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Life Cycle Impact Assessment of Municipal Solid Waste Management System in Phnom Penh, Cambodia

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A Thesis Submitted in Partial Fulfillment of the Requirements
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งานวิจัยนี้มีวัตถุประสงค์เพื่อปรับปรุงระบบการจัดการขยะมูลฝอยชุมชนในกรุงพนมเปญ ประเทศกัมพูชา โดยประยุกต์ใช้การประเมินวัฏจักรชีวิต (Life Cycle Assessment; LCA) และการวิเคราะห์พฤติกรรม (Behavioral Analysis) เพื่อประเมินผลกระทบสิ่งแวดล้อมโดยมุ่งเน้นไปที่การปล่อยก๊าซเรือนกระจก ทั้งนี้การวิเคราะห์เปรียบเทียบกับสถานการณ์หลากหลายที่สะท้อนให้เห็นถึงกลยุทธ์ของระบบการจัดการขยะมูลฝอยทางเลือกในหลายประเทศทั่วโลก สืบเนื่องจากขยะมูลฝอยชุมชนประกอบด้วยขยะจำพวกเศษอาหารในสัดส่วนที่สูง ดังนั้นกระบวนการหมักทำปุ๋ย (Composting method) และการกู้คืนวัสดุ (Material Recovery System) จึงเป็นวิธีที่เหมาะสมในการจัดการขยะมูลฝอยระยะสั้น อย่างไรก็ตามสำหรับการจัดการในระยะยาวนั้น รัฐบาลควรคำนึงถึงการติดตั้งระบบกักเก็บก๊าซที่เกิดจากหลุมฝังกลบเพื่อลดผลกระทบต่อสิ่งแวดล้อมที่จะเกิดขึ้น ทั้งนี้ระบบที่กล่าวมาข้างต้นไม่เพียงแต่เป็นมิตรกับสิ่งแวดล้อม แต่ยังเป็นประโยชน์ในด้านเศรษฐกิจจากการขายปุ๋ยหมักและการผลิตไฟฟ้าจากระบบกักเก็บก๊าซบริเวณหลุมฝังกลบ นอกจากนี้งานวิจัยนี้ยังได้ดำเนินการตรวจสอบพฤติกรรมของประชาชนในกรุงพนมเปญ ต่อการปรับปรุงระบบการจัดการขยะมูลฝอยชุมชนโดยอาศัยแบบสอบถาม (Questionnaire) จำนวนมากกว่า 300 ตัวอย่าง ผลจากการสำรวจพบว่าผู้ที่ทำแบบสำรวจส่วนใหญ่ไม่มีการแยกขยะก่อนทิ้ง อย่างไรก็ตาม 82% ของผู้ที่ทำแบบสำรวจยินดีทำการแยกขยะในกรณีที่มีการให้ความรู้จากรัฐบาล และ 94% ของผู้ที่ทำแบบสำรวจยินดีจ่ายค่าบริการเพิ่มเพื่อปรับปรุงระบบการจัดการขยะมูลฝอย ทั้งนี้จำนวนเงินเฉลี่ยที่ผู้ทำแบบสำรวจยินดีจ่ายเพิ่มคิดเป็น 3-4 ดอลลาร์สหรัฐต่อเดือน ซึ่งข้อมูลดังกล่าวมีความสำคัญต่อการปรับปรุงระบบการจัดการขยะมูลฝอยชุมชนในกรุงพนมเปญในอนาคต

ภาควิชา	วิศวกรรมสิ่งแวดล้อม	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมสิ่งแวดล้อม	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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This study aims to improve the current municipal solid waste management system in Phnom Penh, Cambodia using life cycle assessment (LCA) and behavioral analysis. LCA is used to assess the environmental impact, particularly focusing on GHG emission, on the current MSWM system. The analysis compares various different scenarios that reflect alternative MSWM strategies in many countries around the world. Due to its high fraction of food waste composition, composting and material recovery system is the most favorable waste strategy that should be implemented in the short-term perspective. But for the long-term run, installing the landfill gas collection in the landfill is the most environmental-friendly system that the government should take into consideration. Those systems introduce above are not only beneficial to the environment, but also to the economy as well, from selling compost and generating electricity from landfill gas collection system. In addition to LCA, behavioral study is proceeded to investigate the people behavior toward the improving of the current MSWM system. Questionnaire survey is deployed in this step. More than 300 samples are distributed to many places in city of Phnom Penh. The result of the survey shows that the majority of people do not separate wastes before disposal. But satisfyingly, 82% of the people doing the survey are willing to do the at-source separation if there is an instruction from the government. Around 94% of people are willing to pay more financial fee to improve the system. The average amount of money they are willing to pay more is 3-4 USD (USDollar) per month.

Department:	Environmental Engineering	Student's Signature	....
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INTRODUCTION

I.1 Introduction

Solid Waste Management nowadays is now becoming quite complicated problems throughout the entire world to manage, particularly in the fast-growing areas such as metropolitan, populous city, urban area and so on. As a result of economic development, technology advancement, rapid population growth, urbanization, life-style change and industrialization nowadays, a large number of waste is generated every day. Currently, global MSW generation is estimated about 1.3 billion tons per year, and it will be increased to be about 2.2 billion tons per year in 2025(Daniel Hoornweg 2012). Consequently, major challenges for the municipalities are to collect, recycle, treat and dispose of the increasing quantities of solid waste (Cherubini 2009). Establishment of a proper waste management to deal with this increasing of waste is a very challenging task for every country around the globe. With no exception, the Municipality of Phnom Penh, capital city of Cambodia, is also facing the problems regarding the significant increase of the amount of unsorted and non-recycling waste, and providing an appropriate and environment-friendly solution and management in response to the rocketing of waste generation.

The current municipal solid waste management performance in Phnom Penh municipality is not acceptable in terms of sanitation and environmental friendliness. There is no proper pre-treatment, sorting system, material recovery, energy recovery and other treatments before disposing into the landfill. Moreover, the dump pile is not covered regularly as a proper sanitary landfill always does. The problems that have commonly been seen in the city are illegal dumping, low waste collection efficiency, unseparated waste and so on. The key factors that lead to these problems are from not only technical aspects, but also political, legal and economic factors as well as the availability of supporting information for a better planning and management(Veasna Kum 2005). Although there is a clear sub-decree on solid waste management, both municipal solid waste and hazardous waste, the attention and action taken in this field are not sufficient. According to the United Nation Environmental Program report (UNEP 2012), Cambodia does not have any particular policy and specific long-term plans to improve the current waste management system. Moreover, the laws and regulations regarding waste management are still weak and ineffective that needs to be taken into consideration to improve the current waste management and to get rid of the problems faced nowadays. In addition, the relevant ministries and departments cannot provide sufficient data or information that is needed for the future improvement. For example, the data are outdated and scattered. Most importantly, the willingness to participate of the generators is low because there is not enough operational budget and other related materials or program to educate and raise awareness of the importance of environment to the local residents.

Available evidences illustrate that the best way in managing solid waste is done by taking an integrated view on waste management, beginning at the source of waste generation(Scheinberg 2010). However, at present, the main disposal method of solid waste used in Phnom Penh is only the landfill disposal without prior treatment, separation or resource recovery. The system is still in open-end type of management where the waste is not fully utilized as recycled material in other process. The improper waste dumping causes mixing between the municipal solid waste and other untreated hazardous waste such as medical wastes. It seriously affects the environment and human health as well. Moreover, the organic waste and other potential resources for making compost are left in the landfill without fully utilization. In addition, the recyclable materials such as valuable metal, glass, plastic and paper still has value and have been informally collected by local people to sell for their survival. Therefore, if there are more efforts on establishing formal sector for recycling municipal solid waste, it could help improving performance of waste management in Phnom Penh Municipality.

Many developed countries like Germany, Japan and the United States are successful in executing solid waste management system. The key is that they change the strategy from a direct landfill disposal to an integrated method (Ying Zhuang 2007). Integrated system is widely known as the best way to achieve the success of waste management in many part around the globe (Hu 1998). Waste separation at source is a crucial method in the integrated management system that leads to the success of the waste management in this era (McDougall 2008). Waste separation helps reduce a lot of new material as we can use the used materials by reuse it again by many means. Moreover, we can use the recyclable waste such as plastic bag, plastic bottle and other materials. By doing this, the amount of wastes that we generate each day will decrease. Also, this action will not only reduce the amount of waste generation each day, but also be cost-effective as well. If recycling business is widely established, people can sell some valuable materials like aluminum cans, paper, and glass and so forth to make profit as well. Besides recycle and reuse, waste separation also helps increase the quality and quantity of compost as well. The major challenge of composting nowadays is the mix of waste from every source, which is hard for making the compost. Last but not least, incineration method requires source separation for the optimum efficiency. If the system is operated on the wet waste or material that is not or hard to disintegrate by incineration process, it will waste a lot of energy and money for the operation.

I.2 Background of the case study

The study aims to be conducted in Phnom Penh Municipality, the capital city of Cambodia. Phnom Penh has the cover area of approximately 374 km^2 in 2003 (JICA 2005), and as the population growth and economic development, it is now expanding its area to meet the human needs to be about 678.46 km^2 in 2010 (MPP 2009). The total land area is divided into 8 districts and continuously classified into small 96 communes. (Figure 1) The overall population of the city is reported to be around 1.3 million people in 2008 with the population density of about 4571 people km^2 and an average household size of 5.1 people per household (MOP 2008).

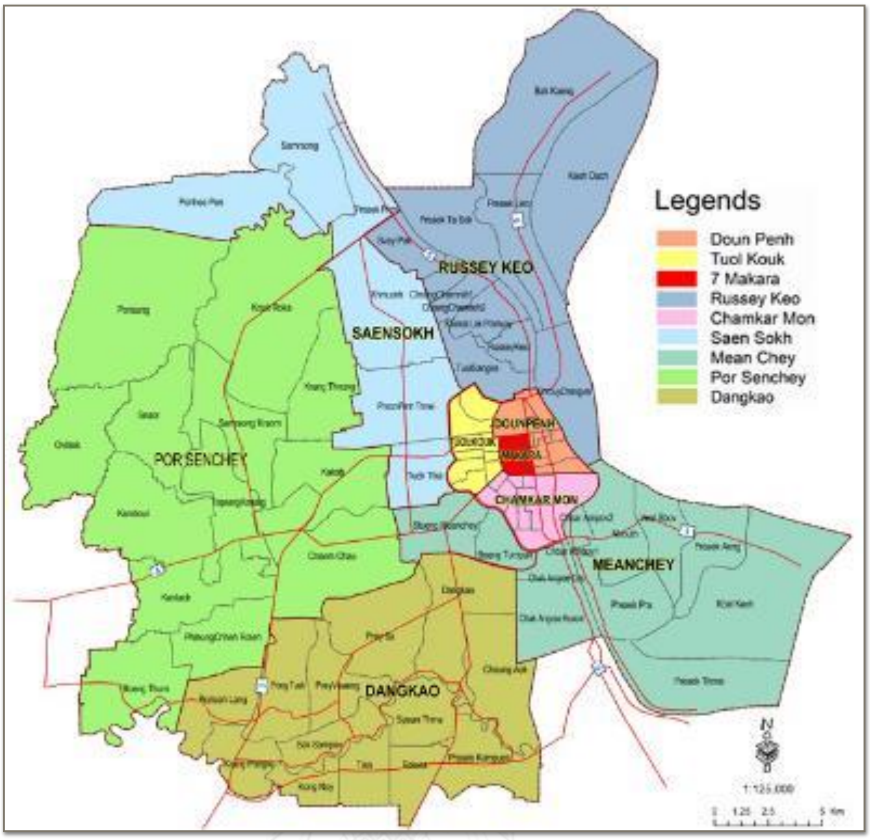


Figure 1: Map of Phnom Penh Municipality

Cambodia met the genocide and political instability almost three decades since 1970s. As a result, there are not many data available regarding waste generation rate even in the capital city, Phnom Penh. The data are available only from the year of 1994 onward, but those data, generally, are not cleared and reliable. From 2009, there is the weighing bridge installed in the landfill to measure the amount of waste transported to dump in the landfill. Consequently, that makes the waste generation rate from that time onward reliable. According to (Cintri 2014), a private company in charge of giving service of municipal solid waste management in Phnom Penh, the waste generation rate in Phnom Penh starting from 2009 to 2013 (Table 1) noticeably keeps increasing every year. The waste generation increase from 355,515 tons in 2009 to 505,094 tons in 2013 (Cintri 2014). Furthermore, the waste generated per capita is estimated to be 0.487 kg per day for Phnom Penh (JICA 2005).

Table 1: Waste Generation Rate from 2009-2013(Cintri 2014)

Year	Waste Generation (Tons)
2009	355,525.00
2010	383,747.90
2011	408,780.10
2012	461,682.40
2013	505,094.70
Total	**2.114.820,10**

In addition to waste generation rate report, there is also a report regarding waste composition in the year of 2013 as well. Actually, this kind of study has been done once before in 2005 by Japanese International Cooperation Agency (JICA). The reports illustrate that the majority of overall solid waste is food waste. It takes accounts for almost 70%. While plastic waste stands at the second ranking accounting for 14.47 percent (Table 2).

