection gears to protect toxic substance which is harmful to human health and the environment.

The advantage for collection system and treatment of mobile phone wastes can help examine the amount of mobile phones wastes remain in the country. Within the next 2 years in 2015, Thailand will be ASEAN Economics Community (AEC), if Thailand has on system and information about management of mobile phone wastes in the country, it will difficult to detect and control in the case of a moving mobile phone wastes from abroad into the country. This will cause problems later in the near future.

IV. Social Issues

There are 2 main issues: Knowledge and Awareness

(a) Knowledge

The knowledge mobile phone wastes should be promoted such as the wastes contained precious metal and hazardous substance, knowledgeable about treatment or recycling of mobile phone wastes and problems of mobile phone wastes are likely increase every year. Government should support the research and technology to produce environmental friendly electronics products, and establish organization that plans to target both the practical and research cooperation with manufacturers / distributors of mobile phone to help minimizing the waste problem.

(b) Awareness

Thailand culture and society should create awareness on environmental sustainability. Companies which do business about mobile phone in the country should make campaign to protect the environment and return benefits to society. The manufacturer need to increase cooperate social responsibility in designing eco-friendly product and in helping to deal with waste management their products.

The dissemination of knowledge about mobile phone wastes problem is considered extremely important in order to raise awareness to people manage problem of mobile phone wastes seriously.

Table 4.28: Summary of suggestions about mobile phone waste management from respondents

Topics	Detailed answers
Financial incentive	- Get discount rates when bring old mobile phone to buy new mobile phone, or can be used as a discount on the monthly service. - Should charge fee into the cost of new mobile phone and collect taxes on the manufacturer or supplier for mobile phones. - There should be incentives for people to use the telephone longer or contract with at least two years after the contract was to bring old mobile phone to a new phone. - Discount rates for utilities such as water or electricity, but it is not directly give the money back for people who bring mobile phone wastes to recycle.
Laws and regulations	- Promote laws about mobile phone wastes management seriously and has a place for collection mobile phone wastes enough. - Make regulation about collection of mobile phones wastes in the work place and then brought to the State in order to recycle. - Government must push for the management of electronic waste (mobile phone) into a national environmental management plan. - Make policy fined 2000 Baht when you dispose mobile phone wastes mixed household waste.
Convenience of the location for drop off	- Increase collection places and public relations for collection places to people. - Provide facilities to people in the disposal of mobile phone wastes.

Social element - Knowledge	 - Public sector should promote the knowledge that the mobile phone wastes have precious metal and hazardous substance. - People should understand mobile phone wastes problems that are likely increase every year. - Promote knowledge about treatment or recycling of mobile phone wastes. - Give knowledge through commercials, billboards and procedure for people to raise awareness about e-waste problems. - Government should support the research and technology to produce environmental friendly electronics products. - Established organization that plans to target both the practical and research cooperation with equipment manufacturers / distributors of mobile phone to solve the problem
- Awareness	- Thailand culture and society should create awareness on environmental sustainability. - Should limit the number of mobile phone for people, such as no more than 2 units / person - Companies which do business about mobile phone in the country make campaign to help the environment and return benefits to society.

CHAPTER V

Recommendation for management end of life mobile phone in Thailand

According to the environmental impacts evaluation results for managing end of life mobile phones, increase the recycling rate can help reducing environmental impacts when compare to management only by landfill. In Thailand, currently, there is no formal collection system of mobile phone wastes to recycle. So establishing e-waste collection center/system is an essential function to solve e-waste problem in the long term. Eventually, after formal collection system being developed, recycling plants and integrated systems are the key to make sustainable waste management in the country. In this research, the public survey primarily focuses on how to increase efficiency of e-waste collection and participate in recycling scheme. Based on results from survey, most people keep end of life mobile phone wastes at home because of lack of knowledge and understanding about how to handle the mobile phone wastes properly. Some people do not know that mobile phone wastes contain toxic substances as well as precious metals. Therefore, it is important to increase participation of mobile phone recycling by providing compulsory or market-based incentives such as recycling regulation or financial benefits from recycling.

The study made suggestions on how to promote a collection of mobile phone wastes to recycling system in Thailand. The recommendations are divided into 3 parts including (1) Strategies for increasing collection of mobile phone wastes to recycle, (2) Responsibilities of key sectors to solve the problem, and (3) Timeline for implementation. The details of recommendation are as following:

5.1 Strategies for increasing collection of mobile phone wastes to recycle

There are 5 recommended strategies for increasing collection rates of mobile phone wastes to recycle ; (1) Strategies for increasing public education, (2) Strategies for increasing recycling activity, (3) Strategies for increasing financial incentive, (4) Strategies for developing law and regulation and (5) Strategies for developing mobile phone wastes management sustainability. The details for each strategy are as following:

5.1.1 Strategies for increasing public education

Public education for management end of life mobile phone in Thailand needs to be improved. It will help increasing awareness of people to recycle mobile phone wastes. Suggestions for improving public education include;

(a) Disseminate knowledge to public

- Contents of Knowledge: 1) Knowledge about mobile phone wastes includes; hazardous substances have high impacts to public health and the environment, and mobile phone wastes contained precious metals, if send to recycle will decease depletion of natural resources and provide other benefits, 2) Knowledge about how to sort mobile phone wastes from municipal wastes to recycle, 3) Knowledge about management mobile phone wastes.
- Approaches: 1) Encourage to include the knowledge into academic curriculum to raise awareness of the environment, resource use efficiency and mobile phone waste management, 2) Disseminate knowledge to explain about impacts from hazardous substances, benefits from recycling and management of mobile phone waste by advertising such as handout, brochures and internet etc. Set workshops to share knowledge with the community and set system to collect end of life mobile phone in community.
- Mechanisms: 1) Voluntary mechanism from academics or organization or official government to promote knowledge, and consumers such as among family members, friends, colleagues to distribute and share knowledge, 2) Voluntary by mobile phone suppliers of mobile phone to be responsible to disseminate knowledge about management of the products to the public

5.1.2 Strategies for increasing recycling activity

To increases recycling activity, the following strategies are suggested:

(a) Increasing collection wastes in local community

- Contents: Set up collection system to collect mobile phone wastes
- Approaches: 1) Set collection points such as donation boxes and bins at appropriate locations for collection end of life of mobile phone such as department store, workplace, school, and etc, 2) Local municipalities should promote to collect end of life of mobile phone to recycle.
- Mechanisms: 1) Voluntary action from public organization, 2) Subsidy provided from the government to set up a system, and 3) Suppliers of mobile phone to set up campaign collected their mobile phone wastes as CSR.

(b) Research and Development of Technology

- Contents: Promote research funding to develop recycling technology appropriate with local contexts to manage the mobile phone wastes problems.
- Approaches: 1) Setting learning center about research and technology about mobile phone wastes management, 2) Promote research funding in academy or university.
- Mechanisms: 1) Subsidy from government to support for setting learning center and 2) Academics or university to conduct this area of research.

5.1.3 Strategies for increasing financial incentives

Based on the survey results, the respondents prefer in policy obtaining financial benefits as incentives when take back end of life of mobile phones to be recycled. The suggestions include:

(a) Offer benefits when buy new mobile phone at mobile phone shops

- Contents: Obtaining benefit or return money from mobile phone shops when bring old mobile phone wastes to buy new mobile phone at mobile phone shop to motivate people bring mobile phone to recycle instead of keeping it at home.
- Approaches: Supplier and mobile phone shop should coordinate and set level of possible benefits to consumers when bring old mobile phone wastes to buy new mobile phone.
- Mechanisms: Voluntary by mobile phone suppliers and mobile shops to set beneficial system in order to collect old mobile phone.

(b) Obtaining benefits from collection centers by government

- Contents: Offer benefits or refund money when consumer bring end of life mobile phone to collection center.
- Approaches: Government should be set collection center and set benefits in order to motivate people bring end of life mobile phone to collection center. Collection center should be set in Bangkok and major cities in the country because these sources are highly consumption of mobile phones, which makes it worth the investment in setting collection centers.
- Mechanisms: Command and control by government charge tax from manufacturers and supplier of mobile phone, tax should bring

to the revenue fund of the state used to support setting collection center and benefit incentives for consumers to take back mobile phone wastes into the system.

5.1.4 Strategies for developing law and regulations

Thailand currently has no laws to manage mobile phone wastes. As a result, there is no cooperation and integration in government, private sector and people to solve this problem seriously. To develop law and regulation, this study suggests the following:

(a) Develop law and regulations to bring informal recycling into quality control standard

- Contents: Set law and regulations to help informal recycling to improve and ensure their practices are technological sound with appropriate protection to the worker in the recycling operation because it has impacts to human health and environment. Set regulation to monitor and control environmental quality in nearby area that has recycling activities.
- Approaches: Government requires manufacturers and importers to inform the type and quality of raw materials in produce mobile phones, as well as hazardous substances and components recycled to be used data to set up and evaluate efficiency of the formal recycling.
- Mechanisms: Command and control by government to set relevant recycling regulation to enforce groups of entrepreneurs take back old mobile phones to recycling system.

5.1.5 Strategies for developing mobile phone wastes management sustainability

To develop mobile phone wastes management sustainability, the following strategies are suggested:

(a) *Set formal recycling plants and promote recycling business in Thailand*

- Contents: Setting formal collection system and recycling plant in Thailand and promote recycling business in order to recycling precious metal and treatment toxic substances in mobile phone wastes.
- Approaches: Set priority on collection mobile phone wastes in sufficient amounts for establishing recycling plants and enough to recover investment benefits to the business sector.

- Mechanisms: Investment from government should set recycling plants and provide support (investment incentive for green business) to potential investor to invest recycling business.

(b) Create awareness on environmental sustainability

- Contents: Thailand culture and society should create awareness on environmental sustainability
- Approaches: Dissemination of knowledge about problem and management of mobile phone wastes is considered extremely important in order to raise awareness of the public to manage problem of mobile phone wastes seriously. Companies which do business about mobile phone in the country should make campaign to promote recycling to society.
- Mechanisms: Voluntary from organization and corporate social responsibility (CSR) from company.

5.2 Responsibilities of key sectors to solve the problem

Management of mobile phone wastes in Thailand requires the cooperation of all sectors to solve the problem. In this study divided to 3 sectors including (1) government, (2) manufacturer and supplier (3) consumers and (4) waste collector/ waste disposer. The details of responsibility each sector summarized as shown in **Table 5.1**.

Table 5.1: Responsibilities of each sector to solve the problem

Sector	Potential Responsibility
Government	- Implement and establish mobile phone wastes management system. - Coordinate all stakeholders involved mobile phone to find solution of problems - Set law and regulation which reasonable and equitable to all parties in order to make practice eventually - Set financial incentive to encourage consumer take back mobile phone wastes to recycle. - Promote knowledge about mobile phone wastes management and sorting e-wastes from municipal wastes in order to recycle to public in country.

Sector	Potential Responsibility
Manufacturer and supplier	- Extended responsibility of EoL mobile phone management in the country. - Promote knowledge about mobile phone wastes management to public. - Pay environmental taxes to the government (in the future when the regulation will be enacted) in order to help financing mobile phone wastes management system in the country.
Consumer	- Promote knowledge among family, friends and community on mobile phone wastes and its management in order to raise awareness to recycle. - Sorting mobile phone wastes from general wastes and collection to recycle. - Collect mobile phone waste into system in order to recycle such as in the work place and setting bins for electronic wastes. - Develop Thailand culture and society to increasing awareness on environmental sustainability
Waste collector/ Waste disposal	- Should be knowledgeable in sorting of e-wastes as well, in order to prevent contamination or leakage of dangerous substances to environment. - Should ware proper protection equipment as the mask and gloves in order to protect themselves from toxic substances of e-wastes

5.3 Timeline for implementation

Reasonable period of time to management of mobile phone wastes in Thailand, in this study are divided to 3 durations including 1) Initial term, 2) Medium term and 3) long term. The details of each duration as follow:

- Initial Term Plan: The plan should promote public education in order to raise awareness the important management of mobile phone waste in Thailand and set collection points and bins at the appropriate locations for collecting mobile phone wastes and separate them from general wastes.
- Medium Term Plan: Develop financial incentives system and measures to motivate people to take end of life mobile phone back to the recycling and management system and set up a recycling facility by government sector or business sector.
- Long Term Plan: Develop recycling laws and regulation to sustainably manage the problems. Laws and regulation will help integrating the efforts between government, private and the public sector to manage the problems of mobile phone wastes sustainably and most effectively.

CHAPTER VI

CONCLUSIONS

6.1 Generals Conclusions

6.1.1 The components from disassembly the model of mobile phones

There are 6 models chosen to be used as case studies (3 regular phone models and 3 smartphone models). By disassembling each model of mobile phone into compartments, the components were classified into 4 groups (mobile phone casing, charger casing, charger, battery)

In component of mobile phone casing, the main material is plastic, metal and rubber. In component of charger casing, the main material is plastic, metal, rubber and paper. In component of charger and battery, the main material is chemicals (inorganic), metal, chemicals (organic), plastic, rubber and paper. The metal found in all components is ferrous metal and non-ferrous metal.

The main composition of regular phone is plastic (32-58%) and non-ferrous metal (15-34%). The main composition of smartphone is plastic (42-52%) and non-ferrous metal (19-32%). The main composition representative of mobile phone (average from representative of regular phone and representative of smartphone) is plastic (43-53%) and non-ferrous metal (19-29%).

6.1.2 Recovered materials and potential benefits from recycling of mobile phone per unit

From calculating recycling system of mobile phone per unit, materials that can be obtained from recycling are Ferro, Steel, Lead, Al, Tin, Nickel, Copper, Palladium, Silver, Gold, Cobalt, MnO_2 and Li salt. The main materials are Aluminum (22%), Copper (20%) and ferrous metal (Iron, Steel) (17%).

From the calculation benefit values from recycling of material from mobile phone per unit found that the price of the quantity of metals from recovery one mobile phone was 10.704 – 11.930 bath. This price does not include operating and recycling cost when setting recycling plant.

6.1.3 Environmental impacts from comparing regular phone and smart phone and components for EoL of mobile phone

Impacts from Human toxicity and Freshwater ecotoxicity of regular phone has higher than smartphone but impact from Climate change human health, Metal depletion and Fossil depletion of regular phone has lower than smartphone. The results of environmental impacts value (end-point) approach found that the total single score from three damage categories of smartphone has 32% higher than regular phone. Impact from human health category has higher impacts than other damage categories, followed by resources category and ecosystems category respectively.

From comparing the environmental impacts of components (mobile phone casing, charger casing, charger, battery) mobile phone per unit, charger has higher environmental impacts every category (Human toxicity, Freshwater ecotoxicity, Climate change human health, Metal depletion and Fossil depletion) than that from other components, followed by mobile phone casing, battery and charger casing. The result of environmental impacts value (end-point) found that the total single score of charger has higher than that of other components, followed by mobile phone casing, battery and charger casing respectively. Impact from human health category has higher impacts than other damage categories, followed by resources category and ecosystems category respectively.

6.1.4 Scenario analysis for end of life of mobile phone

The result of the environmental impacts when compared of 3 scenarios (Scenario 1 is “100% landfill”, Scenario 2 is “95% landfill & 5% recycling” and Scenario 3 is “80% landfill & 20% recycling”) found that Scenario 1 has higher impacts comparing to other scenarios on every impact category. For the end-point analysis, human health impacts contributed the highest proportion from the end of life impacts from mobile phone wastes, followed by resource depletion and ecosystems quality respectively. Scenario 2 and 3 reduced the environmental impacts when compare scenario 1, scenario 2 can reduce 7.60 times and scenario 3 can reduce 30 times from scenario 1 estimated impacts. Therefore, recycling of mobile phone wastes has a good potential to reduce environmental impacts.

When comparing environmental impacts each scenario between the present period or baseline (2012) and the future (2020) that mobile phone wastes will increase from 39,217,000 units in 2012 to 88,022,000 units in 2020. The result from percentage change of impacts different of each scenario between current period (2012) and future period (2020) found that scenario 1 has increased 2.24 times, scenario 2 has decreased 14.82 times and scenario 3 has decreased 66.02 times. Scenario 3 reduced highest environmental impacts if compare with the other scenario but scenario 1 increased environmental impacts. Therefore development of recycling programs that keep used mobile phone out of the waste stream by collecting and recycling, are necessary to solve the environmental problem in the future.

6.1.5 Sensitivity analysis

The results of sensitivity analysis from every scenario are similarly. When varied parameters in measurement of materials by trial and errors at 5% of weighting materials, the different percentage changing of environmental impacts from the results has the interval between -0.059% to +0.001%. So the varied parameter in measurement of materials by trial and errors at 5% of weighting materials has minimal effect to reliability of the results.

6.1.6 Survey from public opinions about mobile phone wastes management

I. Behavior for end of life of mobile phone management

- The main reason to change mobile phone or buy a new phone is phone was damaged and could not be repaired (57%) and phone was not able to response requirements (34%).
- Most of resespondents mainly kept EoL mobile phone at home (69%) and re-sold at mobile phone shop (21%).

II. Level of understanding of the mobile phone waste problems

- The respondents knew about mobile phone wastes increase every year and average lifespan of mobile phone tended to decline steadily (77%) and did not know (23%).
- The respondents knew that mobile phone wastes are contained with hazardous substances which can contaminate into the environment (92%) and did not know (23%).
- The respondents know mobile phone wastes contained precious metal which proper recycling processes could recovery to gain profits (64%) and did not know (23%).
- Most of respondent did not know about management mobile phone in the country (47%) and think there is no management system for mobile phone wastes (44%).

III. Opinion about mobile phone waste management

- The major motivation to recycle that respondents prefer the most (as 1st rank in the questionnaire) is (1) Obtaining money or benefits from recycling (27%), (2) Increase the understanding of mobile phone wastes (25%), (3) Set up laws and regulations to mandate recycle e-wastes (22%).
- The place to bring mobile phone wastes for drop off to recycling that respondents prefer the most (as 1st rank in the questionnaire) is (1) Convenience store (27%), (2) Departments store (21%), (3) At home (19%).
- Policy to manage mobile phone wastes that respondents prefer the most (as 1st rank in the questionnaire) is (1) Provide a discount on the purchase for a new mobile phone in return (69%), (2) Law and regulations (10%), (3) Charge recycling fee by including in the cost of products (8%).
- Type of incentives to bring e-wastes to collection center that respondents prefer the most (as 1st rank in the questionnaire) is (1) Obtaining money or benefit (42%), (2) Voluntary (35%), (3) Laws and regulations (23%).

IV. Suggestions about mobile phone waste management

- <u>Financial incentives</u> (1) benefits: discount rate when you bring old mobile phone to buy new phone and (2) tax: charge fee includes the cost of products or collect tax from the manufacturer or supplier.
- <u>Law and regulations</u> (1) waste generator should be charged when dispose mobile phone wastes mixed household waste and (2) government should promote laws about mobile phone wastes management seriously and has a place for collection mobile phone wastes.
- <u>Convenience of the location for drop off mobile phone wastes to recycle</u> (1) should increase collection stations/locations and (2) inform about collection places to people.
- <u>Social element</u> (1) promote common knowledge about mobile phone wastes contained precious metal and hazardous substance, knowledgeable about treatment or recycling, (2) increase level of awareness: Thailand culture and society should create awareness on environmental sustainability and companies which do business about mobile phone in the country should make campaign to protect the environment and return benefits to society.

6.2 Recommendation for management end of life mobile phone in Thailand

There are 5 strategies for increasing collection rates of mobile phone wastes to recycle**.**

I. Strategies for increasing public education

Public education will help increase awareness of people to recycle mobile phone wastes such as disseminate knowledge mobile phone wastes about hazardous substances and precious metals, management mobile phone wastes and sorting mobile phone wastes from municipal wastes in order to recycle.

II. Strategies for increasing recycling activity

To increases recycling activity, the following strategies are suggested: 1) increasing collection wastes local community such as setting donation box or bin for collection end of life of mobile phone and 2) promote research and appropriate technology to manage the mobile phone wastes.

III. Strategies for increasing financial incentive

To increasing financial incentive, the suggestions are to offer: 1) Obtaining benefit when buy new mobile phone at mobile phone shops in order to motivate people bring mobile phone to recycle replace kept at home and 2) offer benefits or refund money when consumer bring end of life mobile phone to collection center in order to motivate people bring end of life mobile phone to collection center.

IV. Strategies for developing law and regulations for wastes management

To develop law and regulation, this study recommends develop law and regulations to bring informal recycling into quality control standard to help informal recycling to improve and ensure their practices are technological sound with appropriate protection to the worker in the recycling operation.

V. Strategies for developing sustainable mobile phone wastes management

Setting formal collection system and recycling plant in Thailand, promote recycling business and create awareness on environmental sustainability in order to raise awareness of the public to manage problem of mobile phone wastes seriously.

Timeline for implementation

At Initial term, the effort should spend to raise awareness the important management of mobile phone waste in Thailand promote by public education and set collection points for collecting mobile phone wastes. Later in medium term, the action should motivate people to take end of life mobile phone back to the recycling by develop financial incentives system and set up a recycling facility by government sector or business sector. Finally, in the long term, the plan should integrate the efforts management schemes between government, private and public sector to manage the problems sustainably and most effectively by develop recycling laws and regulation to manage the problems of mobile phone wastes.

6.3 Recommendation for future work

There are many issues that should be studied in more details to complete evaluation the environmental impact for EoL of mobile phone in Thailand, as follows:

- Impact evaluation from transportation is another area need to be focus in detail for future research. Since this study does not include the impact from transportation of mobile phones wastes to management system in each scenario.
- Disassembly new model of mobile phone in evaluation, technological innovation speeds up the rates of introducing new models mobile phones.
- Other situation of scenario and include other technology such varied parameters in percentage of landfill and recycling and incineration.

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APPENDICES

Appendix A

Appendix A: Material of mobile phones

Table A-1 Materials form disassembly compartment of 6 mobile phone models

Material/ Model	Model (1)	Model (2)	Model (3)	Model (4)	Model(5)	Model (6)
1.Mobile phone casing						
1.1 Plastic	3.3255E+01	2.8597E+01	9.3996E+00	2.0188E+01	2.0055E+01	2.4510E+01
1.2 Aluminum	0	1.7260E-01	8.9970E-01	3.9077E+00	1.2553E+00	1.3448E+00
1.3 Iron	1.2000E+00	8.9950E-01	9.1720E-01	9.4300E-01	2.4603E+00	4.4910E-01
1.4 Rubber	1.9288E+00	1.4587E+00	1.3875E+00	1.0801E+00	1.1975E+00	3.2100E-01
2.Charger Casing						
2.1 Iron	3.0827E+00	8.0900E-02	1.9553E+00	1.3591E+00	2.3200E-01	1.1690E-01
2.2 Copper	2.3600E-02	0	0	5.1800E-02	1.7000E-03	0
2.3 Gold	3.0000E-03	0	0	0	0	0
2.4 Zinc	0	1.7670E-01	6.9912E+00	0	0	0
2.5 Stainless	0	0	0	5.1711E+00	0	0
2.6 Aluminum	0	0	0	0	1.1968E+00	2.6343E+00
2.7 Plastic	5.6549E+00	1.5824E+01	1.0684E+01	2.5456E+01	1.3405E+01	5.8538E+00
2.8 Rubber	5.6190E-01	0.0000E+00	7.9900E-02	7.6290E-01	0	1.1290E-01
2.9 Paper	4.0530E-01	1.8220E-01	0.0000E+00	4.7350E-01	6.0800E-02	1.5390E-01
3. Charger						
3.1 Print wiring board (PWB)	1.6258E+01	1.7099E+01	1.8492E+01	1.7540E+01	2.0277E+01	1.9078E+01
3.2 LCD	4.0618E+00	8.1832E+00	3.6122E+00	1.4346E+01	8.8132E+00	1.3353E+01
3.3 Aluminum	5.8752E+00	1.4990E-01	3.7171E+00	6.3600E-02	1.1639E+01	7.5355E+00
3.4 Plastic	4.9701E+00	3.1231E+00	1.6050E+00	0	2.7140E+00	8.0647E+00
3.5 Paper	0	5.6900E-01	3.7050E-01	0	2.6570E+00	2.6231E+00
3.6 Paper (carbon)	0	3.9580E-01	3.5700E-01	6.7000E-02	0	0
3.7 Tin	3.7000E-01	0	0	5.5300E-02	7.3320E-01	3.4164E+00

3.8 Copper	0	2.1100E-02	4.3100E-02	0	0	0
3.9 Iron	4.8930E-01	4.8624E+00	2.5847E+00	0	0	1.0024E+00
3.10 Zinc	0	0	0	0	2.0007E+00	1.0638E+01
3.11 Rubber	0	3.8200E-02	1.0940E-01	6.5750E-01	0	1.1360E+00
4. Battery						
4.1 PWB	7.1400E-02	5.5750E-01	6.1570E-01	2.2140E-01	7.6090E-01	4.8520E-01
4.2 Plastic	3.4683E+00	2.3550E+00	1.7060E+00	1.1480E-01	1.6084E+00	1.1306E+00
4.3 Rubber	3.8800E-02	0	0	3.6520E-01	4.2780E-01	1.1384E+00
4.4 Battery pack	1.8947E+01	1.5786E+01	1.4276E+01	1.9443E+01	2.6335E+01	1.7065E+01
4.5 Paper	0	1.0150E-01	1.1648E+00	0	0	0
Total	1.0066E+02	1.0063E+02	8.0968E+01	1.1227E+02	1.1783E+02	1.2216E+02

Table A-2 Components of PWB from Charger [Adapted from ecoinvent 2.1 database]

Material/ Model	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
1 Chemicals (inorganic)	1.9854E+00	1.9650E+00	1.9446E+00	1.1294E+00	2.5515E+00	2.3969E+00
2 Copper	1.2650E+00	1.2520E+00	1.5099E+00	1.4477E+00	3.0271E-01	3.0271E-01
3 Glass	9.4401E-02	9.3432E-02	9.9731E-02	1.0803E-01	1.2132E-01	1.1397E-01
4 Nickel	3.4896E-01	6.7514E-01	3.4308E-01	3.9934E-01	4.4846E-01	4.2128E-01
5.Palladium	3.9588E-03	3.9182E-03	4.0178E-03	4.5303E-03	5.0876E-03	4.7793E-03
6 Sliver	1.5476E-02	2.8614E-01	1.5878E-01	1.7711E-01	1.9889E-01	1.8684E-01
7 Tin	8.2020E-01	8.1178E-01	8.6583E-01	9.3861E-01	1.0541E+00	9.9020E-01
8 Bass	2.5024E-01	2.4767E-01	2.6515E-01	2.8637E-01	3.2160E-01	3.0434E-01
9 Gold	1.3249E-01	1.3113E-01	1.4038E-01	1.5162E-01	1.7026E-01	1.5997E-01
10 Plastic	4.5732E+00	4.5262E+00	4.8456E+00	5.2334E+00	5.8771E+00	5.5298E+00
11 Aluminum	1.1250E+00	1.1135E+00	1.1921E+00	1.2875E+00	1.4458E+00	1.3582E+00
12 Chemicals(organic)	5.3995E+00	5.3441E+00	5.7213E+00	6.1791E+00	6.9391E+00	6.5187E+00
13 Lead	4.5663E-02	4.5194E-01	5.2414E-01	5.2255E-02	5.8683E-01	5.5128E-01
14 Molybdenum	4.1392E-02	4.0967E-02	4.3859E-02	4.7368E-02	5.3195E-02	4.9972E-02
15 Zinc	8.5485E-02	8.4607E-02	9.0578E-02	9.7826E-02	1.0986E-01	1.0320E-01
16 Iron	6.9959E-02	6.9823E-02	7.4127E-01	8.0059E-02	8.9906E-02	8.4459E-02
17 Chromium	1.3435E-03	1.3297E-03	1.4235E-03	1.5374E-03	1.7265E-03	1.6219E-03

Table A-3 Components of LCD from Charger [Adapted from ecoinvent 2.1 database]