Table 2: Waste Composition in 2013 (Cintri 2014)

N	Waste Composition	Jica 2005(%)	Cintri 2013(%)
1	Food	61.45	69.69
2	Cloth	2.57	6.31
3	Plastic	17.83	14.47
4	Wood and Grass	8.46	1.53
5	Metal	0.67	0.53
6	Glass Bottle	0.81	1.76
7	Soil and Stone	1.04	0.38
8	Paper	5.23	2.8
9	Leather	0.14	0
10	Others	1.8	5.24

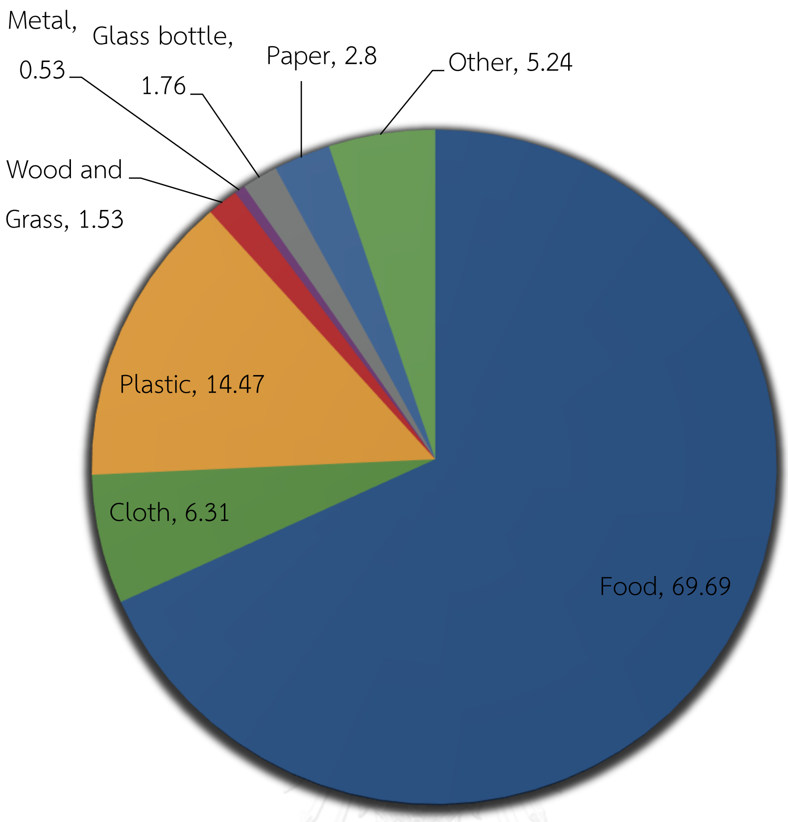


Figure 2: Waste Composition

I.3 Research Objectives

The objectives of this study are to:

1. Investigate the overview of municipal solid waste management system in Phnom Penh.
2. Identify key factors impacting performance of municipal solid waste management in Phnom Penh.
3. Develop suggestion and policy scenarios to improve the environmental performance of the current municipal solid waste management system in Phnom Penh.

I.4 Expected Results

1. Overview of management system structure and the waste management flow.
2. Understanding the factors influencing performance of in the current municipal solid waste management system in Phnom Penh.

3. Recommendations for improving the current municipal solid waste management in Phnom Penh.

I.5 Hypothesis

Increase of waste separation at-source and recycling, will help improving the performance of current municipal solid waste management system in Phnom Penh to the large extent in terms of the environmental benefits.

Chapter II
Literature Review

This section aims to review the related studies and researches in this area that have already been done. In reality, at-source separation system are usually recommended as a best way in the management of municipal solid waste in many countries around the world in present time. Moreover, we would like to compare the situation of municipal solid waste management in Phnom Penh Municipality with the situations of other countries to have a better understanding of situation of waste around the world. The review is to investigate the pros and cons of the at-source separation to improvise the current municipal solid waste management system. This review, we mainly focus on 5 major subjects which are: Municipal solid waste management in Phnom Penh municipality and in regional and global area, Life cycle Assessment (LCA), at-source separation methods and behavioral analysis.

II.1 Overview of Waste Management System

With the alarming increase of municipal solid waste generation rate, waste management is becoming a common concern of any countries around the world. Policies and regulations have been developed and revised to ensure the human welfare and happiness. In this section, waste management in some countries have been raised to compare to see the strengths and weaknesses of each country's system.

II.1.1 Current Waste Management Situation

In Cambodia, only big cities with high number of population in Cambodia receive waste collection service. The current municipal solid waste management mainly focuses on collection, transportation and disposal. Waste treatment is still low. There is a small fraction of recyclable waste that has been collected by scavengers for their survival. Other fractions are dump at open-dump landfill without further treatment. There is no sanitary landfill, incinerator or other facilities to get advantages from waste such as material and energy recovery (Sour Sethy 2014).

In Thailand, almost 100% of waste collection has been collected and transported to three different transfer stations. However, there is improper waste management such as open dumping and open burning in rural areas. There are sanitary landfills but they work insufficiently. Because of the poor separation of waste, composting does not yield a good quality of fertilizer. There are three incinerator plants in Thailand in operation. In 2008, a number of wastes to energy plant have been constructed but they are in an experimental stage. However, the popular method used in Thailand is landfilling as well (Siriratpiriya 2014).

In Vietnam, the average collection rate of the whole country is 72%. Similarly, the most popular method of waste management in urban area in Vietnam is disposal in the Landfills. 80 -85% of landfill in Vietnam are not sanitary that pose a threat to human health by odor and leachate. Incinerator is also one of the method use in Vietnam, but it is not commonly used because of the high moisture content in waste. It is used for hazardous waste such as hospital waste only. Composting is also not widely used too because the separation is not sufficiently enough and other reasons (Thai 2014)

Take a look at waste management in developed country, Japan; at-source separation is very popular in Japan. Waste generators are asked to separate waste into more than 10 kinds of waste before dispose for collection, and follows by immediate treatment and recycling facilities for material recovery. To save the space of landfill, Incineration is very popular in Japan. Approximately 79% of waste is going to incineration facilities. Further, they generate energy and electricity from combustion of waste. Another successful method in Japan is to crush of bulky waste and turning waste to refuse derived fuel (RDF). Interestingly, the waste dispose to the landfill is 4.8 million tons in fiscal year 2010 and expect to reduce the amount from year to year (Tanaka 2014).

In South Korea, the main priority of waste management in South Korea is to reduce waste generation and increase the recycling rate as much as possible. As a result, the government implements the system of “Volume-Based Waste Fee System, a Pay as

You Throw". The recycling rate in Korea is seen to be improved from year to year by develop the advanced technology and encourage the use of recycled waste. The incineration rate is also increased interestingly while the landfilling has significantly decreased from year to year (Dal-Ki Min).

In conclusion, it can be obviously seen that in developing countries landfilling is very popular and it normally cause a lot of problems while developed countries, which is successful in waste management, focus on recycling, material recovery, source reduction, incineration. More importantly, citizens in those countries are willing to recycle and separate waste.

II.1.2 Waste Generation

The waste generation rate of Cambodia is increasing significantly from year to year. According to the Ministry of Environment report in 2004 illustrates that the generation rate of Municipal Solid waste has noticeably increased from 14,500 in 1994 to about 438,000 tons per year in 2011 (Sour Sethy 2014).

Table below illustrates the increase of waste generation from 2000 to 2013 (Table 3).

Table 3: Waste Generation from 2000-2013

Year	Waste Generation (Tones)	Year	Waste Generation (Tones)
2000	20,702	2007	343,657
2001	21,050	2008	361,344
2002	21,367	2009	393,044
2003	240,859	2010	409,335
2004	227,909	2011	438,000
2005	266,781	2012	461,682 (cintri 2013)
2006	324,159	2013	505,094 (cintri 2013)

In 2008, the municipal solid waste in Thailand was estimated to be produced approximately 15.03 million ton per year. According to Pollution Control Department 2009, Bangkok generates the municipal solid waste 1.5kg/capita/day. From 1993 to 2008, the waste generation rate is interestingly increased from 30,640 to 41,064 tons/day and it will continuously increase in the future (Siriratpiriya 2014).

As China is a large country, it might be divided into at least 2 or 3 geographic part. The waste composition of these two parts are generally different. The waste moisture of these two parts are somehow not the same as well. The collection service is given only in the big city or the central of the small town only. At the suburb of these small towns, the service is not regularly given at all. The author illustrates that the waste generation counting from 1986 to 2010 has significantly increased every year. It is shown that at the end of year 2010, china generate municipal solid waste is about 158 million tons. (Su Lianghu 2014).

In the year 2010, the waste generation rate of Japan is about 46.3 million tons. It is worth noticing that the waste collected is up to 42.6 million tons in Japan. It obviously illustrates that the collection efficiency is very high and effective. It is reported that the generation rate per capita per day is about 0.98 kg. 93% of the total is go through the intermediate treatment, which is incineration. Noticeably, the material recovery is done on voluntary basis by the local community. The material recovery is reported about 2.7 million tons. Surprisingly, Because of the best management system of municipal solid waste, the generation rate of Japan has been decreased at the last few years (Tanaka 2014). Table 4 shows and compare the waste generation in many countries including developing and developed countries in the world.

Table 4: Comparing Waste Generation

Country	Generation Rate (ton)	Year	Source
Cambodia	505,094	2013	Cintri 2013
Thailand	15,030,000	2008	O. Siriratpiriya 2014
Vietnam	7,863,195	2008	N.T.K. Thai 2014
Japan	46,300,000	2010	M. Tanaka 2014
South Korea	136,765,500	2010	A. Pariatamby 2014
Malaysia	16,500,000	2007	D.K. Min 2014
India	1,210,000,000	2010	K. Joseph 2014

After seeing the number of the waste generation rate in various countries, it is obvious that the waste generation rate of Cambodia is very low comparing to the neighboring countries like Thailand and Vietnam. This might because of the number of population, the cover area of each country or even economic of each countries. As the number is low, it might be easier to achieve the goal of sustainable development.

II.1.3 Waste Composition

In Cambodia, the waste composition is reported by (JICA 2005) that it comprise about 63% of kitchen waste, which is organic waste and about 15% of plastic waste. However, (CSARO 1999) reported that organic waste is about 87% and plastic is only 7%. This illustrates that the reliability of data is not yet reliable and need to improve.

In Thailand, unsurprisingly, waste composition of Thailand is dominated by organic waste, which 64% of overall municipal solid waste generated. The waste contains with high moisture, which is amenable for composting. It is worth mentioning that, in this research show that urban city and high-income citizen generate the different composition. In Bangkok city the organic waste take account for only about 42%, but the fraction of plastic is 25% which is higher than in less-income area, which is less than 20%.

Surprisingly, unlike other developing countries, developed countries have the different waste composition if comparing with the developing countries. (Table 5) has shown that Cambodia, Thailand and Vietnam have the food waste or organic waste, which is the dominant group. It takes accounts of about 60 percent of the overall waste, and follows by plastic waste. Conversely, Japan has only 31.3% of organic waste, but paper waste is about 44.5 percent which is the highest fraction. The United States is similar to Japan, the highest fraction of waste is no organic waste. It is paper waste, which is 32.7 percent. Surprisingly organic waste takes account only 12.5 percent. Like other developed country, England has similar waste composition. Paper is the dominant fraction, which is 33.2 percent which organic waste is only 20.2 percent (Seng (2010).

Table 5: Comparing Waste Composition

Composition	Cambodia	Thailand	Vietnam	Japan	USA
Kitchen	63.30	64	53.8	31.3	12.5
Textile	2.50	1	1.7	-	-
Wood	6.80	1	-	-	-
Metal	0.60	2	1.4	1.2	8.2
Paper	6.40	8	4.2	44.5	32.7
Plastic	15.50	17	3.42	7.8	12.1
Glass	1.20	3	1.0	1.1	5.3
Others	2.20	4	28	14.1	29.2
Source	Jica (2005)goog	Siriratpiriya (2014)	Thai (2014)	Tanaka (2014)	Burnley S.J (2007)

In short, in developing countries organic waste is the highest fraction among the others; while in developed countries paper is the highest one. The plastic used in develop countries are less in percentage while it is high in developing countries. There are high potentials to improve resource utilization and public hygiene by increasing recycling performance. Food waste, which has highest proportion, can be used as source of renewable energy generation if properly managed.

II.2 Life Cycle Assessment

II.2.1 Theory of LCA

LCA is unanimously considered one of best effective way in environmental management by most of, if not all, the environmental scientists and engineers in the present time. LCA is a kind of technique aiming to assess the environmental impacts of a particular product throughout its life cycle, in other words it is used to assess the impact to environment from the very first day it is made by the factory to the very last day it is disposed in the landfill. Some people called it a "cradle to grave" approach. It is becoming a tool that is widely used for decision making of the various policies and regulations for the better waste management system (Rigamonti 2008).

- ✓ **Goal and Scope Definition**

LCA goal aims to formulate the questions and try to find the answer of the question. In this stage, it is not necessary to collect data, and the result is not needed to calculate or translated. What is important in this stage is to make a clear and unambiguous plan of the study as much as possible (Life Cycle Handbook). The plan that is made is very important because it can affect the whole procedure of the study. Once the plan or goal has been set, it is very important to scope the study area. The detail of the study has to be sufficiently cleared to make that stated goal is achieved (Life Cycle Handbook). The main feature of the goal and scope is the functional unit. It is too obvious that we have to compare two or three systems with a comparable functional unit. It is clearly stated in ISO 14040 that, "The functional unit defines the quantification of the identified function (performance characteristics) of the product.

The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results" (Life Cycle Handbook).