Material/ Model	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
1 Aluminum	8.8591E-02	1.6766E-01	9.5812E-02	3.1319E-01	2.1446E-01	2.9146E-01
2 Chemicals (inorganic)	7.9539E-01	1.4999E+00	8.6023E-02	2.8119E+00	1.9255E+00	2.6168E+00
3 Chemicals (organic)	3.0331E-02	2.9970E-01	3.2803E-02	1.0723E-01	7.3423E-02	9.9785E-02
4 Chromium	4.7191E-01	8.8988E-01	5.1037E-01	1.6683E+00	1.1424E+00	1.5525E+00
5 Copper	3.3671E-01	6.7048E-01	3.5906E-01	1.1707E+00	8.0369E-01	1.0922E+00
6 Lead	4.3364E-03	2.8223E-02	1.2775E-03	1.5330E-02	1.0497E-02	1.4266E-02
7 Mercury	6.4893E-06	1.2237E-05	7.0183E-06	2.2942E-05	1.5709E-05	2.1349E-05
8 Plastics	1.8562E+00	3.6719E+00	2.0075E+00	6.5621E+00	4.4934E+00	6.1066E+00
9 Rubber	1.6361E-02	3.0852E-02	1.7694E-02	5.7840E-02	3.9606E-02	5.3825E-02
10 Gold	3.4541E-04	6.5135E-03	3.7357E-04	1.2211E-03	8.3616E-04	1.1364E-03
11 Nickel	1.0471E-04	1.9745E-03	1.1324E-04	3.7018E-04	2.5348E-04	3.4448E-04
12 Sliver	2.3943E-04	4.5149E-03	2.5894E-04	8.4644E-04	5.7959E-04	7.8769E-04
13 Tin	2.0112E-04	3.7925E-02	2.1751E-03	7.1101E-03	4.8686E-03	6.6166E-03
14 Zinc	2.4134E-04	4.5510E-03	2.6101E-04	8.5321E-04	5.8423E-04	7.9399E-04
15 Glass	4.5327E-02	8.5473E-02	4.9021E-02	1.6023E-01	9.7250E-02	1.4912E-01
16 Iron	4.1554E-01	7.8359E-01	4.4941E-01	1.4691E+00	5.9240E-03	1.3671E+00
17 Bass	1.8441E-05	3.4775E-05	1.9944E-05	6.5195E-05	4.4642E-05	6.0670E-05

Table A-4 Components of PWB from Battery [Adapted from ecoinvent 2.1 database]

Material/ Model	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
1 Chemicals (inorganic)	8.4407E-04	7.2732E-02	7.2732E-02	2.6206E-02	9.3226E-02	5.7391E-02
2 Copper	5.3782E-03	4.6343E-02	4.6343E-02	1.6660E-02	5.2250E-02	3.6510E-02
3 Glass	4.0134E-04	3.4583E-03	3.4583E-03	1.2432E-03	4.0543E-03	2.7245E-03
4 Nickel	1.4836E-03	1.2784E-02	1.2784E-02	4.5955E-03	6.9651E-02	1.0071E-02
5 Palladium	1.6831E-05	1.4503E-04	1.4503E-04	5.2135E-05	1.6380E-04	1.1426E-04
6 Sliver	6.5798E-04	5.2912E-03	5.6696E-03	2.0382E-03	6.3888E-03	4.4667E-03
7 Tin	3.4870E-03	2.6387E-02	3.0047E-02	1.0801E-02	3.3858E-02	2.3672E-02
8 Bass	1.0639E-03	8.0507E-03	9.1674E-03	3.2956E-03	1.0330E-02	7.2224E-03
9 Gold	5.6327E-04	4.2623E-03	4.8535E-03	1.7448E-03	5.4692E-03	3.8238E-03
10 Plastic	1.9443E-02	1.4712E-01	1.6753E-01	6.0226E-02	1.8878E-01	1.3199E-01
11 Aluminum	4.7830E-03	3.6194E-02	4.1214E-02	1.4816E-02	4.6442E-02	3.2470E-02
12 Chemicals (organic)	2.2956E-02	1.7371E-01	1.9781E-01	7.1109E-02	2.2290E-01	1.5584E-01
13 Lead	1.9414E-03	1.4690E-02	1.6728E-02	6.0135E-03	1.9229E-02	1.3179E-02
14 Molybdenum	1.7598E-04	1.3316E-03	1.5164E-03	5.4511E-04	1.7087E-03	1.1946E-03
15 Zinc	3.6344E-04	2.7502E-03	3.1316E-03	1.1258E-03	3.5289E-03	2.4672E-03
16 Iron	2.9743E-04	2.2507E-03	2.5629E-03	9.2131E-04	2.8879E-03	2.0191E-03
17 Chromium	5.7116E-06	4.3221E-05	4.9216E-05	1.7692E-05	5.5458E-05	3.8774E-05

Table A-5 Components of battery pack from Battery [Adapted from ecoinvent 2.1 database]

Material/ Model	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
1 Fe	3.068806402	2.33768708	2.196270609	2.991161478	4.05150141	2.645415453
2 Plastic	1.229224773	0.936371505	0.879726476	1.198123735	1.622847863	1.059633546
3 Chemicals (inorganic)	3.751550857	4.007635644	2.684894323	3.656631581	4.95287471	3.10384156
4 Aluminum	5.758605262	4.386662225	4.121294676	5.612904815	7.602629274	4.96411352
5 Chemicals (organic)	2.676318693	2.038706524	1.915376637	2.608604236	3.533331062	2.307077704
6 Copper	2.462735624	2.637765721	2.478196237	3.375123762	4.571574891	2.984995835

Table A-6 Result of average material of regular phones

Material/ Model	Model (1)	Model (2)	Model (3)	SD	Average	Average from models
1 Mobile phone Casing						
1.1 Plastic	3.3255E+01	2.8597E+01	9.3996E+00	1.2644E+01	3.0926E+01	1,2
1.2 Aluminum	0.0000E+00	1.7260E-01	8.9970E-01	4.7748E-01	3.5743E-01	
1.3 Iron	1.2000E+00	8.9950E-01	9.1720E-01	1.6862E-01	1.0056E+00	
1.4 Rubber	1.9288E+00	1.4587E+00	1.3875E+00	2.9413E-01	1.5917E+00	
2.Charger Casing						
2.1 Iron	3.0827E+00	8.0900E-02	1.9553E+00	1.5163E+00	2.5190E+00	1,3
2.2 Copper	2.3600E-02	0.0000E+00	0.0000E+00	1.3625E-02	7.8667E-03	
2.3 Gold	3.0000E-03	0.0000E+00	0.0000E+00	1.7321E-03	1.0000E-03	
2.4 Zinc	0.0000E+00	1.7670E-01	6.9912E+00	3.9863E+00	8.8350E-02	1,2
2.5 Plastic	5.6549E+00	1.5824E+01	1.0684E+01	5.0845E+00	8.1696E+00	1,3
2.6 Rubber	5.6190E-01	0.0000E+00	7.9900E-02	3.0398E-01	2.1393E-01	
2.7 Paper	4.0530E-01	1.8220E-01	0.0000E+00	2.0299E-01	1.9583E-01	
3. Charger						
3.1 Chemical (inorganic)	2.7808E+00	3.4649E+00	2.0306E+00	7.1738E-01	2.7588E+00	
3.2 Copper	1.6017E+00	1.9436E+00	1.9120E+00	1.8893E-01	1.8191E+00	
3.3 Glass	1.3973E-01	1.7891E-01	1.4875E-01	2.0516E-02	1.5579E-01	
3.4 Nickel	3.4906E-01	6.7711E-01	3.4319E-01	1.9112E-01	4.5646E-01	
3.5 Palladium	3.9588E-03	3.9182E-03	4.0178E-03	5.0104E-05	3.9649E-03	
3.6 Sliver	1.5716E-02	2.9066E-01	1.5904E-01	1.3751E-01	1.5514E-01	
3.7 Tin	1.1904E+00	8.4970E-01	8.6800E-01	1.9164E-01	9.6937E-01	
3.8 Bass	2.5026E-01	2.4771E-01	2.6517E-01	9.4329E-03	2.5438E-01	
3.9 Gold	1.3283E-01	1.3764E-01	1.4076E-01	3.9911E-03	1.3708E-01	
3.10 Plastic	1.1399E+01	1.1321E+01	8.4581E+00	1.6761E+00	1.1360E+01	1,2

3.11 Aluminum	7.0888E+00	1.4310E+00	5.0050E+00	2.8614E+00	6.0469E+00	1,3
3.12 Chemical (organic)	5.4299E+00	5.6438E+00	5.7541E+00	1.6484E-01	5.6093E+00	
3.13 Lead	4.9999E-02	4.8017E-01	5.2541E-01	2.6240E-01	3.5186E-01	
3.14 Molybdenum	4.1392E-02	4.0967E-02	4.3859E-02	1.5611E-03	4.2073E-02	
3.15 Zinc	8.5726E-02	8.9158E-02	9.0839E-02	2.6060E-03	8.8575E-02	
3.16 Fe	9.7480E-01	5.7158E+00	3.7754E+00	2.3835E+00	4.7456E+00	2,3
3.17 Chromium	4.7325E-01	8.9121E-01	5.1180E-01	2.3099E-01	6.2542E-01	
3.18 Rubber	1.6361E-02	6.9052E-02	1.7694E-02	3.0044E-02	3.4369E-02	
3.19 Paper	0.0000E+00	9.6480E-01	7.2750E-01	5.0273E-01	5.6410E-01	
4. Battery						
4.1 Chemical (inorganic)	3.7524E+00	4.0804E+00	2.7576E+00	6.8881E-01	3.5301E+00	
4.2 Copper	2.4681E+00	2.6841E+00	2.5245E+00	1.1203E-01	2.5589E+00	
4.3 Glass	4.0134E-04	3.4583E-03	3.4583E-03	1.7649E-03	2.4393E-03	
4.4 Nickel	1.4836E-03	1.2784E-02	1.2784E-02	6.5241E-03	9.0170E-03	
4.5 Palladium	1.6831E-05	1.4503E-04	1.4503E-04	7.4014E-05	1.0229E-04	
4.6 Sliver	6.5798E-04	5.2912E-03	5.6696E-03	2.7907E-03	3.8729E-03	
4.7 Tin	3.4870E-03	2.6387E-02	3.0047E-02	1.4395E-02	1.9974E-02	
4.8 Bass	1.0639E-03	8.0507E-03	9.1674E-03	4.3918E-03	6.0940E-03	
4.9 Gold	5.6327E-04	4.2623E-03	4.8535E-03	2.3252E-03	3.2264E-03	
4.10 Plastic	4.7170E+00	3.4385E+00	2.7533E+00	9.9668E-01	3.6362E+00	
4.11 Aluminum	5.7634E+00	4.4229E+00	4.1625E+00	8.5903E-01	4.7829E+00	
4.12 Chemical (organic)	2.6993E+00	2.2124E+00	2.1132E+00	3.1368E-01	2.3416E+00	
4.13 Lead	1.9414E-03	1.4690E-02	1.6728E-02	8.0139E-03	1.1120E-02	
4.14 Molybdenum	1.7598E-04	1.3316E-03	1.5164E-03	7.2644E-04	1.0080E-03	
4.15 Zinc	3.6344E-04	2.7502E-03	3.1316E-03	1.5003E-03	2.0817E-03	
4.16 Iron	3.0691E+00	2.3399E+00	2.1988E+00	4.6708E-01	2.5360E+00	
4.17 Chromium	2.6763E+00	4.3221E-05	4.9216E-05	1.5451E+00	4.6218E-05	2,3
4.18 Rubber	3.8800E-02	0.0000E+00	0.0000E+00	2.2401E-02	1.2933E-02	

Table A-7 Result of average material of smartphones

Material/Model	Model (4)	Model (5)	Model (6)	SD	Average	Average from models
1 Mobile phone Casing						
1.1 Plastic	2.0188E+01	2.0055E+01	2.4510E+01	2.5346E+00	2.0121E+01	4,5
1.2 Aluminum	3.9077E+00	1.2553E+00	1.3448E+00	1.5062E+00	1.3001E+00	5,6
1.3 Iron	9.4300E-01	2.4603E+00	4.4910E-01	1.0481E+00	6.9605E-01	4,6
1.4 Rubber	1.0801E+00	1.1975E+00	3.2100E-01	4.7579E-01	8.6620E-01	
2 Charger casing						
2.1 Iron	1.3591E+00	2.3200E-01	1.1690E-01	6.8637E-01	5.6933E-01	
2.2 Stainless	5.1711E+00	0.0000E+00	0.0000E+00	2.9855E+00	0.0000E+00	5,6
2.3 Aluminum	0.0000E+00	1.1968E+00	2.6343E+00	1.3190E+00	1.9156E+00	5,6
2.4 Copper	5.1800E-02	1.7000E-03	0.0000E+00	2.9428E-02	1.7833E-02	
2.5 Plastic	2.5456E+01	1.3405E+01	5.8538E+00	9.8866E+00	9.6293E+00	5,6
2.6 Rubber	7.6290E-01	0.0000E+00	1.1290E-01	4.1176E-01	2.9193E-01	
2.7 Paper	4.7350E-01	6.0800E-02	1.5390E-01	2.1646E-01	2.2940E-01	
3. Charger						
3.1 Chemical (inorganic)	3.9414E+00	4.4769E+00	5.0136E+00	5.3613E-01	4.4773E+00	
3.2 Copper	2.6184E+00	1.1064E+00	1.3950E+00	8.0271E-01	1.7066E+00	
3.3 Glass	2.6826E-01	2.1857E-01	2.6309E-01	2.7319E-02	2.4997E-01	
3.4 Nickel	3.9971E-01	4.4871E-01	4.2163E-01	2.4547E-02	4.2335E-01	
3.5 Palladium	4.5303E-03	5.0876E-03	4.7793E-03	2.7915E-04	4.7991E-03	
3.6 Sliver	1.7795E-01	1.9947E-01	1.8763E-01	1.0777E-02	1.8835E-01	
3.7 Tin	1.0010E+00	1.7921E+00	3.5220E+00	1.2893E+00	1.3966E+00	4,5
3.8 Bass	2.5026E-01	2.4771E-01	2.6517E-01	9.4329E-03	2.5438E-01	
3.9 Gold	1.5284E-01	1.7110E-01	1.6111E-01	9.1457E-03	1.6168E-01	
3.10 Plastic	1.1795E+01	1.3084E+01	1.9701E+01	4.2415E+00	1.2440E+01	4,5