✓ **System boundaries**

System boundary must address which products or unit processes that need to be included in the LCA system. The geographic and time boundaries of the analysis, and the flows and impact categories can be included in the system boundaries as well. (Life Cycle Handbook).

✓ **Life Cycle Inventory**

ISO consider the life cycle inventory (LCI) as "phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle." (Life Cycle Handbook). In this section, quantification and number are very important as we need to calculate and show the result in number. The data of input and output are described in the quantitative terms. LCI is very important in the Life Cycle Assessment because it can answer the questions of the environmental impacts that we have in the goal and scope section.

✓ **Impact Assessment**

Life Cycle Impact Assessment (LCIA) is "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product."(Life Cycle Handbook). It is the last step of the whole process. With it, the policy makers or any involved stakeholder can analyze about the impact to environment of the study. This process will convince policy makers to accordingly establish the policy base on environmental, economic, and social benefits.

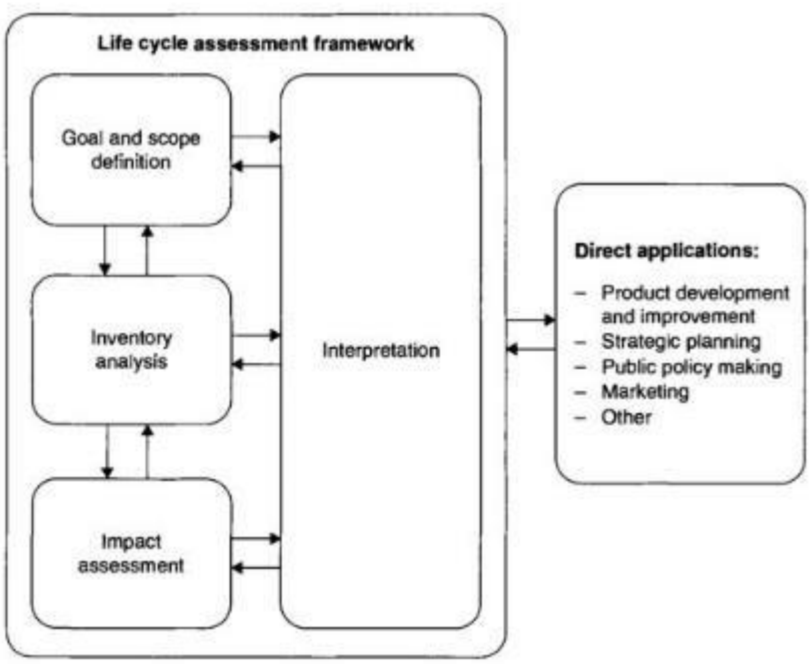


Figure 3; Life Cycle Impact Assessment

II.2.2 Study on LCA

There are a number of studies that used LCA as a tool to evaluate the environmental impacts of the products or processes. Several scenarios have been raised to compare the impacts to the environment. After LCA assessments, recommendations to improve current system have been suggested to reduce the harmful level of the products to our environment.

(Rigamonti 2008) used LCA as a tool to find the optimizing levels of separated collection that is beneficial to environment in integrated Municipal Solid Waste Management System in Italy. The study analyzes material and energy recovery of the separated collection of Municipal Solid Waste. Moreover, the direct impacts to environment have been raised in this study as well. The final aim of this study is to find the optimum level of at-source separation collection that gives the benefits in term of energetic and environmental matters. LCA has been used to assess Global Warming Potential, Human toxicity Potential, Acidification Potential and Photochemical Ozone Creation Potential. In this study, the author suggested three different scenarios to do the evaluation and comparison. The three scenarios are: 35 percent of source-separation, 50 percent of source-separation and 60 percent of source-separation. The result illustrates that the scenario 60% of source-separated collection is beneficial in term of energy recovery and environmental impacts (Figure 4).

	Per t of MSW	Scenario 35%	Scenario 50%	Scenario 60%
CED	MJ eq	−10890	−13678	−14440
Global warming	kg CO_2 eq	−177	−202	−255
Acidification	kg SO_2 eq	−2.31	−2.32	−2.38
Human toxicity	kg 1,4-DCB eq	−162	−175	−245
Photochemical ozone creation	kg C_2H_4 eq	−0.168	−0.188	−0.209

Figure 4: Impact of Each Scenarios

There is another similar study has been done in Singapore by (Hsien H.Khoo 2012) The study is to attempt to improve the future municipal solid waste management system in Singapore by taking the environmental welfare as the first priority. This study used LCA to assess and compare three different scenarios of landfilling activity according to the source-separation level in term of environmental impacts such as Global Warming Potential, Acidification and Human toxicity. The three scenarios that have been proposed in this study are: scenario one is that the current waste management, the second one is the barge is replaced by a fuel oil-powered coastal bulk carrier, for the third scenario, waste water treatment plant to remove 70% of toxic substance from leachate, and the last scenario is recycling of 70% of source-separated collection. The author assesses the impact of each scenario to the year of 2030. The result of LCA assessment shows that the most beneficial option in account with environmental well-being for a best municipal solid waste management system is the scenario of recycling 70% of the waste generation (Figure 5).

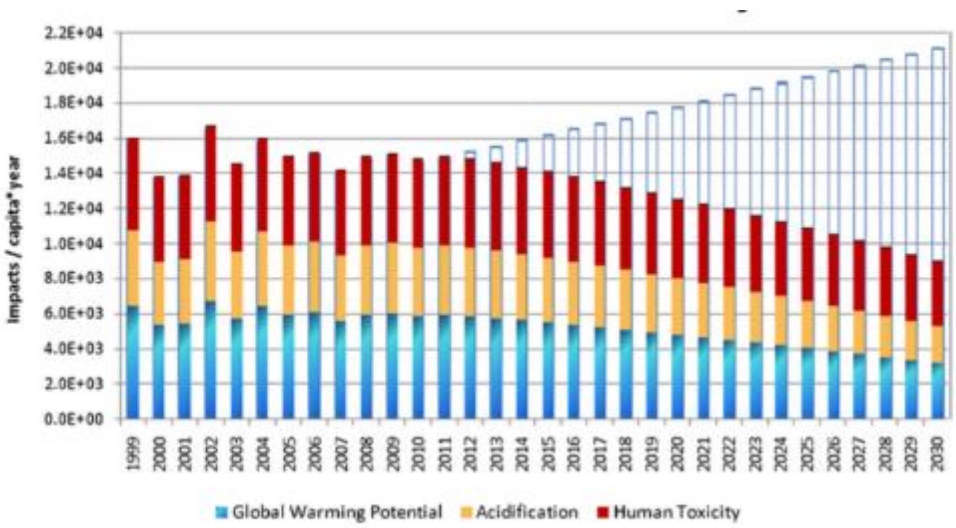


Figure 5: Reduction of Impacts of Recycling

(Komal 2013)also used LCA as a tool to evaluate the historical development of Municipal Solid Waste Management in Denmark starting from 1970 to 2010. The authors focus on Global Warming Potential in this study. The author gives the scenarios in the past year of waste management system. Scenario one is the management in the year 1970. In this system, all the municipal solid waste is transported to landfill. The second scenario is in 1980, this system use incineration but without energy recovery. The third scenario is in 1990, incinerator with energy recovery is introduced but in form of district heating. The fourth scenario is in 2000; waste in this system is incinerated with heat and electricity recovery. And the last scenario is in 2010, source separated is popular in this system, and electricity recovery efficiency is improved as well. After coming up with these scenarios, the author use LCA to assess the environmental impacts to these five different scenarios to find out what is the root of a best management system that have ever exist in the past years, and to attempt to carry out and improve that management system. The result of LCA assessment demonstrates that the greenhouse gas emission, gas that leads to global warming, has been remarkably reduced in the last 40 years. It is reduced from the net emission of 618 kg CO_2-eq. tonne^{-1} in 1970 to net saving of 670 kg CO_2-eq. tonne^{-1} in 2010 (Figure 6).

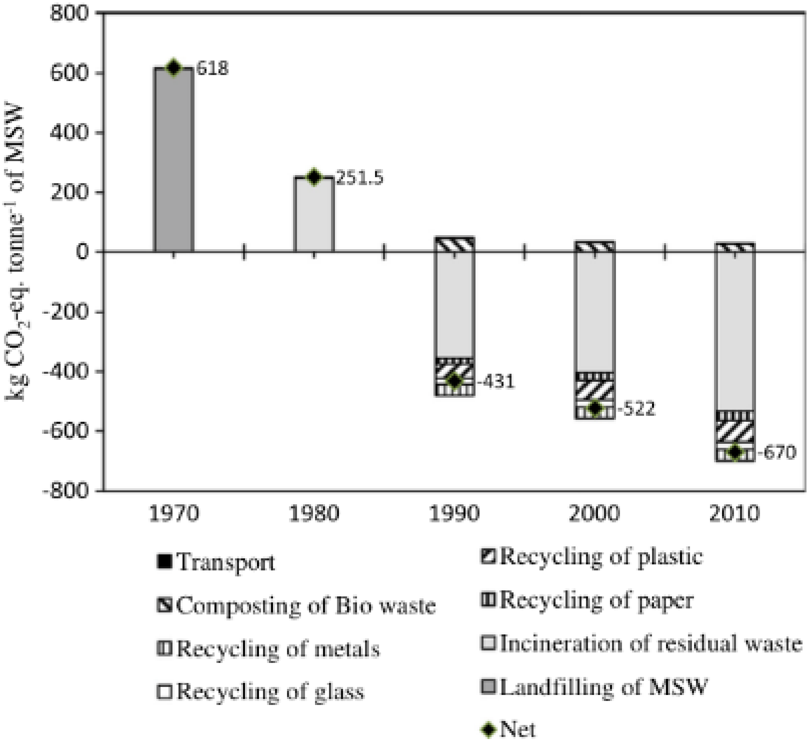


Figure 6: GHG Emission in Denmark

(Francesco Cherubini 2008) also used LCA to compare the environmental impacts of municipal solid waste management strategies amongst: Landfilling, sorting plant and incineration system in Italy. Likewise other previous studies, the author raise some scenarios and do the environmental impact assessment by using LCA approach to each scenario to see its impacts. There are three scenarios have been proposed in this study. The first scenario, waste is transported to landfill without any further treatment. The second scenario, part of gas released in landfill is captured and treated and burnt to produce electricity. In the third scenario, a sorting plant is used to separate waste and to do material recovery. And in the last scenario, wastes are burnt in incineration plant to produce electricity. LCA gave a result of these scenarios as follow (Figure 7)

Scenario	GWP, kt CO_2	AP, t SO_2	EP, t NO_3	Dioxins, g TCDD
Scenario 0				
Gross	1914	546	126	0.24
Net				
Scenario 1				
Gross	966	338	126	0.35
Net	868	186	126	0.29
Scenario 2				
Gross	704	852	n.a.[a]	0.25
Net	−340	−441	n.a.[a]	−0.28
Scenario 3				
Gross	948	1902	n.a.[a]	1.38
Net	224	780	n.a.[a]	0.92

Figure 7: Gas Emission of Each Scenario

In conclusion, as seen in the section above, Life cycle Assessment (LCA) is very important and useful tool to assess the impact to the environment of any products or processes throughout its life cycle. LCA approach is an effective way to convince the policy maker to consider about the environmental wellbeing.

II.3 At-Source Separation

At the present time, it is believed by environmentalist and scientists that the end-pipe management system is out of date. It is shifted to at-source management as it is proved that at-source management leads to sustainable society and development. There are quite a number of recent studies and researches put a lot of effort in this method to prove the world that it is one of the success method that need to put into consideration of any policy maker. The concept of at-source separation of municipal solid waste is to separate the waste the generation site. In order words, the generators that are the residents have to cooperate into separating waste into categories as commanded by regulations. For example, the residents have to classify his or her waste into wet waste, dry waste and recyclable waste in advance before discharging or before collected.

A lot of studies have been done on at-source separation and prove that it is the best method for municipal solid waste management. (Ying Zhuang 2007) studied about separation of household waste in China. Moisture content amount in waste is the main factor that limited the recycling and material recovery. By comparing the at-source separation with the conventional waste management, the result illustrates that the at-source separated collection system is cost effective. The revenue that comes from selling recycling material is more than the operational cost. (Hsien H.Khoo 2012) also conducted a study to find out which management system is the best one. This study is conducted in Singapore. The author suggests four different scenarios in his study and compare amongst all of them. The result illustrates that at-source separation and recycling is not only beneficial in term of economic, but also in term of environmental impacts as well. Once the high rate of recycle is achievable, the emission from waste is significantly reduced. Another group of researcher also conduct a research comparing the benefits between mixed to source-separated collections. (Mentore Vaccari 2012) try to find out the benefits changing from mixed to source-separation collection in Italy. The study shows that mixed collection system is harmful to human health and dangerously impact to the environment we are living in. The author suggests six different scenarios to evaluate and compare cost environmental and economic of each scenario. The scenarios are classified by the rate of separation and recovery rate. The result shows that the implementation of source-separated collection helps save landfill volume and cost. The author conclude that implementation of at-source separation has a positive effects to environment and all the stakeholders who are involved. Another study conducted by (Francesco Cherubini 2008) try to find out which one amongst Landfilling, sorting plant and incineration plant is the best system in the present time. The study is done in Italy. The study aims to evaluate the environmental impacts by assess the gas that release in each scenario. The result demonstrates that among the three scenario is the worst one, whereas the sorting and recycling is the best system in term of gas emission that lead to global warming. Moreover, sorting system help saving in term of energy and cost. The author suggest that sorting plant with electricity and biogas production is likely to be the best option of municipal solid waste management.

In conclusion, many studies unanimously illustrate that at-source separation system is the best option amongst the other varieties. It is not only cost effective, but also environmental friendly as well.

II.4 Scenario Analysis

Scenario analysis is the process of analyzing the outcome of the suggested scenarios that highly likely happens in the future. It is possible to suggest more than two scenarios at the same times and try to figure out which one amongst all scenarios giving an optimal and best result. It is used to convince that the possibility of the success of the study is high comparing to the present practice. The factors that take into account of the scenario analysis can be environmental, economic and social field. It also leads to develop the policies and strategic plans for the improvement of the present management system.

Sometimes it is difficult to say that one management system is better than the others. For example, you want to suggest that recycling is the best way for the municipal solid waste management nowadays than the current existing solid waste management. So the best way is to raise some scenarios and then compare with the current one. There are a number of studies that have been done this way. (Ferreira 2014) assess the environmental impacts of a packaging waste recycling system in Portugal. The author wants to know that recycling packaging waste is a best option for the environment or not. So the author raises two different alternatives or scenarios of waste management. The first scenario is recycling, the second scenario is to incinerate the packaging waste, and the last scenario is to dispose the packaging waste in the landfills. After that the authors apply the technique to assess the environmental impacts of the three scenarios. After getting the result, the authors can conclude that which one is the best option for waste management. (Lei Wang 2012) also use this method to evaluate and find for the best option for waste management system as well. In the study, the authors use LCA to assess the environmental profile and greenhouse gas emissions for bioethanol production from paper. The authors also raise to more scenarios to do the comparison. The alternative management system options are recycling and incineration with energy recovery. After suggest three different option, the authors apply LCA method to assess the environment profile and global warming to each scenario. The result of the study shows that incineration with the advanced technology is the best option amongst the other suggested scenario. The author might suggest for the policy marker to do consider doing the incineration system rather than the others.

In short, it is necessary to assume a number of scenarios to compare and to find out which option is the best that should be implemented.

II.5 Behavioral Analysis

The behavioral analysis is the analyzing of the people behavior toward the particular things. This kind of study aims to find the factors that affect people' perspective toward environmental matter. After figuring out the impacting factors, strategies and plans will be accordingly made to bring about change of the perspective and behavior of the people. For example, people in one area do not separate waste at source. The study will be conducted to find out what make people do not separate waste. The result might show that level of education is the main roots that make people are not willing to separate waste. Consequently, the strategic plan has to be established to deal with it by having a short course to the people to raise their awareness. Behavioral Analysis can be conducted by distributing a number of questions in the form of questionnaire, or to be more reliable, interview is the best form of behavioral analysis to study about the people behavior. The choice amongst questionnaire and interview depends on time, labor and budget availability.

Although there is a best system in the world, but if the citizens do not co-operate, that system will become pointless to take into consideration. Before implementing new system, it is important to study whether citizens are willing to participate in advance, and try to find out the factors that make the system fail and successful. (Mbiba 2014) studied about the willingness to participate in implementing the at-source separation in South Africa. Author stated that the awareness of integrated municipal solid waste management is increased in many developed countries. So, the author aims to examine the people behavior of citizen towards at-source separation. The study is done by field survey. In other word, author goes to the field to observe something like waste generation rate, waste composition and the factors affecting that rate and the fraction of waste. For the willingness to separate waste before dispose for collecting is done by personal interview. The result shows that more than 80% of citizens are willing to separate waste at the source. It means that it is likely that the implementation of the at-source separation is successful. (T.Sekito 2013) also focused on people's behavior in waste reduction. This study is to evaluate people's attitude toward waste management system in Indonesia. In this study, the main methodology to study people attitude is a questionnaire. The questionnaire is divided into three parts as (Figure 8).

I. Respondent General Information
Name, Gender, Age, Education degree, Income, House type

II. Awarenesses of Environmental and Solid Waste Management issues
What environmental issues are you aware of?
What kind of issue about waste management that you aware
Where did you get information regarding global

III. Waste Management Awareness
Where do you usually discharge your household
Have you ever heard of 3R and do you know what is it?
Satisfaction level for current waste
How much can you afford to pay for the waste management?
Can you cooperate to separate your household waste?

Figure 8: Section in Questionnaire

With this kind of information, it allows the author to know the factors that have relationship to each other. For example, Education and income level affects to waste generation rate and so on. After knowing these kinds of factor, author can give recommendations and suggestions accordingly to implement the system successfully. It is the goal of this study.

(Ying Zhuang 2007) also studied about the behavior of the citizens in China as well. After introduce at-source separation and do the economic assessment, the author finds out that at-source separation is cost effective; it also gives benefits to environment as well. Besides doing the assessment, the author also want to study people attitude toward separation. As a result, the author does the performance survey and distribute questionnaire to every stakeholder to promote at-source separation. About two hundreds were provided questionnaire and interviewed. The result shows that there is an active support from every stakeholder such as citizens, Estate Company and other involved stakeholders.

In short, study behavior of the citizen and key stakeholder is one crucial part in our implementing the new system. Without co-operation from every stakeholder, the new system intended to implement is not successfully achieved.

Chapter III

Methodology

In this section, the steps of how to do the research have been described in detail, as shown in the Figure below, in order to attain the objectives, which are mentioned above.

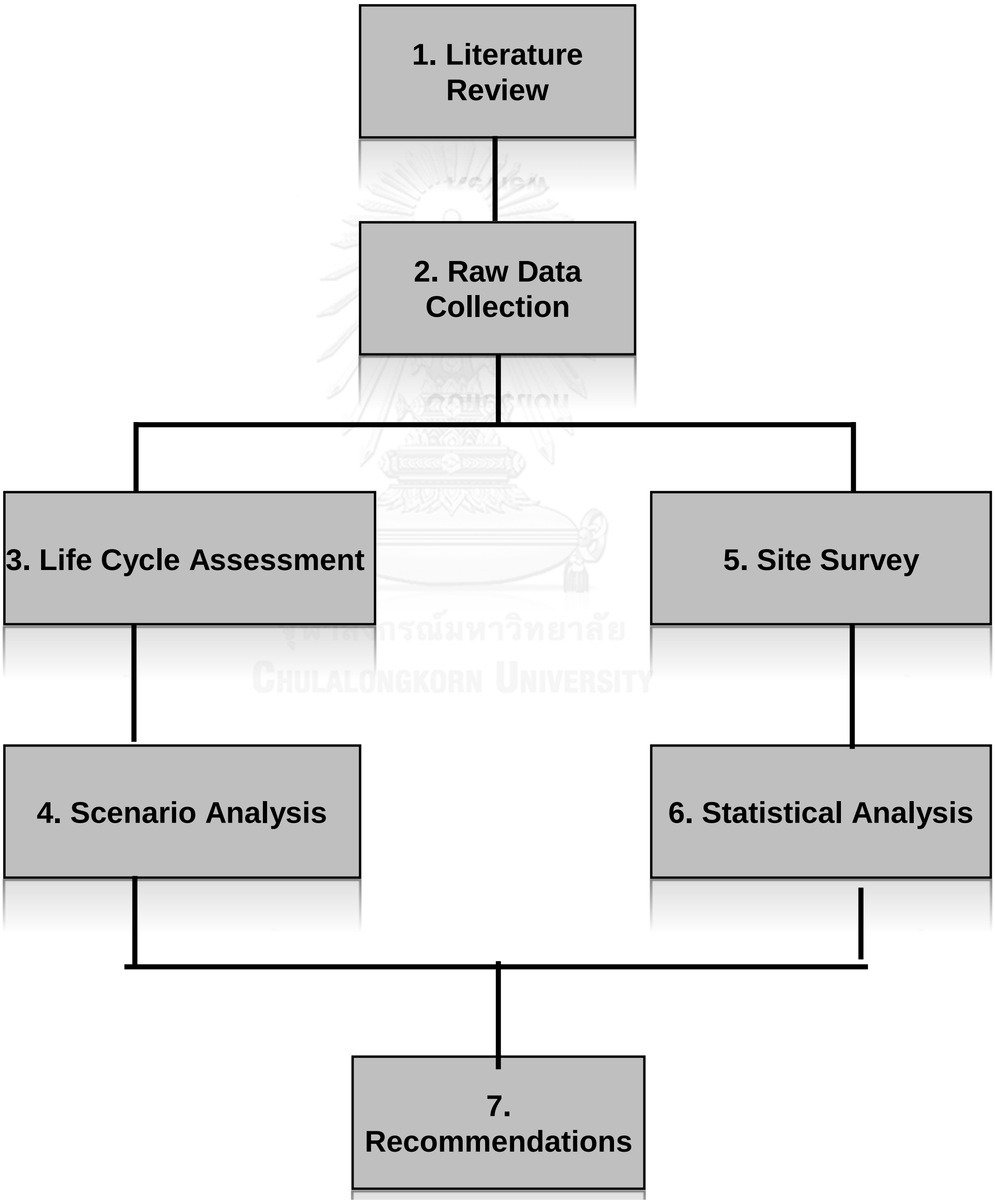


Figure 8: Methodology

III.1 Literature Review

In this section, many literatures and past studies and official documents regarding municipal solid waste management in Phnom Penh municipality published by state government have been reviewed to get the information and understand about the Phnom Penh Municipality as well as the current municipal solid waste management.

There is no separation system of waste before dumping in the landfill. All kinds of waste that coming from every source were transferred to the landfill. There is only one landfill which is in operating nowadays. The recycling method is not widely practical in Cambodian society as well. The recycling, up until now, basically have been done by waste owner, waste collectors or any other scavengers to make a little profit from it. There is no proper system to separate and take advantage from recyclable waste. (Figure 9).

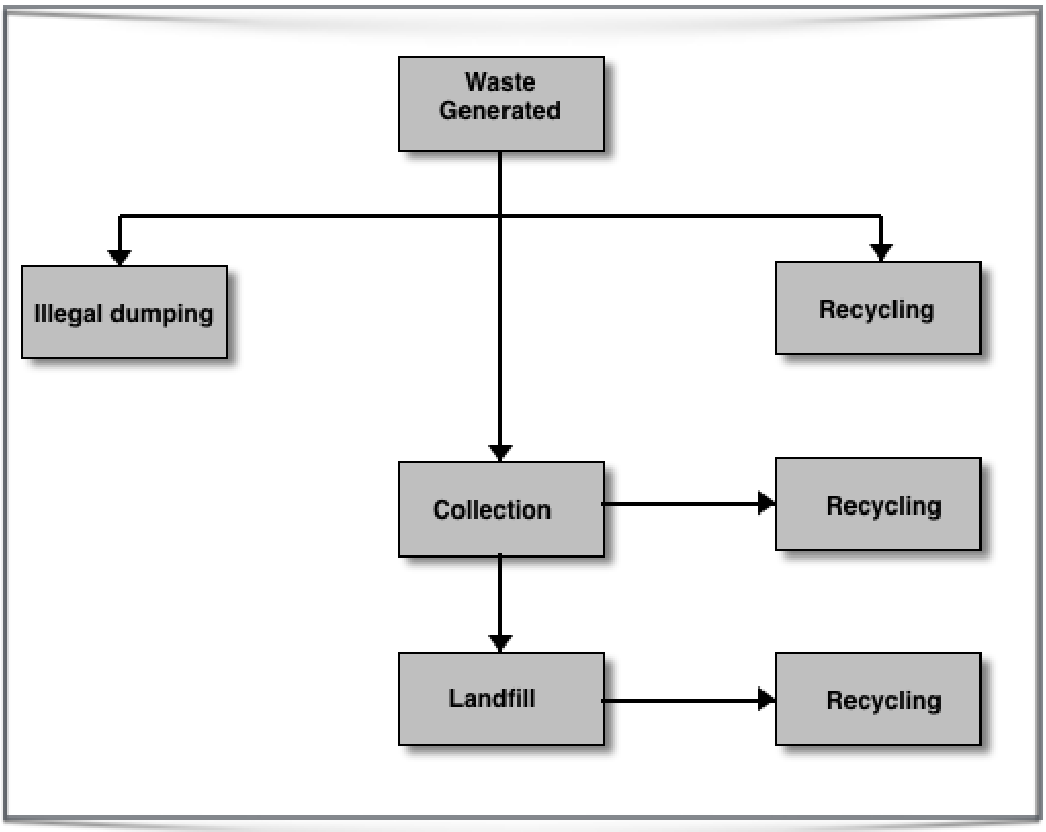


Figure 9: Waste Flow in Cambodia

III.2 Raw Data Collection

The main purpose of this site visit is to get to know the real situation of the Municipal Solid Waste Management of Phnom Penh regarding the existing problems every day, the management of all waste generated, the resident behavior toward waste problems and management, last but not least the willingness to cooperate and to pay more to make improved of the current management system. To acquire that information, it is important to make an interview with the three related person who are working in the company which is in charge of the whole municipal solid waste management in Municipality Phnom Penh. We also interview with the waste collectors to know about the problem of waste generated by the residents in the area. In addition to this, we also distribute about 100 questionnaires to the residents itself to study about their background, their understanding toward environmental problems and awareness and their willing to cooperate and so forth.