3.11 Aluminum	1.6642E+00	1.3300E+01	9.1852E+00	5.9002E+00	1.1242E+01	5,6
3.12 Chemical (organic)	6.2863E+00	7.0126E+00	6.8102E+00	3.7479E-01	6.7030E+00	
3.13 Lead	6.7586E-02	6.0181E-01	5.6554E-01	2.9851E-01	4.1164E-01	
3.14 Molybdenum	4.7368E-02	5.3195E-02	2.9146E-01	1.3927E-01	1.3067E-01	
3.15 Zinc	9.8680E-02	2.1111E+00	1.0742E+01	5.6541E+00	1.1049E+00	4,5
3.16 Iron	1.5491E+00	9.5830E-02	2.4539E+00	1.1896E+00	2.0015E+00	4,6
3.17 Chromium	1.6699E+00	1.1441E+00	1.5542E+00	2.7627E-01	2.7627E-01	
3.18 rubber	6.5750E-01	0.0000E+00	1.1360E+00	5.7035E-01	5.9783E-01	
3.19 Paper	6.7000E-02	2.6570E+00	2.6231E+00	1.4856E+00	2.6401E+00	5,6
4.Battery						
4.1 Chemical (inorganic)	3.6828E+00	5.0461E+00	3.1612E+00	9.7325E-01	3.9634E+00	
4.2 Copper	3.3918E+00	4.6238E+00	3.0215E+00	8.3889E-01	3.6790E+00	
4.3 Glass	1.2432E-03	4.0543E-03	2.7245E-03	1.4062E-03	2.6740E-03	
4.4 Nickel	4.5955E-03	6.9651E-02	1.0071E-02	3.6083E-02	2.8106E-02	
4.5 Palladium	5.2135E-05	1.6380E-04	1.1426E-04	5.5948E-05	1.1006E-04	
4.6 Sliver	2.0382E-03	6.3888E-03	4.4667E-03	2.1802E-03	4.2979E-03	
4.7 Tin	1.0801E-02	3.3858E-02	2.3672E-02	1.1554E-02	2.2777E-02	
4.8 Bass	3.2956E-03	1.0330E-02	7.2224E-03	3.5252E-03	6.9494E-03	
4.9 Gold	1.7448E-03	5.4692E-03	3.8238E-03	1.8664E-03	3.6792E-03	
4.10 Plastic	1.3731E+00	3.4200E+00	2.3222E+00	1.0243E+00	1.8477E+00	4,6
4.11 Aluminum	5.6277E+00	7.6491E+00	4.9966E+00	1.3856E+00	5.3122E+00	4,6
4.12 Chemical (organic)	2.6797E+00	3.7562E+00	2.4629E+00	6.9264E-01	2.9663E+00	
4.13 Lead	6.0135E-03	1.9229E-02	1.3179E-02	6.6153E-03	1.2807E-02	
4.14 Molybdenum	5.4511E-04	1.7087E-03	1.1946E-03	5.8310E-04	1.1495E-03	
4.15 Zinc	1.1258E-03	3.5289E-03	2.4672E-03	1.2042E-03	2.3739E-03	
4.16 Iron	2.9921E+00	4.0544E+00	2.6474E+00	7.3335E-01	3.2313E+00	
4.17 Chromium	1.7692E-05	5.5458E-05	3.8774E-05	1.8926E-05	4.7116E-05	5,6
4.18 Paper	3.6520E-01	4.2780E-01	1.1384E+00	4.2948E-01	6.4380E-01	

Appendix B

Appendix B: Treatment and recycling of mobile phone.

Table B-1 Results from separation parts of one mobile phone for further treatment**.**

Material/ Model	Weight	Part	Scrap for metal production	Shredder process	Plastics to incineration	PWB further treatment	Batteries further treatment	LCD incineration
1. Mobile phone Casing								
1.1 Plastic	2.5524E+01	1.3 plastic parts, outside	0	1.2762E+01	1.2762E+01	0	0	0
1.2 Aluminum	8.2874E-01	1.1 metal parts, outside	4.1437E-01	4.1437E-01	0	0	0	0.
1.3 Iron	8.5081E-01	1.1 metal parts, outside	4.2540E-01	4.2540E-01	0.0000E+00	0	0	0
1.4 Rubber	1.2289E+00	1.3 plastic parts, outside	0	6.1447E-01	6.1447E-01	0	0	0
2. Charger Casing								
2.1 Iron	1.5442E+00	1.2 metal parts, inside	0	1.5442E+00	0	0	0	0
2.2 Copper	1.2850E-02	1.2 metal parts, inside	0	1.2850E-02	0	0	0	0
2.3 Aluminum	9.5778E-01	1.2 metal parts, inside	0	9.5778E-01	0	0	0	0

2.3 Gold	5.0000E-04	1.2 metal parts, inside	0	5.0000E-04	0	0	0	0
2.4 Zinc	4.4175E-02	1.2 metal parts, inside	0	4.4175E-02	0	0	0	0
2.5 plastic	8.8994E+00	1.4 plastic parts, inside	0	8.8994E+00	0	0	0	0
2.6 Rubber	2.5293E-01	1.4 plastic parts, inside	0	2.5293E-01	0	0	0	0
2.7 Paper	2.1262E-01	1.4 plastic parts, inside	0	2.1262E-01	0	0	0	0
1. Charger								
3.1 PWB		3.1 high quality, mounted						
3.1.1 Chemicals (inorganic)	1.9955E+00		0	9.9773E-01	0	9.9773E-01	0	0
3.1.2 Copper	1.0133E+00		0	5.0667E-01	0	5.0667E-01	0	0
3.1.3 Glass	1.0515E-01		0	5.2573E-02	0	5.2573E-02	0	0
3.1.4 Nickel	4.3938E-01		0	2.1969E-01	0	2.1969E-01	0	0
3.1.5 Palladium	4.3820E-03		0	2.1910E-03	0	2.1910E-03	0	0
3.1.6 Sliver	1.7054E-01		0	8.5270E-02	0	8.5270E-02	0	0
3.1.7 Tin	9.1345E-01		0	4.5672E-01	0	4.5672E-01	0	0
3.1.8 Bass	2.7923E-01		0	1.3962E-01	0	1.3962E-01	0	0
3.1.9 Gold	1.4764E-01		0	7.3821E-02	0	7.3821E-02	0	0
3.1.10 Plastic	5.0976E+00		0	2.5488E+00	0	2.5488E+00	0	0
3.1.11 Aluminum	1.2537E+00		0	6.2684E-01	0	6.2684E-01	0	0
3.1.12 Chemicals (organics)	6.0170E+00		0	3.0085E+00	0	3.0085E+00	0	0

3.1.13 Lead	3.6868E-01		0	1.8434E-01	0	1.8434E-01	0	0
3.1.14 Molybdenum	4.6125E-02		0	2.3063E-02	0	2.3063E-02	0	0
3.1.15 Zinc	9.5260E-02		0	4.7630E-02	0	4.7630E-02	0	0
3.1.16 Iron	1.8925E-01		0	9.4623E-02	0	9.4623E-02	0	0
3.1.17 Chromium	1.4971E-03		0	7.4854E-04	0	7.4854E-04	0	0
3.2 LCD		6.2 LCD module						
3.2.1 Al	1.9520E-01		0	0	0	0	0	1.9520E-01
3.2.2 Chemicals (inorganic)	1.6226E+00		0	0	0	0	0	1.6226E+00
3.2.3 Chemical (organic)	1.0721E-01		0	0	0	0	0	1.0721E-01
3.2.4 Chromium	1.0392E+00		0	0	0	0	0	1.0392E+00
3.2.5 Copper	7.3882E-01		0	0	0	0	0	7.3882E-01
3.2.6 Lead	1.2322E-02		0	0	0	0	0	1.2322E-02
3.2.7 Mercury	1.4291E-05		0	0	0	0	0	1.4291E-05
3.2.8 Plastics	4.1163E+00		0	0	0	0	0	4.1163E+00
3.2.9 Rubber	3.6030E-02		0	0	0	0	0	3.6030E-02
3.2.10 Gold	1.7377E-03		0	0	0	0	0	1.7377E-03
3.2.11 Nickel	5.2677E-04		0	0	0	0	0	5.2677E-04
3.2.12 Sliver	1.2045E-03		0	0	0	0	0	1.2045E-03
3.2.13 Tin	9.8161E-03		0	0	0	0	0	9.8161E-03
3.2.14 Zinc	1.2141E-03		0	0	0	0	0	1.2141E-03
3.2.15 Glass	9.7737E-02		0	0	0	0	0	9.7737E-02
3.2.16 Iron	7.4843E-01		0	0	0	0	0	7.4843E-01
3.2.17 Bass	4.0611E-05		0	0	0	0	0	4.0611E-05
3.3 Aluminum	7.1918E+00	1.2 metal parts, inside	0	7.1918E+00	0	0	0	0

3.4 Plastic	2.7018E+00	1.4 plastic parts, inside	0	2.7018E+00	0	0	0	0
3.5 Tin	2.5879E-01	1.2 metal parts, inside	0	2.5879E-01	0	0	0	0
3.6 Iron	2.0288E+00	1.2 metal parts, inside	0	2.0288E+00	0	0	0	0
3.7 Copper	1.0700E-02	1.2 metal parts, inside	0	1.0700E-02	0	0	0	0
3.8 Zinc	5.0018E-01	1.2 metal parts, inside	0	5.0018E-01	0	0	0	0
3.9 Rubber	3.1610E-01	1.4 plastic parts, inside	0	3.1610E-01	0	0	0	0
3.10 Paper	1.6021E+00	1.4 plastic parts, inside	0	1.6021E+00	0	0	0	0
2. Battery								
4.1 PWB		3.1 high quality, mounted						
4.1.1 Chemicals (inorganic)	5.3855E-02		0	2.6928E-02	0	2.6928E-02	0	0
4.1.2 Copper	3.3914E-02		0	1.6957E-02	0	1.6957E-02	0	0
4.1.3 Glass	2.5566E-03		0	1.2783E-03	0	1.2783E-03	0	0
4.1.4 Nickel	1.8562E-02		0	9.2808E-03	0	9.2808E-03	0	0
4.1.5 Palladium	1.0618E-04		0	5.3089E-05	0	5.3089E-05	0	0
4.1.6 Sliver	4.0854E-03		0	2.0427E-03	0	2.0427E-03	0	0
4.1.7 Tin	2.1375E-02		0	1.0688E-02	0	1.0688E-02	0	0
4.1.8 Bass	6.5217E-03		0	3.2608E-03	0	3.2608E-03	0	0
4.1.9 Gold	3.4528E-03		0	1.7264E-03	0	1.7264E-03	0	0
4.1.10 Plastic	1.1918E-01		0	5.9591E-02	0	5.9591E-02	0	0

4.1.11 Aluminum	2.9320E-02		0	1.4660E-02	0	1.4660E-02	0	0
4.1.12 Chemicals (organic)	1.4072E-01		0	7.0360E-02	0	7.0360E-02	0	0
4.1.13 Lead	1.1963E-02		0	5.9817E-03	0	5.9817E-03	0	0
4.1.14 Molybdenum	1.0787E-03		0	5.3937E-04	0	5.3937E-04	0	0
4.1.15 Zinc	2.2278E-03		0	1.1139E-03	0	1.1139E-03	0	0
4.1.16 Fe	1.8232E-03		0	9.1161E-04	0	9.1161E-04	0	0
4.1.17 Chromium	3.5012E-05		0	1.7506E-05	0	1.7506E-05	0	0
4.2 Plastic	1.4909E+00	1.4 plastic parts, inside	0	1.4909E+00	0	0	0	0
4.3 paper	5.3295E-01	1.4 plastic parts, inside	0	5.3295E-01	0	0	0	0
			0					
4.4 Battery		5.1 Batteries	0					
4.4.1 Iron	2.8818E+00		0	0	0	0	2.8818E+00	0
4.4.2 Plastic	1.1543E+00		0	0	0	0	1.1543E+00	0
4.4.3Chemicals (inorganic)	3.6929E+00		0	0	0	0	3.6929E+00	0
4.4.4 Aluminum	5.4077E+00		0	0	0	0	5.4077E+00	0
4.4.5Chemicals (organic)	2.5132E+00		0	0	0	0	2.5132E+00	0
4.4.6 Copper	3.0851E+00		0	0	0	0	3.0851E+00	0
			0					
4.5 Rubber	6.4667E-03	1.4 plastic parts, inside	0	6.4667E-03	0	0	0	0
Total	1.0205E+02		8.3978E-01	5.2075E+01	1.3376E+01	9.2942E+00	1.8735E+01	8.7284E+00

Shredder Process

Table B-2: Calculation in shredder process

Input Materials	Input Weight (g)	Resulting fraction			
		Ferro	Aluminium	Copper	Residue
Aluminum	9.2054E+00	4.6027E-02	7.6019E+00	4.5291E-01	1.1047E+00
Copper	5.4718E-01	5.1430E-03	2.7359E-02	4.2795E-01	8.6727E-02
Iron	4.0939E+00	3.8893E+00	4.0940E-02	4.0939E-02	1.2282E-01
Glass	5.3851E-02	3.0200E-04	3.0160E-04	5.3850E-03	4.7869E-02
Plastics	3.2000E+01	3.8720E-01	1.6000E-01	3.2000E+00	2.8253E+01
Silver	8.7313E-02	8.6400E-04	8.6440E-04	7.4146E-02	1.1438E-02
Gold	7.6047E-02	7.5300E-04	7.5290E-04	6.0838E-02	1.3704E-02
Lead	1.9032E-01	2.2460E-03	2.2458E-03	1.5226E-01	3.3592E-02
Others	5.8213E+00	4.0167E-02	3.9003E-02	2.0543E+00	3.6878E+00
Total	5.2075E+01	4.3720E+00	7.8733E+00	6.4687E+00	3.3361E+01

Material inputs from parts of mobile phone to shredder process was multiplied by transfer coefficients for the materials flows in shedder process based on literature that it contacts with German and Dutch recycling companies can be seen in the ecoinvent report No.18 / Part V page 21 (Hischier and Gallen, 2007). **Table B-2** shows the outputs from shredder process. The material output is as shown in **Table B-3**.

Table B-3: Summary material outputs from shredder process

Material	**Amount (g)**
Iron	4.3720E+00
Aluminum	7.8733E+00
Copper	6.4687E+00
Residue	3.3361E+01
Total	5.2075E+01

PWB recycling

Table B-4 Calculation in PWB recycling process from PWB inputs 9.2942 g

Materials	% Recovery	Amount (g)
1. Secondary copper conversion		
1.1 Epoxies (co-combusted)	3.07E+01	2.85E+00
1.2 Slag, silica, at converter	3.10E+01	2.88E+00
1.3 Lead, secondary	1.60E+00	1.49E-01
2. Secondary copper refining		
2.1 Other (Al, Fe)	9.05E+00	8.41E-01
2.2 Nickel, secondary	3.34E+00	3.10E-01
2.3 Copper, secondary	1.00E+02	9.29E+00
3. Precious metal refining, secondary copper		
3.1 Palladium, secondary	3.11E-02	2.89E-03
3.2 Sliver secondary	5.61E-01	5.21E-02
3.3 Gold secondary	1.71E-02	1.59E-03
Total	1.00E+02	9.29E+00

Batteries recycling

The total weight of battery is 18.7350 g. The treatment technology to recycle Lithium ion Batteries has mixed technology between pyrometallurgical treatment (50%) and hydrometallurgical treatment (50%). So the total weight of battery to pyrometallurgical treatment is 9.3675 g and hydrometallurgical treatment is 9.3675 g.

Table 4.13: Material recovery from pyrometallurgical treatment

Metal	% Recovery	Amount (g)
1.1 Steel	2.70E+01	2.53E+00
1.2 Cobalt	1.92E+01	1.80E+00
1.3 Al	1.53E+01	1.43E+00
1.4 Cu	8.70E+00	8.17E-01
1.5 MnO_2	2.70E+01	9.37E-02

Table 4.14: Material recovery from hydrometallurgical treatment

Metal	% Recovery	Amount (g)
2.1 Co	3.40E+01	3.18E+00
2.2 Li salt	1.98E+01	1.85E+00
2.3 Steel	1.65E+01	1.55E+00
2.4 Al	9.55E+00	8.95E-01
2.5 Cu	5.45E+00	5.10E-01

Appendix C

Appendix C: The questionnaire used in the study

แบบสอบถาม

พฤติกรรมการใช้และข้อคิดเห็นเกี่ยวกับการจัดการขยะโทรศัพท์มือถือ

คำชี้แจง

แบบสอบถามนี้เป็นส่วนหนึ่งของการศึกษาของนิสิตปริญญาโท หลักสูตรวิทยาศาสตร์มหาบัณฑิต สาขาการจัดการสิ่งแวดล้อม จุฬาลงกรณ์มหาวิทยาลัย โดยทำวิจัยเรื่อง การประเมินผลกระทบสิ่งแวดล้อมและแนวทางการจัดการสำหรับโทรศัพท์มือถือที่สิ้นสุดอายุการใช้งานในประเทศไทย โดยมีวัตถุประสงค์เพื่อที่จะเสนอแนวทางในการจัดการปัญหาขยะโทรศัพท์มือถือที่เหมาะสม ซึ่งจะสามารถช่วยลดปัญหาผลกระทบทางสิ่งแวดล้อมได้

แบบสอบถามประกอบด้วย 5 ส่วนดังนี้ คือ

ส่วนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

ส่วนที่ 2 พฤติกรรมการใช้และการจัดการโทรศัพท์มือถือ

ส่วนที่ 3 ความเข้าใจเกี่ยวกับสถานการณ์ปัญหาขยะมือถือ

ส่วนที่ 4 ข้อคิดเห็นเกี่ยวกับการจัดการขยะโทรศัพท์มือถือ

ส่วนที่ 5 ข้อเสนอแนะเกี่ยวกับการจัดการขยะโทรศัพท์มือถือ

แบบสอบถามนี้มีทั้งหมด 3 หน้า โดยให้ท่านทำเครื่องหมาย ⁄ ลงในช่อง ☐ ที่ท่านเลือกหรือเติมข้อความลงในช่องว่างตามความจริงให้มากที่สุด

ผู้วิจัยขอความกรุณาจากผู้ตอบแบบสอบถาม โปรดตอบแบบสอบถามทุกข้อ เพื่อความสมบรูณ์ในการประกอบงานวิจัยและการศึกษาต่อไป สำหรับข้อมูลที่ท่านตอบผู้วิจัยของรับรองว่าจะไม่มีผลกระทบหรือเกิดความเสียหายต่อผู้ตอบแบบสอบถาม แต่ประการใดโดยมีวัตถุประสงค์เพียงเพื่อนำไปใช้ประกอบการวิจัยเท่านั้น และผู้วิจัยขอขอบพระคุณเป็นอย่างสูงในความร่วมมือของท่านไว้ ณ โอกาสนี้ด้วย

ผู้วิจัย

<u>คำชี้แจง</u> **ส่วนที่ 1 – 3 ให้ท่านทำเครื่องหมาย / ลงในช่อง ☐ ที่ท่านเลือก**

1. ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

1.1 เพศ ☐ ชาย ☐ หญิง

1.2 อายุ ☐ ต่ำกว่า 20 ปี ☐ 20 - 30 ปี ☐ 31- 40 ปี

☐ 41- 50 ปี ☐ 51- 60 ปี ☐ มากกว่า 60 ปี

1.3 ระดับการศึกษาสูงสุด ☐ ประถมศึกษา ☐ มัธยมศึกษา ☐ อนุปริญญา / ปวส.

☐ ปริญญาตรี ☐ ปริญญาโท ☐ ปริญญาเอก

☐ อื่นๆ (ระบุ)......................

1.4 รายได้ในแต่ละเดือน ☐ ต่ำกว่า 10,000 บาท ☐ 10,000 – 30,000 บาท

☐ 30,000 – 50,000 บาท ☐ 50,000 บาท ขึ้นไป

1.5 อาชีพ ☐ นักเรียน/นักศึกษา ☐ ลูกจ้างชั่วคราว ☐ พนักงานบริษัทเอกชน

☐ ข้าราชการ/พนักงานรัฐวิสาหกิจ ☐ ธุรกิจส่วนตัว ☐ อื่นๆ (ระบุ)..................

2. พฤติกรรมการใช้และการจัดการโทรศัพท์มือถือ

2.1 ปัจจุบันท่านใช้โทรศัพท์มือถืออยู่จำนวนกี่เครื่อง

☐ 1 เครื่อง ☐ 2 เครื่อง ☐ 3 เครื่อง ☐ มากกว่า 3 เครื่อง ☐ อื่นๆ (ระบุ).........

2.2 ท่านมีความถี่ในการเปลี่ยนโทรศัพท์เป็นเครื่องใหม่ บ่อยแค่ไหน

☐ 6 เดือนครั้ง ☐ 1ปีครั้ง ☐ 2 ปีครั้ง ☐ 3 ปีครั้ง ☐ 5 ปีครั้ง ☐ อื่นๆ (ระบุ).....

2.3 สาเหตุที่ท่านเปลี่ยนโทรศัพท์มือถือหรือ ซื้อโทรศัพท์มือถือเครื่องใหม่

☐ เมื่อเครื่องของท่านชำรุดและไม่สามารถซ่อมแซมได้ ☐ เมื่อมีเทคโนโลยีใหม่ๆ ออกมาจำหน่าย

☐ เมื่อท่านรู้สึกเครื่องที่ท่านใช้ไม่สามารถตอบสนองประโยชน์การใช้งานได้ครบ ☐ อื่น ๆ (ระบุ).......

2.4 โทรศัพท์มือถือที่ท่านไม่ใช้งานแล้วท่านมีการจัดการอย่างไร

☐ เก็บไว้ที่บ้านเฉยๆ ☐ ทิ้งรวมกับขยะทั่วไปจากบ้านเรือน ☐ นำไปขายให้กับร้านโทรศัพท์มือถือ

☐ นำไปใส่กล่องรับบริจาคเพื่อนำไปกำจัด ☐ อื่นๆ (ระบุ) ....

3. ความเข้าใจเกี่ยวกับสถานการณ์ปัญหาขยะมือถือ

3.1 ในประเทศเทศไทยในแต่ละปีจะมีปริมาณขยะมือถือที่เพิ่มมากขึ้นทุกปี และอายุการใช้งานโดยเฉลี่ยของโทรศัพท์มือถือ 1 เครื่อง ของคนในประเทศ ก็มีแนวโน้มลดลงเรื่อย ☐ ทราบ ☐ ไม่ทราบ

3.2 โทรศัพท์ที่ไม่ได้ใช้งานแล้วจะกลายมาเป็นขยะที่มีสารพิษหรือสารอันตรายอยู่ถ้านำไปจัดการไม่ถูกต้อง โดยจะมีสารจำพวกโลหะหนัก เช่น ตะกั่ว ปรอท เป็นต้น ซึ่งมีโอกาสจะปนเปื้อนสู่สิ่งแวดล้อมทำให้เป็นอันตรายต่อสิ่งมีชีวิตและระบบนิเวศน์ ☐ ทราบ ☐ ไม่ทราบ

3.3 ซากโทรศัพท์มือถือเมื่อหมดอายุการใช้งานแล้ว ถ้านำไปจัดการ โดยการคัดแยกจะทำให้ได้โลหะมีค่า ที่สามารถนำกลับมาใช้ประโยชน์ได้ เช่น ทอง เงิน ทองแดง เป็นต้น ☐ ทราบ ☐ ไม่ทราบ

3.4 ท่านคิดว่าประเทศไทยในปัจจุบันมีระบบการจัดการซากโทรศัพท์มือถืออย่างไร

☐ ไม่มีระบบการจัดการอะไรเลย ☐ มีการจัดการอย่างเป็นระบบ ☐ ไม่ทราบ ☐ อื่นๆ (ระบุ)....

<u>คำชี้แจง</u> ส่วนที่ 4 ให้ท่าน <u>เรียงลำดับตามความสำคัญ</u> โดยที่ 1 คือ สำคัญที่สุด 2, 3 , 4, ...รองลงมา

4. ข้อคิดเห็นเกี่ยวกับการจัดการขยะโทรศัพท์มือถือ

4.1 ท่านคิดว่าอะไรเป็นแรงจูงใจที่สำคัญในการจัดการปัญหาขยะโทรศัพท์มือถือ เพื่อที่จะให้คนนำมารีไซเคิลโทรศัพท์ให้มากขึ้น

☐ ความรู้ความเข้าใจกับปัญหาขยะ ☐ มีกฎหมายและระเบียบข้อบังคับ

☐ การทำแล้วได้เงินหรือผลตอบแทนคืนมา ☐ วัฒนธรรมที่ตระหนักถึงสิ่งแวดล้อม

☐ ความสะดวกของสถานที่ที่จะนำไปให้เพื่อกำจัด ☐ อื่นๆ (ระบุ).....................

4.2 สถานที่ใดที่ท่านคิดว่าน่าจะสะดวกในการนำโทรศัพท์มือถือมารีไซเคิล

☐ ห้างสรรพสินค้า ☐ ที่หน้าบ้าน ☐ ร้านค้าปลีก/ซ่อมโทรศัพท์มือถือ

☐ ร้านสะดวกซื้อ/ร้านซุปเปอร์มาเก็ต ☐ หน่วยงานราชการ

☐ สถานที่รถขนส่งสาธารณะ เช่น BTS/MRT/ป้ายรถเมล์ ☐ อื่นๆ (ระบุ).....................

4.3 หากภาครัฐจะมีระบบการจัดการขยะโทรศัพท์ท่านคิดว่าวิธีการใดที่ท่านจะสนใจมากที่สุด

☐ การเก็บค่าธรรมเนียมรวมกับค่าของผลิตภัณฑ์ ☐ การจ่ายค่าทิ้งเมื่อจะทิ้งขยะโทรศัพท์มือถือ

☐ การนำขยะโทรศัพท์มาเป็นส่วนลดซื้อเครื่องใหม่/ได้เงินตอบแทน ☐ การบริจาคให้รัฐนำไปกำจัด

☐ ออกกฎหมายบังคับห้ามทิ้งและให้นำมาสู่ระบบจัดการที่เหมาะสม ☐ อื่น ๆ (ระบุ)..............

4.4 หากภาครัฐมีการตั้งศูนย์เพื่อรวบรวมขยะโทรศัพท์มือถือท่านคิดว่าภาครัฐควรดำเนินการอย่างไรต่อประชาชนในการนำขยะโทรศัพท์มายังศูนย์รวบรวม

☐ เป็นไปโดยความสมัครใจ ☐ ใช้กฎหมายหรือนโยบายบังคับ

☐ มีการให้ผลตอบแทน ☐ อื่น ๆ(ระบุ).................

5. ข้อเสนอแนะเพิ่มเติมเกี่ยวกับการจัดการขยะโทรศัพท์มือถือต่อหน่วยงาน ภาครัฐหรือภาคเอกชนที่เกี่ยวข้องในการจัดการปัญหาขยะโทรศัพท์มือถือ ท่านคิดว่าควรทำอย่างไรเพื่อการแก้ไขปัญหาในอนาคตจะเป็นไปได้อย่างมีประสิทธิภาพ

....
....

ขอขอบพระคุณทุกท่านที่ให้ความร่วมมือในการตอบแบบสอบถาม

Questionnaires (English)

<u>Explanation</u> **Section 1-3, you marked / in ☐ that you selected.**

1. General information of the respondents

1.1 Sex ☐ Male ☐ Female

1.2 Age ☐ Less than 20 years ☐ 20 - 30 years ☐ 31- 40 years
☐ 41- 50 years ☐ 51- 60 years ☐ More than 60 years

1.3 Education background ☐ Elementary education ☐ Secondary education
☐ Diploma ☐ Undergraduate
☐ Graduate ☐ Ph.D. ☐ Other (specify)……

1.4 Income each month ☐ Less than 10,000 bath ☐ 10,000 to 30,000 baht
☐ 30,000 to 50,000 baht ☐ More than 50,000 bath

1.5 Career ☐ Students ☐ Officers/Employees
☐ Employees of private companie ☐ Casual worker
☐ Private business ☐ Other (specify)……...

2. Behavior and Management for end of life of mobile phone

2.1 How many units of mobile phones are you currently using?

☐ 1 unit ☐ 2 units ☐ 3 units
☐ More than 3 units ☐ Other (specify)….........................