By studying about their information background, we can determine the key factors that affect waste generation, willingness to cooperate and willingness to pay. The factors are such as:

- Gender
- Education level
- Family size
- Income
- Living area
- House type

III.3 Life Cycle Assessment

This technique is used to assess and evaluate the system performance by evaluating its products transformation through its life cycle, from cradle to grave. LCA has been a principal tool for decision-making and for policy maker for a better waste management and waste management planning. The purpose is to study about the environmental impacts of each the suggested scenario and find out which one of the scenarios provide the most benefit with the less environmental impacts.

✓ Goal and Scope

The goal of this study is to evaluate the GHG emission from the current existing municipal solid waste management system in Phnom Penh from life cycle perspective. Another goal is to compare the GHG emissions with other MSW management system to see the potential GHG mitigation in different strategies by using scenarios analysis.

✓ Functional Unit

The functional unit in this study is "The total amount of municipal solid waste collected in Phnom Penh municipality". The waste collected is mainly the household waste in the urban area. The total amount of MSW in 2013 is 505,094 tons (Cintri 2013). The vast majority of overall MSW waste is food waste fraction. It takes accounts for almost 70% of the overall amount of MSW while plastic waste stands at the second position accounting for 14.47 percent.

✓ System boundary

The system boundary in this study begins with the transportation of the truck from household to landfill which located approximately 16km from the heart of the city. The GHG emission of the landfill and the substitution of primary production are included in the boundary. The system boundary is shown in the figure 16 below.

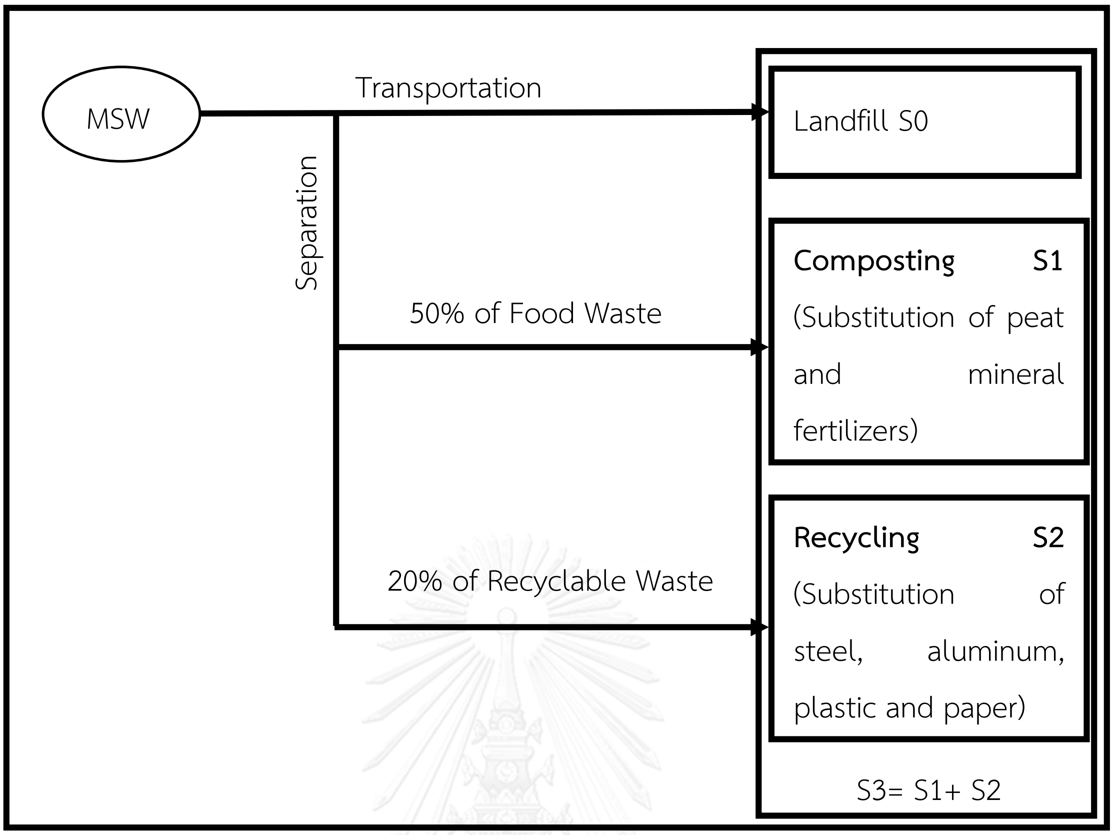


Figure 10: System boundary of LCA analysis

III.4 Waste Management Scenario Analysis

After identifying the problems in the current waste management, three scenarios are proposed to evaluate the environmental impacts.

In part one, the study focuses on the calculation of the greenhouse gas emission in the year 2009, the starting year of the new landfill. The calculation is estimated the greenhouse emission emitted from 2009 to 2100.

1. 20% of recycling valuable material
2. 50% of food waste utilization, composting.
3. 20% of recycling and 50% of food waste utilization

In the second part, it is necessary to estimate the future trend of greenhouse gas emission caused by municipal solid waste management. The calculation is estimated the greenhouse emission of solid waste that disposed in landfill from 2009-2030. The emission is projected to 2100 as well. The waste disposed to landfill from 2016 onward is estimated based on the national data of the estimation of population growth in Cambodia multiplied by the waste per capita of the current waste management. It is assumed that there is no change in waste composition and the amount of waste generation. In this calculation, there are 7 assuming scenarios used to do the evaluation to see the potential reduction of greenhouse emission of each system, which reflects the waste management strategies.

1. 20% of waste recovery, recycling.
2. 50% of food waste utilization, composting.
3. The combination of 20% recycling and 50% of composting.
4. Accumulatively increase 2% of waste prevention each year until reach 20% prevention.
5. The change of waste composition in 2020.
6. 50% of gas collection system installed in 2020.
7. 70% of gas collection system installed in 2025.

The valuable material that are recycled in this study are: plastic, paper, metal and glass bottle. To measure the performance of the existing waste management system comparing to the scenarios which suggested above, Life Cycle Impact Assessment has been employed as an indicator to evaluate and assess the impact to the environment. After finding out the performance of existing waste management and the suggested scenarios, recommendations will be given afterward.

III.5 Site Survey

Even though there are the best solid waste management systems proposed, there will be useless if the residences do not cooperate in the proposed system. The key element of implementation of a new system is people. This survey is to study whether people are cooperating and willing to pay depends on cost in the proposed system or not. Furthermore, it also investigates the factors that make people do not want to cooperate in the new system. After knowing the factors making people do not cooperate in the system, it is easy to find solutions and help to implement the new system successfully. Willingness to pay is also the key element that is needed to study as well because in order to implement a new system successfully, the people cooperation is important, but people willingness to pay more is also a key factor that important too.

To study about people behavior, the most popular method is to distribute the questionnaires to as many people as possible with good representatives of each demographic group. In this study, the simple descriptive method of the statistical analysis is deployed to study about people' behavior and willingness.
The questionnaire covers:

- Citizen general background information
- Understanding of Environment
- Willingness to pay more to improve the current existing waste management

The above information will tell about the relationship between the citizen background such as sex, age, education level, career and so on with:

- Understanding of Environmental Issue
- Understanding of solid waste issue
- Waste generation and composition
- Waste separation

- Willingness to separating and recycling
- Willingness to pay for a better solid waste management.

III.6 Statistical Analysis

As hundreds samples are collected, to be more efficient and reliable, it is important to use computer software to help us to analyze the data statistically. In this stage, we use the software, which is call SPSS (Statistical Package for the Social Science) as it is well known software by any researchers around the world.

SPSS is a software used for statistical analysis. This software is widely used by the researchers, scientist, professor and students from all fields of study. SPSS allows users to enter the data and analyze those data. The program will create the table and plot the graph as the final output. SPSS is capable of deal with large amounts of data including texts and numbers, and perform all kind of analysis. The program will help users a great deal in term of time and efficiency. Descriptive Analysis is used in this study.

III.7 Recommendation

After accomplishing all the processes mentioned above, the last step is to give the recommendations and suggestions to deal with the problems existing in the current municipal solid waste management system to have a better municipal solid waste management in Phnom Penh municipality.

Chapter IV
Results and Discussions

It is very important to understand about the overview of the current waste management and address the problems existing in the current system in order to find solutions to improve the current system. The first section of this study is to get understanding the current waste management system such as waste storage, waste collection and transportation, waste treatment, waste disposal and so on. After getting the information of the current waste management system, problems existing in the system are identified. Several scenarios are suggested to do the assessment in term of environmental impacts, focusing only on Greenhouse emission, to compare with the current waste management system. After finding out the best waste management system scenarios, it is important to study about the feasibility of the implementation of the system. Behavioral study is proceeded afterward.

IV.1 Current Waste Management System

IV.1.1 Waste Storage

Because of the fact that there is no storage available in the residential area, normally, waste is packaged in the plastic bag placed along the curbside of the road waiting for the collection from the service provider. Scavengers often come at night and try to find the valuable material in the bag, or some animals like dogs try to find something to eat from the waste pile; as a result, the waste might become scattered on the street. If it is the case, it makes the collection difficult and inefficient. It is time-consuming and it is not possible to collect everything left on the street. In some areas like food market, there are storage bins available for storing the waste; but because those bins are not big or the number of bins are not enough or maybe the amount of waste generation is too great, it is commonly seen that the waste are dumped outside the bin. And it is seen that the waste are disposed in the free-spaced area. When the collectors come to collect those waste, generally, the transferring of waste from these storages or containers to the collection vehicles is done by hand. Consequently, the high efficiency of collection is not obtained. The waste is seen littering around the bins. It is worth mentioning that waste is not separated at all before collecting and disposing.

IV.1.2 Waste Collection and Transportation

Cintri is a private company that has been received the privilege from the government to provide the collection, transferring and disposal service to the whole city since 2002. All waste collected are transfer directly to the landfill. There is no at-source separation or collection practiced in the city. The collection and transferring are done by mixing all kind of waste at the collection time. All types of waste from almost every sources, except medical and industrious waste, are collected, transferred and dumped in the landfill, which located about 16km from the city. The waste collection service is not provided regularly to every place in the city. Generally, the service is given regularly only to the commercial or the highly visible area; or in other word, area that collection service fee is higher and regularly paid. For some areas such as poor areas, especially the outskirt or suburban, the service is provided irregularly. It is estimated that the waste collection efficiency in the whole city is improved slowly from 60% in 2003 to 82.1% in 2009 (Seng et al. 2010). In 2013, it is estimated that the waste collection efficiency is improved to about 85% in the whole city (Cintri 2013).

IV.1.3 Waste Disposal and Treatment

Landfill is the only management option practicing in Cambodia nowadays. There is no incinerator or other facility in Cambodia. Steung Mean Chey landfill site, the first landfill in Cambodia, is the place where waste is disposed. It covers the area of 6.8 ha. All kinds of waste from almost every sources sent to this landfill without pre-sorting or pre-treatment. The landfill was practiced by open-dumping method, not a sanitary one. It was seen that even hazardous waste such as medical and industrial waste disposed in this landfill. Steung Mean Chey was completely ceased its operation in 2009. With the cooperation with JICA (Japan International Cooperation Agency), new landfill was built to replace the old one. Since 2009, a new landfill has been launched.

It is called Dorngkor Landfill Site, which covered the area of 26 ha. It is designed to be a sanitary landfill. It consists of leachate pond and other treatment facility. But because of the financial and technical barrier, the Dorngkor is not a sanitary as its purpose. The soil that is supposed to cover the garbage every day is covered irregularly, or never covers at all recently. The leachate that is drained to the leachate pond is left without further treatment. It is left to evaporate to the atmosphere. Additionally, there is no formal recycling facility existing in the system. The recyclable waste is done by the scavengers that live their lives by collecting the valuable material from the waste pile such as from the landfill. Some scavengers collect the valuable material from the waste that left at the curbside while the others who give some money to the gate keeper to be able to enter and collect in the landfill site. It is estimated that there are 1400 tons of waste dumped in Dorngkor landfill every day (Cintri 2013).

IV.2 Existing Problems

It is normal that developing country like Cambodia has a lot problems regarding solid waste management. In order to improve the current municipal solid waste management, it is important to identify the problems existing in the current waste management. It is commonly seen in many developing that the waste collection efficiency are still low. The collection service is not given to everywhere in the city. The service is given regularly to the commercial and highly visible area. The low collection efficiency might partly because of the infrastructure in the city. Some roads are very small that disable the truck accessing to that area to collect the waste. As a result, the citizens illegally drop their waste along the street or illegally dumping. In Phnom Penh, capital city of Cambodia, is facing the problems regarding providing proper waste management in the city. Below are the photos of the problems that exist in Phnom Penh when we do the survey.

First of all, the waste collection efficiency is still low. This is partly because of the poor condition of the infrastructure in the city. Some roads are very small that disable the truck accessing to collect the waste from that area. Moreover, the irregularity of the collection time in the poor area makes situation worse. The residents cannot wait for the collector to collect their waste. These factors lead to illegal dumping of solid waste along the street or in the free space (Figure 10). This problem is not only difficult for the collection, but also affect the image of the city as well.

Figure 11: Waste Waiting for Collection

Second, the environmental awareness and caring toward environment issue is still low. People cannot wait for the truck to collect the waste from their residents. In figure 11, people just dispose their waste in the free space area or even along the main street in the city. It is common for people disposing their waste along the street or even in the middle of the street in many part of Municipality Phnom Penh. This action gives a very bad looking of the city of one country for the tourists. We can see in the figure that a lot of bags of garbage are disposed in public area where you can people commute in that area. Consequently, the waste produces the bed smell in that public area. Plus, that waste sometimes becomes scattered on the street because the scavengers looking for the valuable things like aluminum cans, and other any sellable materials and so on, and because the dogs try to find food in the garbage bag too.