2.2 How often you change new phone?

☐ Every 6 months ☐ Every 1 year ☐ Every 2 years
☐ Every 3 years ☐ Every 5 years ☐ Other (specify)……................

2.3 What is a cause you change or buy new phone?

☐ Phone was damaged and could not be repaired ☐ New technology is released
☐ Phone is not able to response your requirements ☐ Other (specify)…….......

2.4 How management for end of life of mobile phone?

☐ Kept at home ☐ Disposed with municipal wastes

☐ Re-sold at mobile phone shop ☐ Bring to donation box to disposal

☐ Other (specify)…….................

3. Understanding the situation of the mobile phone waste problems

3.1 Do you know mobile phone wastes that increase every year and average lifespan of mobile phone tended to decline steadily? ☐ Know ☐ Did not know

3.2 Do you know mobile phone wastes are contained with hazardous substances including lead, mercury, if the management is not effective, the hazardous substances can contaminate into the environment and pose a risk to human health and ecosystems? ☐ Know ☐ Did not know

3.3 Do you know mobile phone wastes are contained with precious metals which proper recycling processes could recovery to gain profits such as gold, silver and copper? ☐ Know ☐ Did not know

3.4 Do you think about mobile phone wastes management in Thailand?

☐ No management at all ☐ Managed in systematic way

☐ Did not know ☐ Other (specify)…….......

Explanation **Section 4,** there are options that respondents rank from the most preferred to least options by 1 is most preferred 2, 3, 4, ……. respectively.

4. Opinion about mobile phone waste management

4.1 Do you think major motivations to mobile phone wastes management for the public to recycle of mobile phone wastes?

☐ Increase the understanding of mobile phone wastes

☐ Set up laws and regulations to mandate recycle e-wastes

☐ Obtaining money or benefits from recycling

☐ Increase public awareness on environmental value

☐ Convenience of the location for drop off

☐ Other (specify)………....

4.2 Where is the place you think to bring mobile phone wastes to send in recycling?

☐ Department store ☐ At home ☐ Mobile phone shop/ Repair shop

☐ Convenience store ☐ Government agency

☐ Public transport such as BTS/MRT/Bus stop etc. ☐ Other (specify)………....

4.3 What policy public is most interested for managing mobile phone waste?

☐ Charge recycling fee by including in the cost of products

☐ Paying for mobile phone waste management when disposal

☐ Provide a discount on the purchase for a new mobile phone in return

☐ Donation to government agency to recycling

☐ Law and regulations

☐ Other (specify)………....

4.4 What is government action to generate public incentive to take mobile phone wastes to collection center?

☐ Voluntary ☐ Laws and regulations

☐ Obtaining money or benefit ☐ Other (specify)………....

5. Suggestions and comment about improvement mobile phone waste management in the country to government agency or private sector in the future.