From this problem, we can say that the waste disposal regulation of the government is still weak and need to be strengthening.

Figure 12: Free Space Disposal Area

In figure 12, it might be because the fact that there is no storage system installed in the community, people disposed in the public area to get rid of the garbage out of their house; but very disappointingly, in figure 13 illustrates that there is storage system for them to disposed their garbage, but people just disposed it outside the storage system. It is obviously show that the awareness regarding the environment especially regarding solid waste issue is still alarmingly low. This issue need to be addressed and solved to raise people awareness to improve the current municipal solid waste management system.

Figure 13: Waste Put Outside Bin

In figure 13, we can see that people dispose waste illegally despite the fact that there is the instruction not to dispose in this area. In the picture, we can see there is an instruction notice written in Khmer which translate in English as “This area is prohibited to dispose any waste”. Even there is such a prohibition, people seem not to obey or even care about the instruction. This not only means that the people awareness is low, but also the law or regulation must be enforced to deal with the violators with heavy penalty.

Figure 14: Waste Disposed Illegally despite the Instruction

Third, because of the irregularity of collecting the waste disposed along the street on time, it causes a flood when there is a big rain because those scattered waste clog the water way that do not allow the water to go through. It takes hours after raining for the flood to disappear in the city.

Figure 15: Waste Clog the Water Way

Fourth, currently there is no waste separation practiced in the city. The small amount of recyclable waste is recycled informally by the scavengers or the waste collectors. Moreover, the waste is wet that makes it hard to recycle some material such as paper or paperboard. Last but not least, open burning is still practiced in some areas especially in the outskirt of the city. They normally burn the household waste, the leaves of the true in mixing with the plastic bag. This can cause air pollution and affect to the human health.

Figure 16: Informal Recycling

After getting insight into problems, giving solutions to solve problems is needed to proceed, but the involvement of the citizens are equally crucial. Consequently, this study focuses on two part to improve the current waste management system. First, several different scenarios, reflecting the waste management strategies in many countries, are suggested to compare the environmental burden to the current waste management. Life Cycle Impact Assessment in used to evaluate the environmental impacts of the system. Greenhouse gas emission is considered as the indicator to assess and compare the burden of the system to the environment. Second, behavioral analysis is the main purpose of this study too. It is meaningful to study about how people think and care about the environment. The questionnaire survey is deployed in this study. The distribution of questionnaire survey is carefully done to obtain the reliability as much as possible. Plan and targeted area have been carefully made and chosen before doing the survey. Mostly the questionnaire survey is done by using house to house approach, and by distributing at crowded area like market and so on. To conduct the survey faster, two people that have experiences in doing this kind of survey were hired to help. Prior to doing the survey, two session of training were conducted. The first session is to explain the material in the questionnaire survey and identify the questions that might be asked during doing the real survey. The second session is a mock survey. Several people of about thirty years old are asked to answer the questionnaire survey. They asked many questions what they are not cleared about the question in the survey. After making sure that they understand about each question in the survey, the real survey has been launched.

IV.3 Life Cycle Assessment Result

The main purpose of this study is to estimate the greenhouse gas emission (GHG) from the current waste management system in Cambodia. Before doing the calculation, the concept of landfill gas emission from disposal site is necessary to understand.

IV.3.1 Transportation

Transportation in this context refers to the collection the waste from the municipality and transport it to the landfill by using the trucks equipped with the compacting function. Waste collection and transport carried out in Phnom Penh Municipality is based on diesel consumption trucks. According to Cintri, company in charge of providing MSW management service in Phnom Penh municipality, there are 138 trucks consisting of compactor trucks and arm roller trucks are in operating for cleaning and transporting at all the MSW at all area in the municipality. The total amount of MSW that is transported to dump site, which located approximately 16 km out the municipality, is 1200 tons per day (Cintri). Because there is no data about the total distance the trucks travel for collection and transfer to the landfill, Google map is used to estimate the average distance that the truck travelling for collection and transfer to landfill. Various points in Phnom Penh were pinpointed to estimate the distance from the landfill site, namely Dongkor landfill site, by using Google map. The travelling distance of the trucks has been estimated by calculating for the average distance. The places that are chosen are mostly from food markets which normally located in urban areas where there are crowded of people living in. Waste in this area is also generated a lot. The trucks used in transportation in Phnom Penh municipality is a 10 wheel trucks. Assuming that it is a 16 ton truck with the 75% loading. According to Thai National Database, 10 wheel truck with75% of 16 tons loading emits greenhouse gas 0.0689 kgCO_2 eq per kmt (TGO 2011).

Table 6: Distances to Different Plasces

Location	Distance	Location	Distance
Wat Phnom	16 Km	BeungKengkong Market	13.9 Km
Central Market	16.4 Km	Chhba Ampoeu Market	11.7 Km
Orussey Market	16.1 Km	Kandal Market	16.4 Km
TuolTompong	10.1 Km	Olympic Market	16 Km
Kilo 6 Market	22 Km	Prek Pnov Market	32 Km
Jas Market	16.9 Km	Prek Anchanh Market	35.6 Km

It is assumed that the average transportation distance is 18.6 Km based on the table above. The main emission from transportation is carbon dioxide (CO2) produced from the combustion of the diesel used in the trucks. Table below shows the summarization of the important value for calculate the greenhouse gas emission and the carbon dioxide emitted from transportation.

Table 7: Emission Factor and GHG Emission

Transportation	Loading (tons)	Quantity	Avg.Distance (Km)	Emis(kgCO2 eq/kmt)
10 wheel truck	10	138	18.6	0.0689

According to the calculation of the value shown in Table 7, the carbon dioxide emission from collection and transportation is 1319 tons CO2. This number is generally too small comparing the greenhouse emission emitted from landfill.

IV.3.2 Greenhouse Gas Emission from Landfill

Landfilling produces significant amount of landfill gas. Landfill gas mainly consists of methane (CH_4). Beside methane, it also produces the biogenic carbon dioxide (CO_2) and other small amount of nitrous oxide (N_2O), nitrogen oxides (NO_X) and carbon monoxide (CO). Methane produced by waste disposal site contributes approximately 5 percent of the global anthropogenic greenhouse gas emissions (IPCC, 2001). Methane and other landfill gas are developed in four stages. Gas composition varies in each stage. After being disposed in the landfill, degradable material in waste is decomposed by aerobic bacteria. After the process complete to consume oxygen, anaerobic bacteria take turn to deplete the remaining waste. It breaks the organic matter into the several substances. For example, cellulose, amino acids, sugar and so on. After this process, fermentation process takes pace to further break these substances into gases and organic compound which is a short-chain compound. In this process, methanogen bacteria is growing. This bacteria transform the products that come from fermentation process into the biogas and stabilized organic materials. The biogas is generally known as landfill gas. Generally, the biogas contains of methane (CH_4) and carbon dioxide (CO_2). According to USEPA report, the composition of landfill gas is 41% CH_4, 34% CO_2, 22% Nitrogen (N_2) and 3% Oxygen (O_2) (U.S. EPA 2008). This data come from the measurement at the landfill site with active landfill gas collection system. But it is commonly assumed that 50% of the carbon in the landfill will be degraded and transformed to CH_4, and the remaining 50% of carbon degraded in landfill transform to CO_2. There is only a very small amount of carbon degraded in landfill convert into carbon monoxide (CO), which is generally ignored. Besides these substances, there are also an ignorable substances that released from landfill such as volatile organic. Landfill gas usually consists of 50-55% of CH_4, 45-50% of CO_2 by volume, and 2-5% of other landfill gas. Landfill gas is produced stably in the last stage, stage IV.

Recently, there are a few studies about greenhouse gas emission that have been done to estimate the greenhouse gas emission in Cambodia. This study will estimate the methane and carbon dioxide by using the IPCC waste model. The IPCC methodology is based on First Order Decay (FOD) method. This method assume that degradable organic carbon (DOC) slowly decay in a few decades of the landfill. During this time, CH4 and CO2 is produced. As a result, CH4 is a main landfill gas emission in the first few year, but it gradually decrease because the degradable carbon in the waste is consumed by the bacteria for the decay. (IPCC 1996).

It is generally acceptable to assume that the biogas generation is modeled using the first-order decay model. It means that the aerobic degradation takes place for only a short period of time, typically no more than a month. With the oxygen absent because of the burying of waste, it normally spends up to a year or two for the anaerobic degradation process to take place (IPCC, 2006). There are several models available to estimate the methane emission as well as carbon dioxide emission from landfill. In this study, the equation that adapted from IPCC, 2006 and U.S. EPA 2008 has been used to calculate the amount of methane emission from landfill. The first-order decay model for CH4 generation is shown as follows:

$$A = \left[\sum_{x=S}^{T-1} \left\{ W_x L'_x \left(e^{-k(T-x-1)} - e^{-k(T-x)} \right) \right\} \right]$$

where

A = CH_4 generation (Mg/yr)
x = Year in which waste was disposed
S = Start year of inventory calculation
T = Inventory year for which emissions are calculated
W_x = the quantity of waste disposed at the solid waste disposal site (Mg)
L' = CH_4 generation potential (Mg CH_4/Mg waste)
= $MCF \times DOC \times DOC_F \times F \times 16 / 12$ [IPCC nomenclature]
= $L_0 \times 16/0.02367 \times 10^{-6}$
L_0 = CH_4 generation potential (m^3 CH_4/Mg waste) [AP-42 nomenclature]
MCF = CH_4 correction factor (fraction), typically 1 for managed landfills
DOC = degradable organic carbon [fraction (Mg C in waste/Mg waste)]
DOC_F = fraction of DOC decomposed (fraction), generally assumed to be 0.5
F = fraction by volume of CH_4 in landfill gas, generally assumed to be 0.5
k = decay rate constant (yr^{-1}).

Figure 17: GHG Emission Calculation Equation

The methane correction factor (MCF) varies depend on the way waste is managed. For example, the value is equal to 1 when the site is well managed, anaerobic site. The value will become 0.4 when the site is unmanaged, or shallow waste, less than 5m. The fraction of methane (F) in the landfill is normally 50% of the landfill gas. As a result, the value of the fraction of CH4 of the landfill gas is 0.5 is highly recommended. The oxidation fraction (OX) is the amount of CH4 from the site that is oxidized in the soil. The value is ranging from 0-0.1. It normally equals to 0.

Table 8: Important Parameters (IPCC 2006)

Parameter	Parameter Description	Parameter Value
MCF	Methane correction factor	1
DOCF	Fraction of DOC degraded	0.5
F	Fraction in CH4 in generated gas	0.5
OX	Soil oxidation factor	0.1
Delay Time	Time prior to the start of anaerobic decay	6

Degradable organic carbon (DOC) can be calculated by:

% DOC by weight = 0.15(A) + 0.2(B) +0.4(C) + 0.43(D) + 0.24(E)

Where

A =% Food waste

B = % Garden

C = % Paper

D = % Wood and straw

E = % Textiles

Table illustrates the important parameters that need to be included in the calculation. These parameters are degradable organic carbon (DOC) and decay rate (K). These numbers are the recommendation number for landfill from IPCC and US EPA. It can be chose according to the real situation and condition of the landfill. It is worth to mention about the climate condition that determine the value of decay rate (K). The climate classification is based on the annual rainfall of the countries. It can be considered as the dry climate when the annual precipitation is less than 20 inches/ year. It can be classified as the moderate climate when the annual precipitation is in between 20-40 inches/ year. When the annual precipitation is more than 40 inches/ year, it is considered that it is in the wet climate category.

Table 9: DOC and K Value (IPCC 2006)

Waste Model/Waste Type	DOC (weight fraction, wet basis)	k [dry climate[b]] (yr^{-1})	k [moderate climate[b]] (yr^{-1})	k [wet climate[b]] (yr^{-1})
MSW Landfills—Bulk Waste Option				
All waste materials	0.2028	0.02	0.038	0.057
MSW Landfills—Bulk MSW Option				
Bulk MSW	0.30	0.02	0.038	0.057
Construction and demolition waste	0.08	0.02	0.03	0.04
Inert waste (glass, metal, plastic)	0.0	0.0	0.0	0.0
MSW Landfills—Waste-Specific Option				
Food waste	0.15	0.06 [c]	–[c]	0.185 [c]
Garden waste	0.20	0.05 [c]	–[c]	0.10 [c]
Paper waste	0.40	0.04 [c]	–[c]	0.06 [c]
Wood and straw waste	0.43	0.02 [c]	–[c]	0.03 [c]
Textile waste	0.24	0.04 [c]	–[c]	0.06 [c]
Diapers	0.24	0.05 [c]	–[c]	0.10 [c]
Sewage sludge	0.05	0.06 [c]	–[c]	0.185 [c]
Inert waste (glass, metal, plastic)	0.0	0.0	0.0	0.0
Industrial Waste Landfills				
Food processing industry	0.22	0.06	0.12	0.18
Pulp and paper industry	0.20	0.02	0.03	0.04
Wood and wood products	0.43	0.02	0.03	0.04
Construction and demolition waste	0.08	0.02	0.03	0.04
Inert waste (glass, metal, plastic)	0	0	0	0
Other industrial solid waste (not otherwise listed)	0.20	0.02	0.04	0.06

According to IPCC guideline, it is highly recommended to calculate GHG emission in the inventory at least 50 years; it is because it takes long time for some material such as wood or textile to degrade its carbon. In this study, GHG emission is planned to calculate the GHG emission from 2009 to 2030 because the food waste should be degraded almost to nothing in this timeframe. To be sure that the calculation is not underestimated, the graph of decay rate of materials are plotted to see the organic carbon after 2030. The graph below illustrates the decay rate of some carbon-containing material from 2009 to 2030.