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

Thank you for participation in questionnaires survey

Online survey

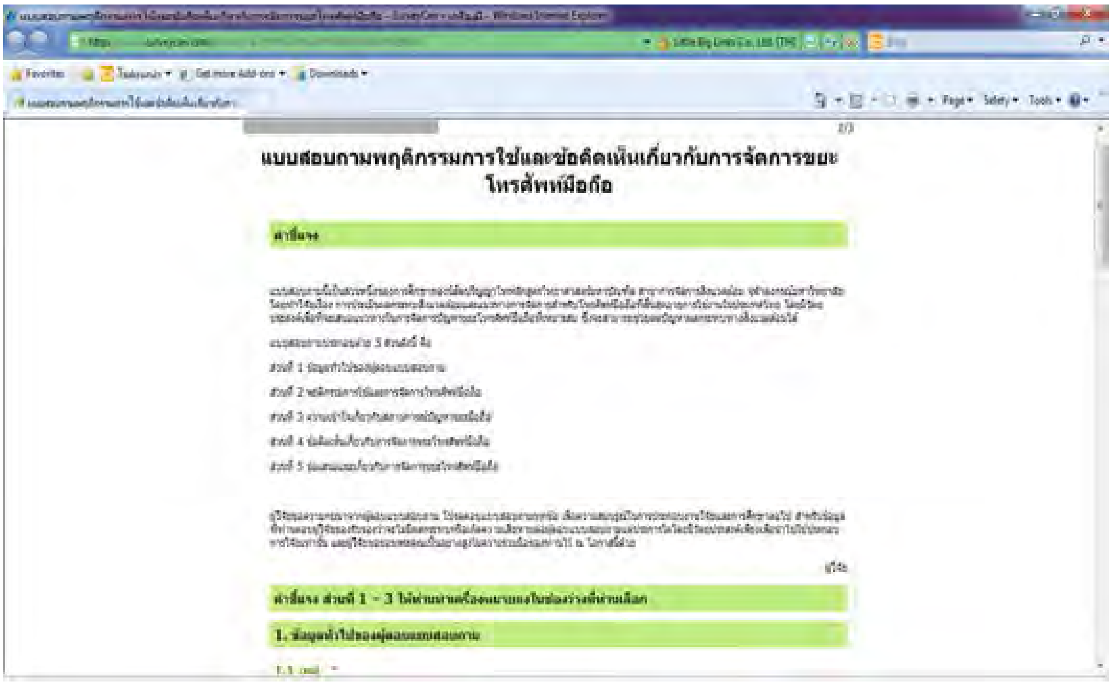


Figure C-1: Questionnaires in online survey

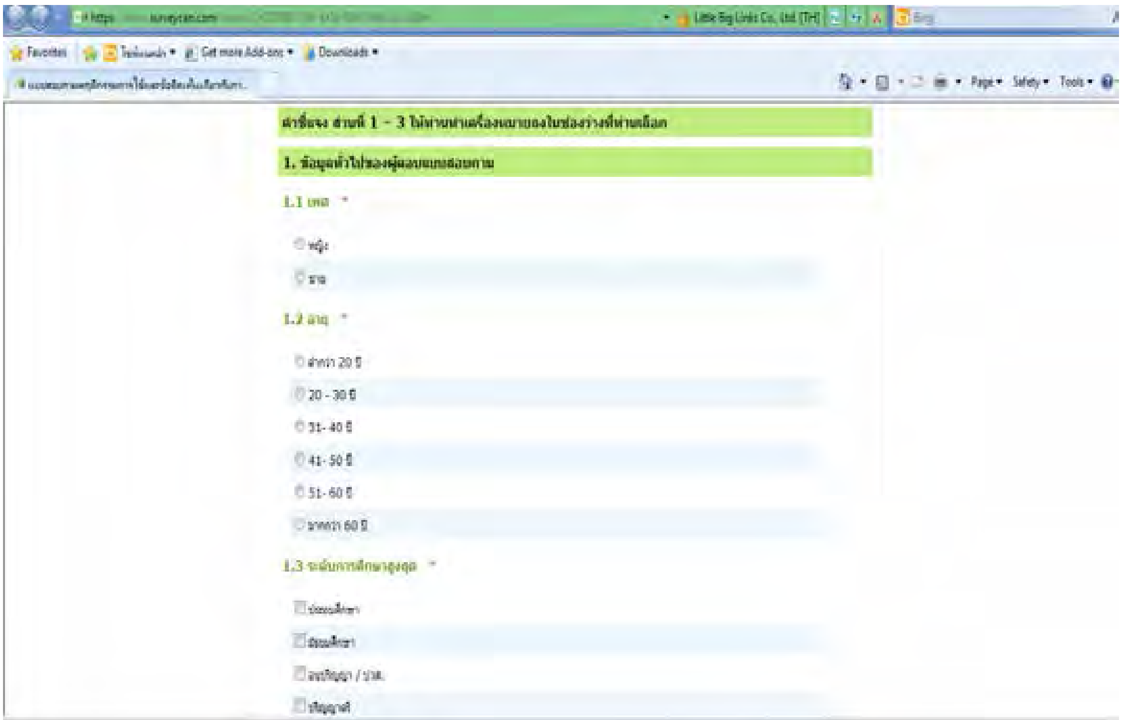


Figure C-2: Questionnaires in online survey

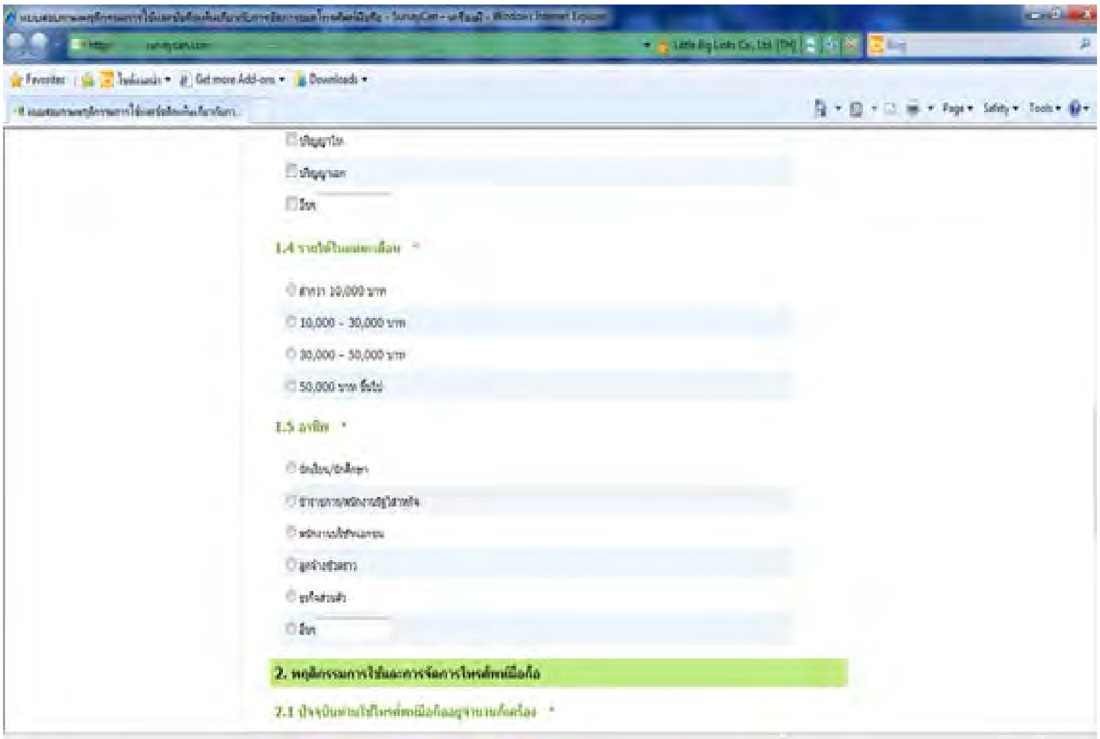


Figure C-3: Questionnaires in online survey

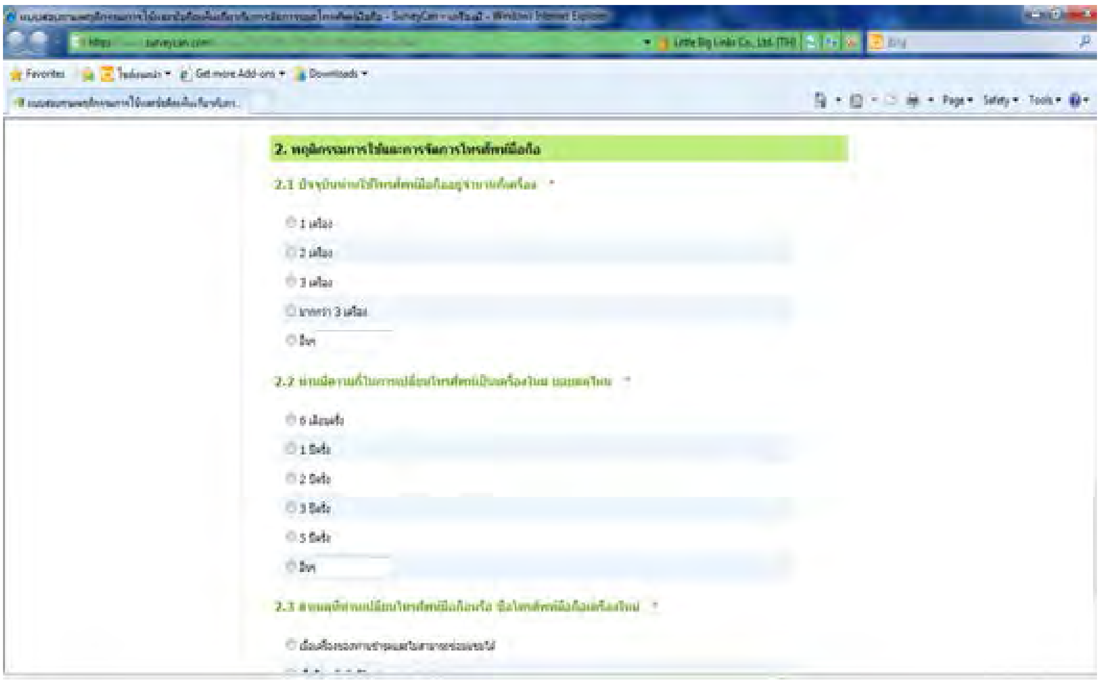


Figure C-4: Questionnaires in online survey

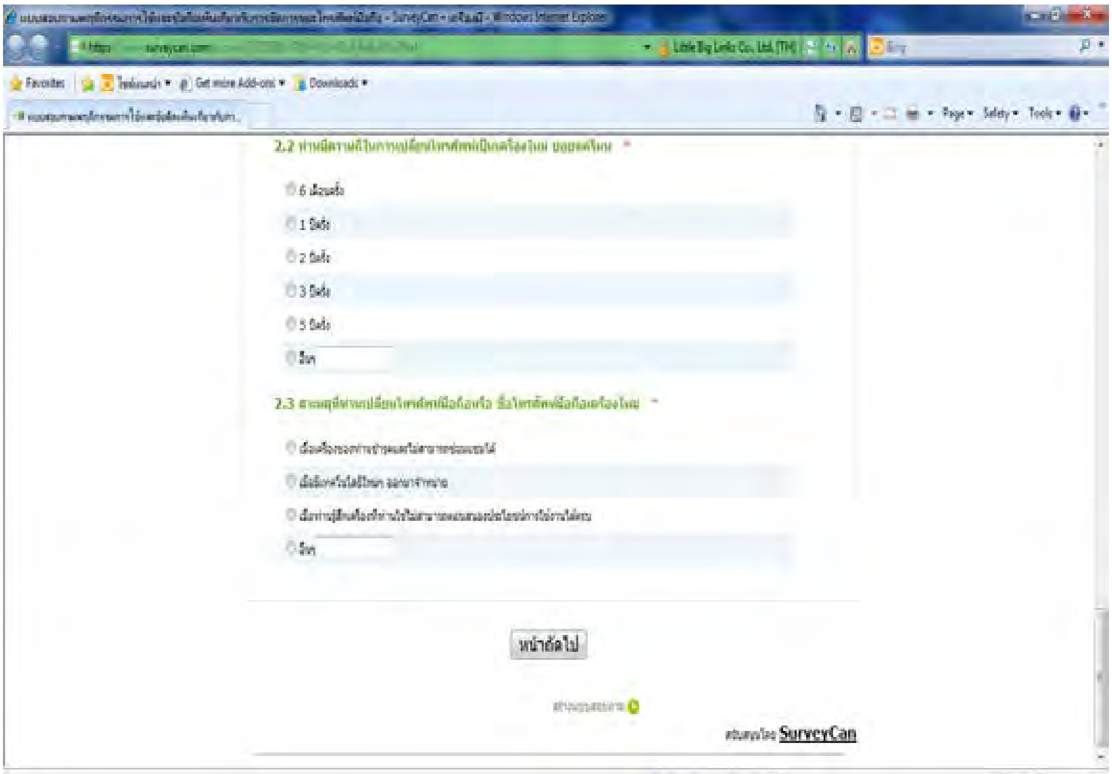


Figure C-5: Questionnaires in online survey

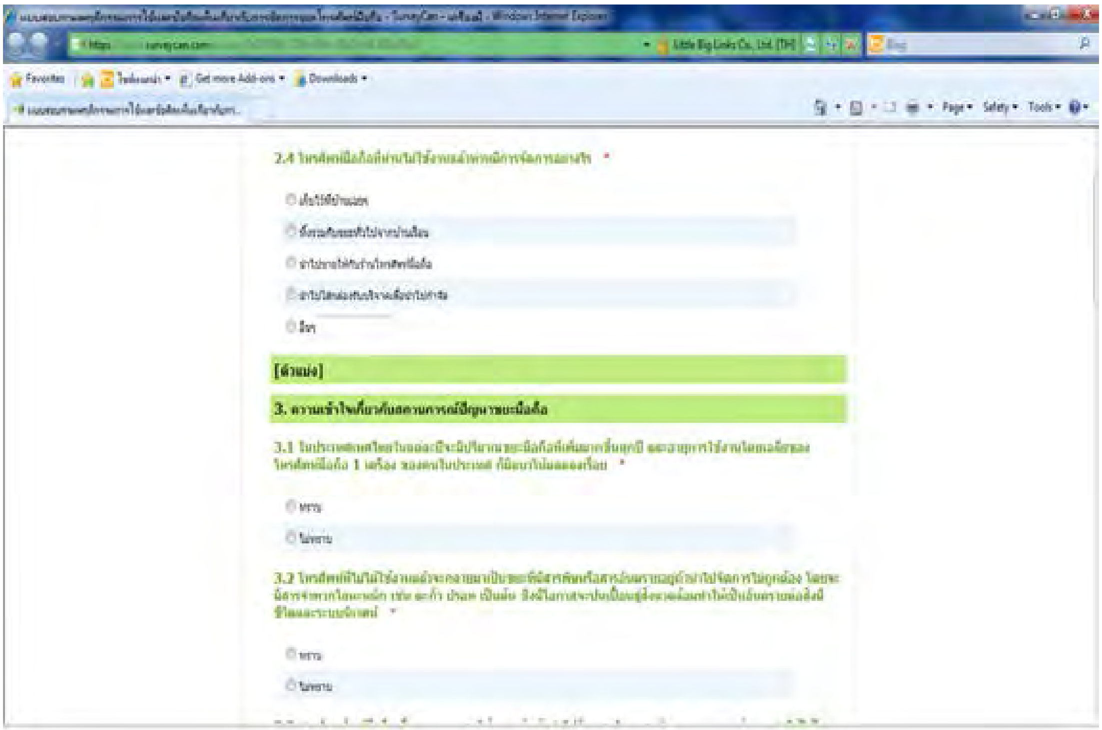


Figure C-6: Questionnaires in online survey

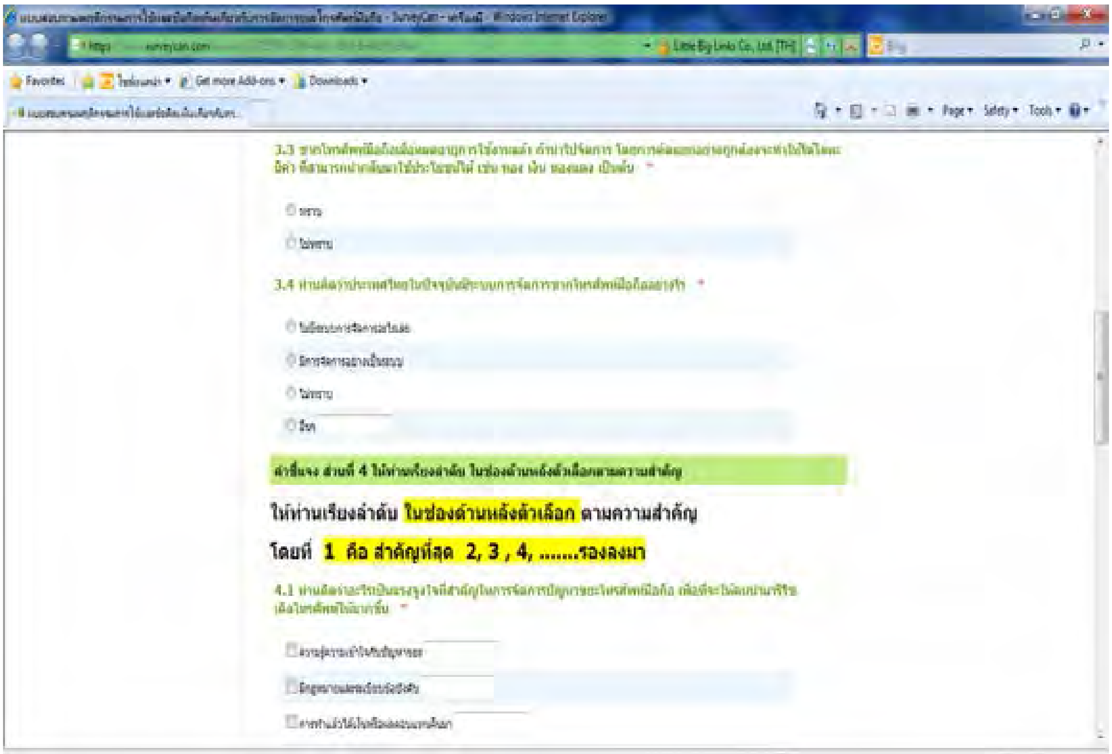


Figure C-7: Questionnaires in online survey

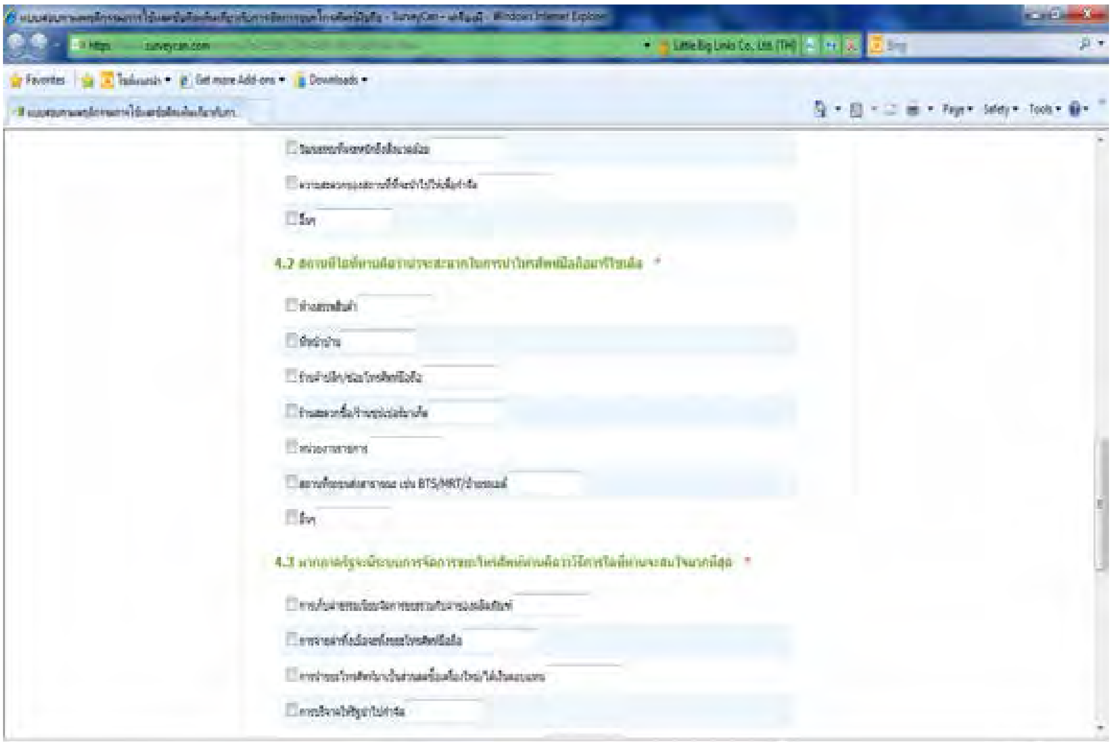


Figure C-8: Questionnaires in online survey

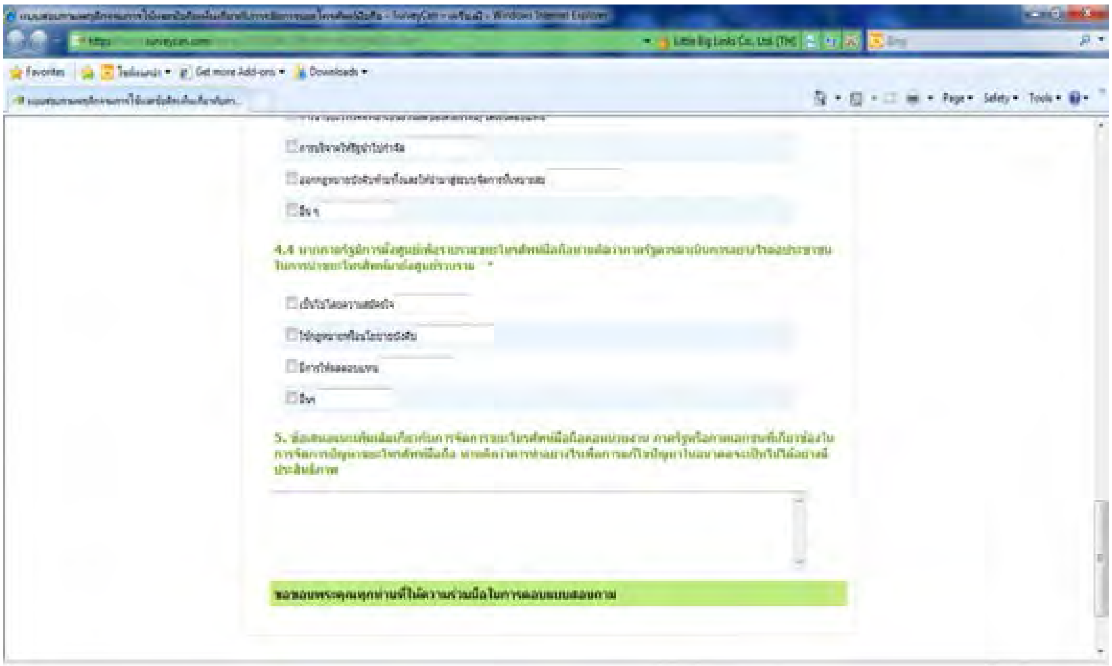


Figure C-9: Questionnaires in online survey

Appendix D

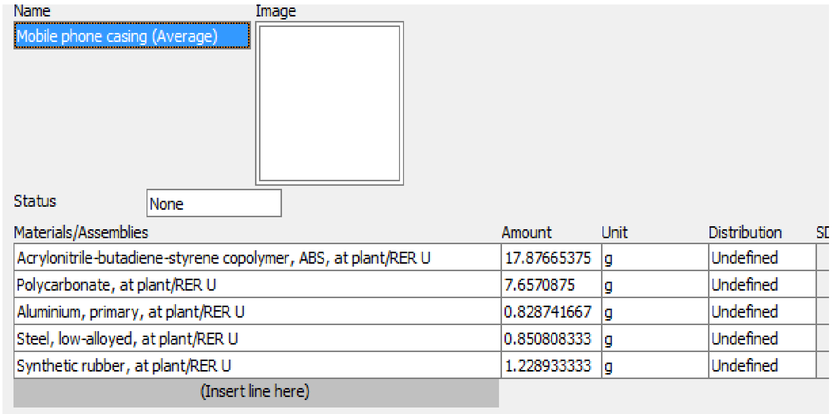
Appendix D: Analysis steps and characterization of impact categories in mid-point and end point level.

Analysis step

In this study evaluated environmental impacts by using LCA software Simapro Version 7.3.3 and expressed with ReCiPe method version 1.06, Ecoinvent 2.1 database. The detail of analysis steps as following;

1) Set life cycle inventory (LCI) of mobile phone waste in product stages of inventory

1.1 Set materials from disassembly of components in each part (mobile phone casing, charger casing, charger and battery) in assembly step of product stages

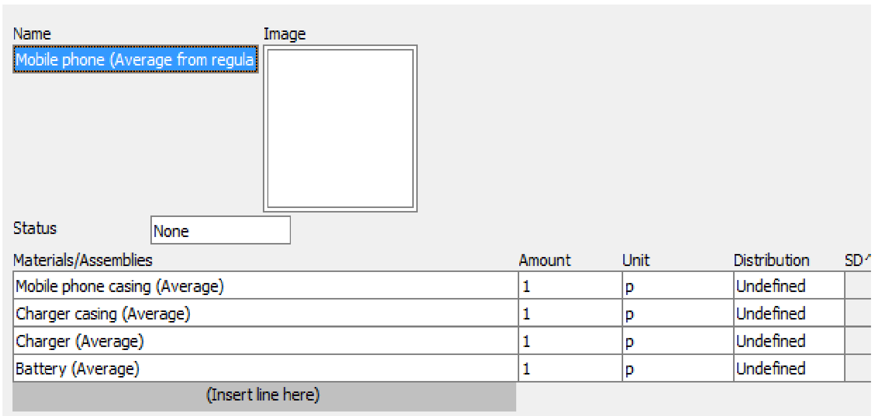


Name: Mobile phone casing (Average)
Image
Status: None

Materials/Assemblies	Amount	Unit	Distribution	SD
Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER U	17.87665375	g	Undefined	
Polycarbonate, at plant/RER U	7.6570875	g	Undefined	
Aluminium, primary, at plant/RER U	0.828741667	g	Undefined	
Steel, low-alloyed, at plant/RER U	0.850808333	g	Undefined	
Synthetic rubber, at plant/RER U	1.228933333	g	Undefined	
(Insert line here)				

Figure D-1: Materials from disassembly of components

1.2 Set mobile phone one unit from compose of 4 parts (set from 1.1) in assembly step of product stages to represent of mobile phone in management scenarios.



Name: Mobile phone (Average from regula
Image
Status: None

Materials/Assemblies	Amount	Unit	Distribution	SD
Mobile phone casing (Average)	1	p	Undefined	
Charger casing (Average)	1	p	Undefined	
Charger (Average)	1	p	Undefined	
Battery (Average)	1	p	Undefined	
(Insert line here)				

Figure D-2: Mobile phone one unit from compose of 4 parts

2) Set scenario management in processes of inventory

2.1 Set landfill system of mobile phone wastes in wastes scenario of processes

Waste specification

Name	Amount	Unit	Category	Comment
Landfill for mobile phone	102.4556905	g	Landfill	

Inputs

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD Min	Max	Comment
(Insert line here)						

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD Min	Max	Comment
(Insert line here)						

Outputs

Materials and/or waste types separated from waste stream

Waste scenario/treatment	Material / Waste type	Percentage	Comment
Disposal, steel, 0% water, to inert material landfill/CH U	All waste types	8.444790483 %	Ferro
Disposal, glass, 0% water, to inert material landfill/CH U	All waste types	0.200515889 %	Glass
Disposal, waste, Si waferprod., inorg, 9.4% water, to residual material	All waste types	7.188277812 %	Inorganic
Disposal, steel, 0% water, to inert material landfill/CH U	All waste types	23.62579075 %	Non Ferro
Disposal, emulsion paint, 0% water, to sanitary landfill/CH U	All waste types	8.598927401 %	Organic
Disposal, paper, 11.2% water, to sanitary landfill/CH U	All waste types	2.291372646 %	Paper
Disposal, plastic plaster, 0% water, to sanitary landfill/CH U	All waste types	47.88913977 %	Plastics
Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	All waste types	1.761185254 %	Rubber
(Insert line here)			

Figure D-3: Landfill system of mobile phone wastes

2.2 Set recycling system of mobile phone wastes in wastes scenario of processes

Waste specification

Name	Default material / waste type	Amount	Unit
Recycling mobile phone	All waste types	102.4556905	g

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 o
Steel, low-alloyed, at plant/RER U	4.43950476	g	Undefined	
Steel, low-alloyed, at plant/RER U	4.459851465	g	Undefined	
Lead, primary, at plant/GLO U	0.148706921	g	Undefined	
Aluminium, primary, at plant/RER U	11.04937211	g	Undefined	
Tin, at regional storage/RER U	0.326069432	g	Undefined	
Nickel, 99.5%, at plant/GLO U	0.310397814	g	Undefined	
Copper, primary, at refinery/RER U	10.01296111	g	Undefined	
Silver, at regional storage/RER U	0.052148879	g	Undefined	
Palladium, primary, at refinery/RU U	0.002887723	g	Undefined	
Gold, primary, at refinery/GLO U	0.001585417	g	Undefined	
Cobalt, at plant/GLO U	4.983519563	g	Undefined	
Lithium chloride, at plant/GLO U	1.854768559	g	Undefined	
(Insert line here)				

Figure D-4: Recycling system of mobile phone wastes

2.3 Set scenario analysis for mobile phone wastes in in product stages of inventory

Set system scenario analysis by referring to assembly of one mobile phone (from 1.2) and waste scenario (from 2). Percentage of waste scenario depended on condition in scenario management (landfill/ recycling).

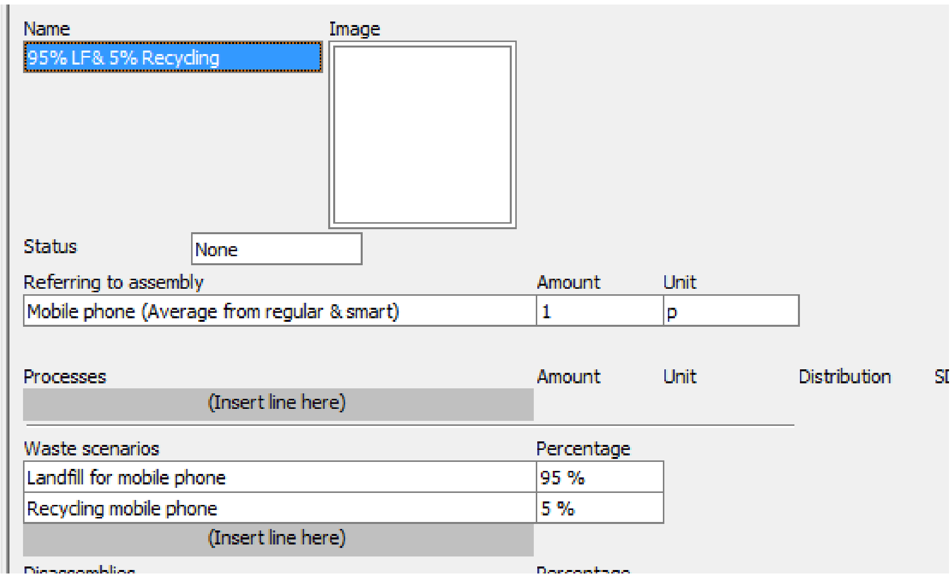


Figure D-5: Scenario analysis for mobile phone wastes

3) Select method to evaluate life cycle impact assessment (LCIA)

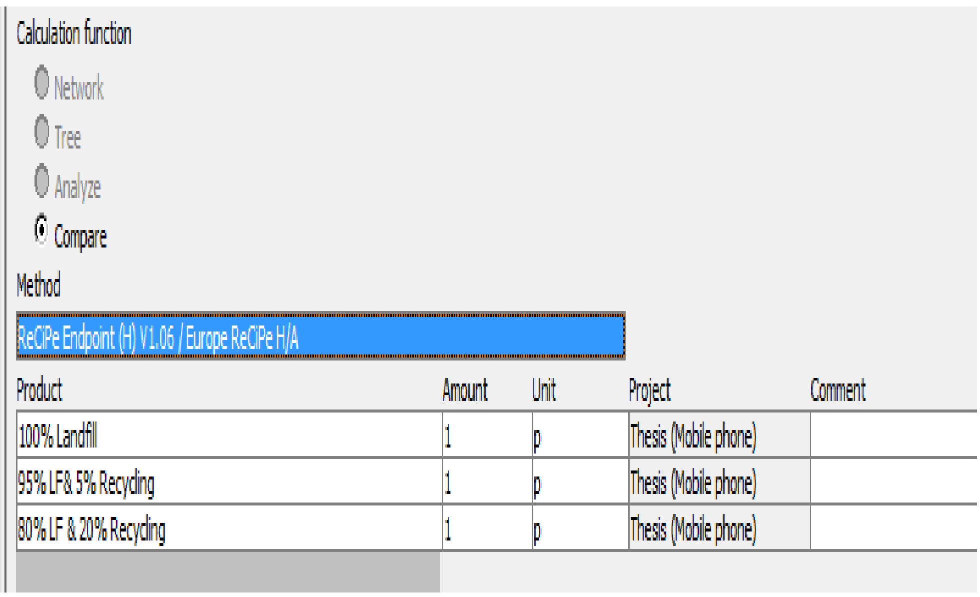


Figure D-6: Method to evaluate life cycle impact assessment

4) Results of impacts from life cycle impact assessment

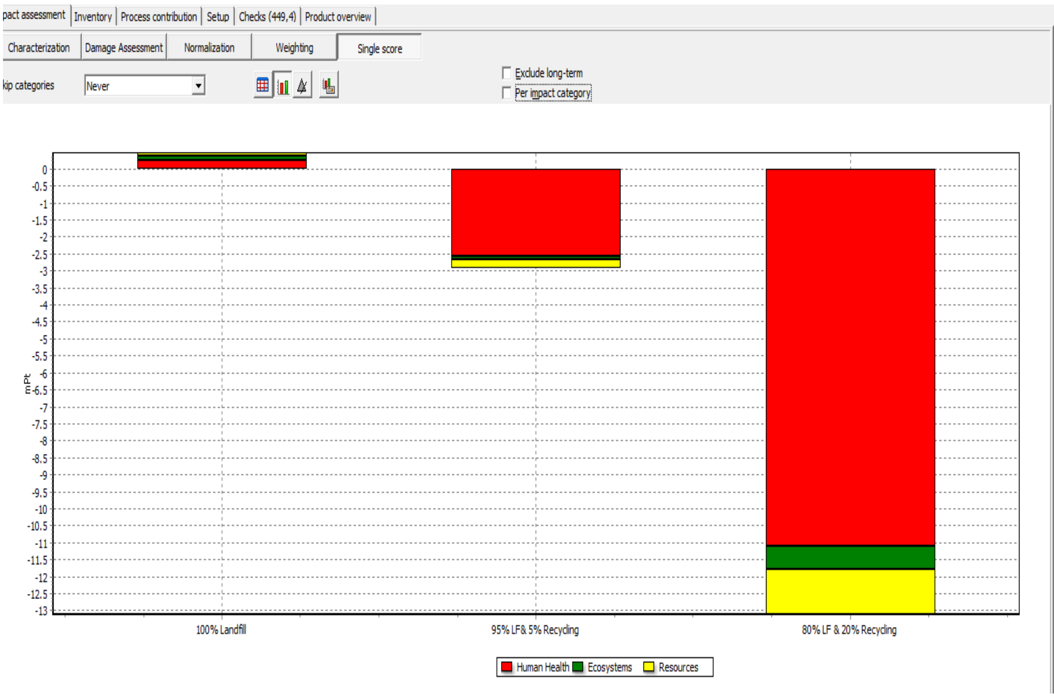


Figure D-7: Results of impacts from life cycle impact assessment

Characterization of impact categories in mid-point and end point level

Table D-1 Characterization of impact categories in mid-point level (Goedkoop et al, 2010)

Impact categories	Characterization
Ozone depletion	The characterization factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). The unit is yr/kg CFC-11 equivalents.
Human toxicity and ecotoxicity	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 unit is yr/kg 1, 4-dichlorobenzeen (14DCB).
Radiation	The characterization factor of ionizing radiation accounts for the level of exposure. The unit is yr/kg Uranium 235 equivalents.
Photochemical oxidant formation	The characterization factor of photochemical oxidant formation is defined as the marginal change in the 24h-average European concentration of ozone (*dCO3* in kg·m–3) due to a marginal change in emission of substance *x* (*dMx* in kg·year–1). The unit is yr/kg NMVOC.
Particulate matter formation	The characterization factor of particulate matter formation is the intake fraction of PM10. The unit is yr/kg PM10 equivalents.
Climate change	The characterization factor of climate change is the global warming potential. The unit is yr/kg CO_2 equivalents.
Agricultural and urban land occupation	The amount of either agricultural land or urban land occupied for a certain time. The unit is m2*yr.
Natural land transformation	The amount of natural land transformed and occupied for a certain time. The unit is m^2*yr.
Marine eutrophication	The characterization factor of marine eutrophication accounts for the environmental persistence (fate) of the emission of N containing nutrients. The unit is yr/kg N to freshwater equivalents.

Impact categories	Characterization
Freshwater eutrophication	The characterization factor of freshwater eutrophication accounts for the environmental persistence (fate) of the emission of P containing nutrients. The unit is yr /kg P to freshwater equivalents.
Fossil fuel depletion	The characterization factor of fossil depletion is the amount of extracted fossil fuel extracted based on the upper heating value. The unit is MJ.
Minerals depletion	The characterization factor for minerals depletion is the decrease in grade. The unit is kg Iron (Fe) equivalents.
Freshwater depletion	The factor for the freshwater depletion is the amount of fresh water consumption. The unit is m^3.

Table D-2 Characterization of impact categories in end point level (Goedkoop et al, 2010)

Impact categories	Characterization
Human Health	Expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the Worldbank and WHO. The unit is years
Ecosystems	Expressed as the loss of species over a certain area, during a certain time. The unit is years.
Resources surplus costs	Expressed as the surplus costs over an infinitive timeframe, considering a3% inflation.

BIOGRAPHY

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Presentation:

- Witthawin Sangpraseart and Chanathip Pharino. "Evaluation the Environmental Impacts for End-of-Life (EOL) of E-Wastes". The 9th International Conference on Environmental and Public Health Management: Towards Better Health and Well-Being, Bangkok, Thailand, October 2-4, 2012, Co-organized by College of public health sciences Chulalongkorn University, Thailand.

- Witthawin Sangpraseart and Chanathip Pharino. "Environmental Impacts Evaluation of Mobile Phone via Life Cycle Assessment". The 3rd International Conference on Chemical, Biological & Environment Sciences (ICCEBS'2013), Kuala Lumpur, Malaysia, January 8-9,2013, Co-organized by PLANETARY SCIENTIFIC RESEARCH CENTRE (PSRC).

- Witthawin Sangpraseart and Chanathip Pharino. Comparison of Environmetal Impacts for End-of-Life (EOL) Management of Smartphone". International Conference on Environmental and Hazardous Substance management towards a Green Economy (EHSM 2013, Bangkok, Thailand, May 21-23, 2013, Co-organized by Center of Excellence for Environmental and Hazardous Waste Management (EHWM) Chulalongkorn University, Thailand.