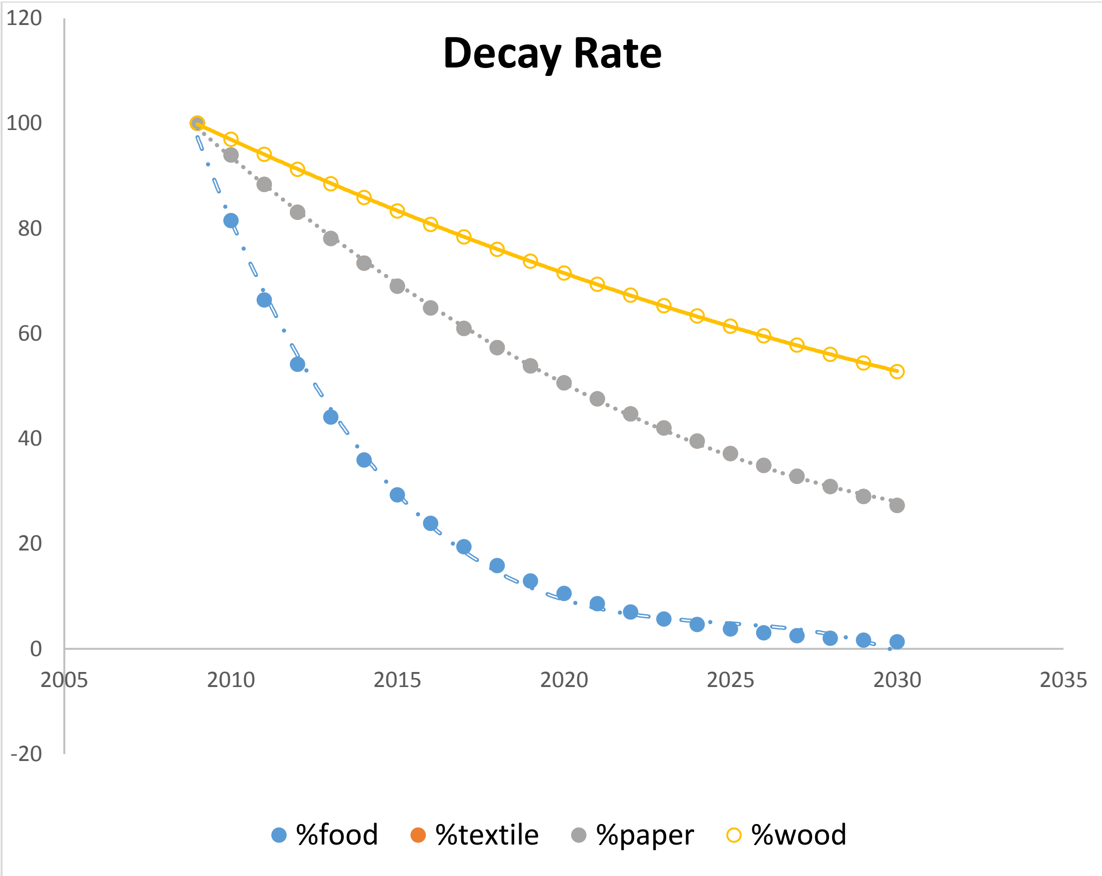


Figure 18: Decay Rate of Waste in 2030

Figure shows the decay rate of waste in Phnom Penh according to the calculation of K value in Table 9. In the graph shows that the amount of food waste is degrade to almost 0% in 2030, but if we take a look to paper and textile, there are around 30% of carbon remaining in the landfill in 2030. This carbon can be degraded and continue to release methane in the future. Wood has more than 50% that do not degrade in 2030. As a result, the calculation cannot be stop at 2030. As a result, it is necessary to continue the calculation from 2009 to 2100.

IV.3.2.1 GHG Emission Calculation of Waste in 2009

- Scenario 0 (Baseline Scenario) – Current Existing Waste Management

After gathering all of the important parameter, GHG emission from 2009 can be calculated. Before calculated, it is also important to know about the waste flow of the system that we need to calculate. In order word, we have to know the system boundary of the system. After knowing the system boundary, it is easy to calculate since it tells what is included in the boundary and what can be ignored from the boundary.

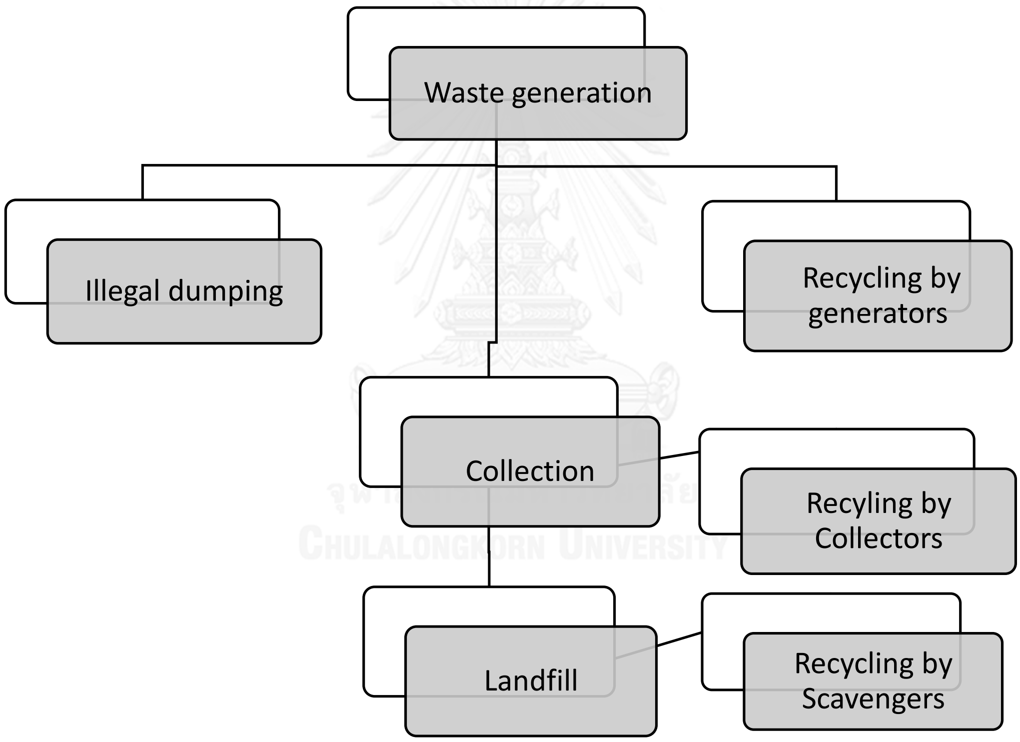


Figure 19: Waste Flow in Scenario 0

The flow chart above illustrates the waste flow in the current waste management. The majority of waste generation at source is collected and transported to the landfill directly, only a small amount of waste is illegally dumped by the residents, and the other small amount of waste is informally recycled by waste collectors or scavengers for selling purpose to make some profit. The waste is disposed in landfill without doing any pretreatment or post treatment, no sorting system, no gas collecting system installed in site.

Table 10: GHG Emission in Scenario 0

Category	Amount (Tons)	DOC	Decay Rate (K)	GHG emission (Tons CH4)
Food	248868	0.15	0.185	12,443
Paper	10666	0.4	0.06	1,416
Textile	21332	0.24	0.06	1,699
Wood	7111	0.43	0.03	953
Total	-	-	-	16,511

Table above demonstrate the amount of greenhouse gas emission in 2009 to 2100. In 2100, the waste that dispose in the landfill in 2009 release the methane gas 16,511 tons. It is worth to mention that the unit of this result is in tons of methane (Ton CH4). The common unit of greenhouse gas is in ton CO2 eq. According to IPCC 2007, CH4 is stronger than CO2 25 times. As a result, in order to convert from tons CH4 to ton CO2 eq., it can be simply done by multiplied the number by 25. The chart below illustrates the greenhouse gas emission by categories in CO2 equivalent.

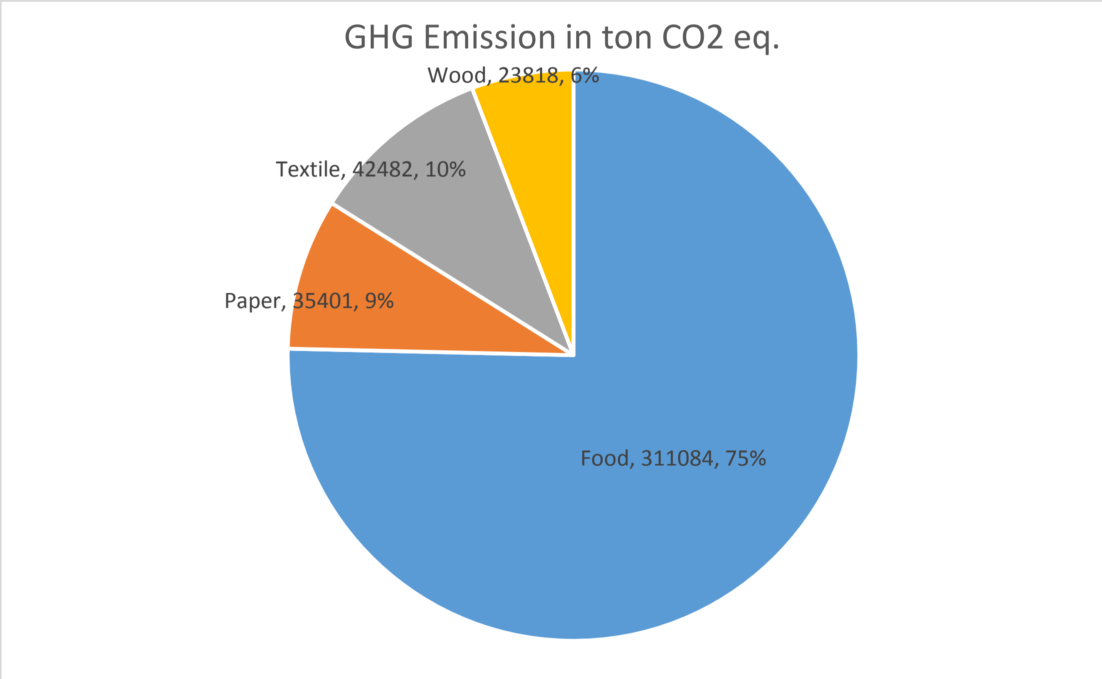


Figure 20: GHG Emission by Categories

The total of GHG emission is 412,785 tons CO_2 equivalent. Amongst the whole emission, food waste, which account for 70 percent of total waste, is also the dominant group of GHG emission. It takes account for 75% of the total emission. Paper, textile and wood release the GHG in the similar amount which is 9%, 10% and 6% respectively.

After getting the amount of greenhouse gas emission in the current existing waste management system, according to LCA theory, it is necessary to compare with other systems to do the comparison. In this study, three different scenarios, reflecting waste management strategies in various countries, are chosen to evaluate the environmental impact, Greenhouse Gas emission, and compare with the scenario 0. These three scenarios are: 50% of composting, 20% of material recovery, the combination of 50% of food composting and 20% of material recovery.

- **Scenario 1: 50% of Food Waste Composting**

Before doing the calculation, it is necessary to understand the waste flow in this system. Figure below show about the waste flow from source until disposal.

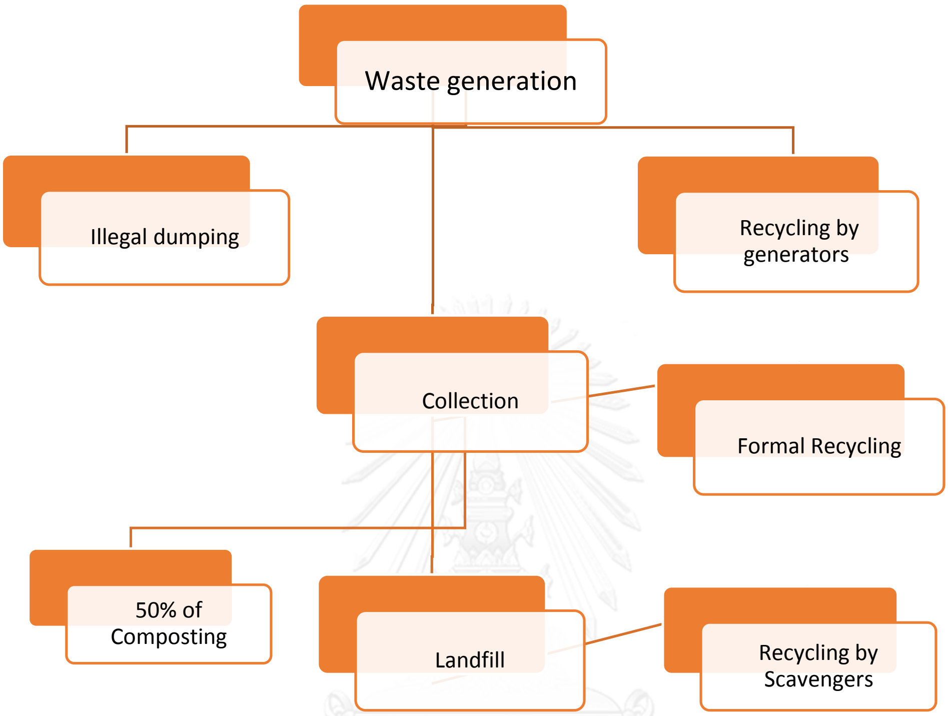


Figure 21: Waste Flow in Scenario 1

The chart flow clearly illustrates that waste flow is similar to that in the baseline scenario except that 50% of food waste are separated at collection stage and transferred to the facility to do the composting. This scenario is according to the government vision to promote the composting in the system. Some amount of waste are still assumed to dispose illegally, and some amount are recycled illegally, and the rest are transferred and dispose in landfill without further treatment. To calculate the reduction of GHG emission of composting, emission factor of EPA 2008 is adopted. Table below shows the emission factors for recycling and composting for some material.

Table 11: Emission Factor of Each Waste Management

Material	Recycling (EPA)	Composting (EPA)	Landfilling (Own Data)
Mixed Paper	-0.96	-	0.905224
Mixed Metal	-1.43	-	0
Mixed Plastic	-0.41	-	0
Mixed Organic	-	-0.05	0.3409091

Emission Factor of composting is adopted from U.S. EPA. The number illustrates in the negative number. It means that doing composting is beneficial to the environment, or it can be said that composting is an environmental friendly strategy. The emission factor of landfilling is estimated by using the data from the calculation of greenhouse gas emission from the current waste management system. To see the potential reduction of GHG emission from composting activity, it can be simply done by substrate the emission of landfilling by the emission of the composting. Table 12 below demonstrate the potential reduction of GHG emission in the system.

Table 12: Summary of the Result

Scenario 1: 50% Composting (Tons CO2 eq.)				
Category	Amount (Tons)	Emi. Factor	Reduction	GHG Emission
Food	248,868	-0.390909	-178,355	234,429

The emission factor of potential GHG emission reduction of composting is -0.390909074. It is in a negative sign. It means that the composting is giving the benefit to the environment. The calculation shows that after doing 50% composting, 178,355 tons CO2 equivalent are reduced. As a result, only 234,429 tons CO2 equivalent are emitted in the system from 2009 to 2100. The chart below shows the emission of the GHG by the waste categories in the scenario 1 system.

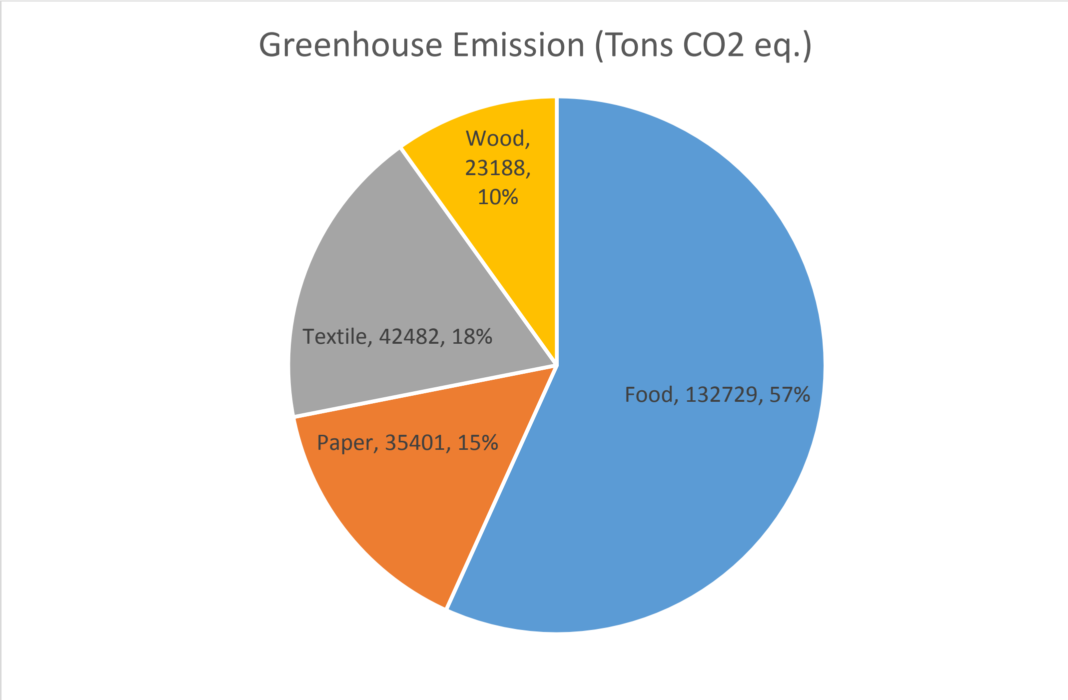


Figure 22: GHG Emission by Categories

The Total GHG emission in Scenario 1, 50% of composting, is 234,429 tons CO2 equivalent. It is obvious that only the emission that from food waste fraction is reduced; it is because we take benefit from composting only. Food waste that releases the GHG emission 75% in baseline scenario, current waste management system, reduces to only 57%. Even though the percentage of the GHG emission from Paper, Wood and Textile is increased, the amount of the emission of these material is remaining the same. The change of the percentage occurs because the total emission is changed due to the composting implemented.

Scenario 2: 20% of Material Recovery

After getting insight in the benefit of composting activities, it is also important to find out the benefits of material recovery. In this study, 20% of recyclable waste is assumed to be separated at source and transfer the recycling facility. 20% of recycling comes from the government vision to implement the 20% recycling. It is assumed that the recycling activity is done in closed loop. The informal recycling of waste that is done by scavengers still remain in the system. To get further about the calculation, it is important to understand about the waste flow in this system. Figure below illustrates about the system boundary in this scenario.

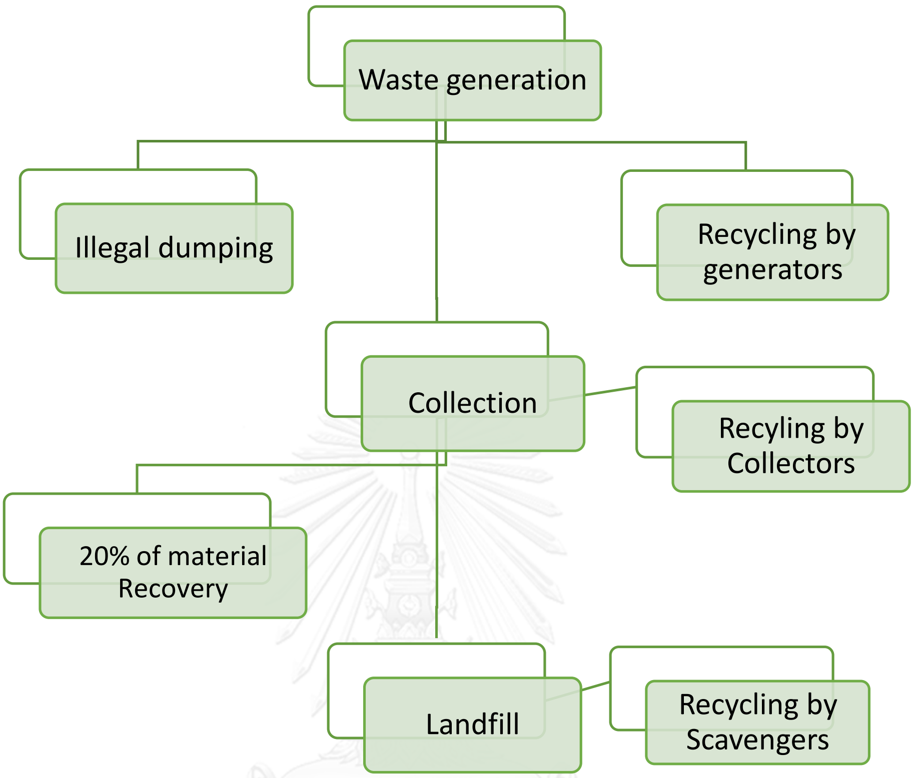


Figure 23: Waste Flow in Scenario 2

Waste generated is assumed to be separated before disposed for collection. 20 percent of recyclable material such as plastic, paper and metal are separated transfer to the recycling facilities. To calculate the GHG emission in this system, emission factor from US EPA is adopted for the calculation. Table shows about the emission factor from recycling activity in the US. The negative number illustrate the benefit of the substitution of raw material by doing the recycling. It is assumes that metal and plastic do not release any GHG emission if they are disposed in the landfill.

Table 13: Emission Factor of Each System

Material	Recycling (EPA)	Composting (EPA)	Landfilling (Own Data)
Mixed Paper	-0.96	-	0.905224
Mixed Metal	-1.43	-	0
Mixed Plastic	-0.41	-	0
Mixed Organic	-	-0.05	0.3409091

Table below show about the potential reduction of greenhouse gas emission of the 20% of material recovery comparing to the current waste management system, which is the scenario 0 or baseline scenario.

Table 14: Summarization of GHG Emission

Scenario 2: Material Recovery (Tons CO2 eq.)				
Category	Amount (Tons)	Emi. Factor	Reduction	GHG Emission
Paper	10,666	-1.86522404	-14,589	382,161
Plastic	53,329	-0.41	-16,034	

According to the result, the substitution of plastic production from raw material with the plastic production from the recycling plastic reduces 14,589 tons CO2 equivalent. If the 20% paper production recycling activity is implemented successfully, 14,589 tons CO2 equivalent is reduced from the system. The amount is similar to the reduction of the substitution of the plastic even though the percentage of plastic is much higher in the system; it is because the degradable organic carbon in very high, and it can be clearly seen that the emission factor of paper is -1.86 which is much higher than that of the plastic which is -0.41. The total emission of greenhouse gas in this scenario, 20% material recovery scenario, is 382,161 ton CO2 equivalent. The figure below illustrates the percentage of GHG emission from each materials in the system.

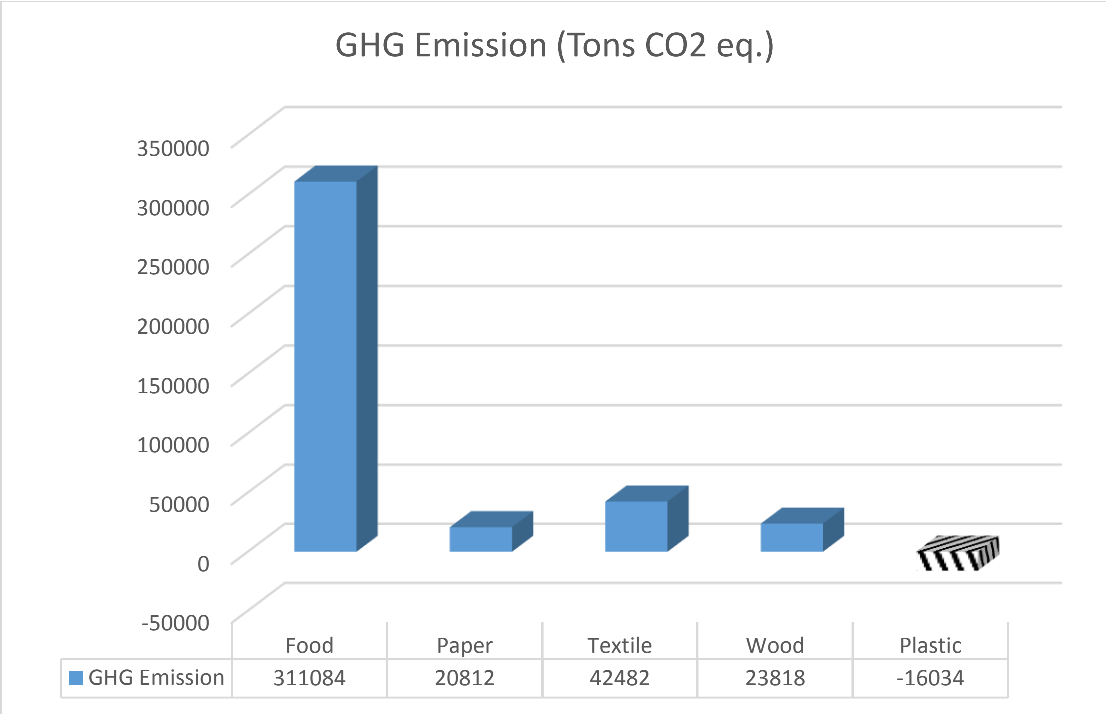


Figure 24: GHG Reduction

The graph shows the emission of greenhouse emission. If it is looked closely, the plastic has a negative result. It is because of the fact that it is assumed that plastic has no emission if it is disposed it in landfill. But the production of plastic from raw material release a great amount of greenhouse gas that emitted to the atmosphere. If it is substituted the raw material with the used plastic by doing the recycling, the greenhouse emission can be reduced up to 16,034 tons CO_2 equivalent.

- **Scenario 3: 50% composting + 20% Material Recovery**

This scenario is assumed to find out the benefit of the combination of scenario one and scenario two to see how much the potential reduction of greenhouse emission is. In this scenario, it is assumed that 50% of food waste is separated at source and transferred to the composting facility. Moreover, it also makes use of material recovery. 20 percent of recyclable waste is separated at source before it is transferred to the recycling facility. Figure below is the waste flow in the system in Scenario 3.

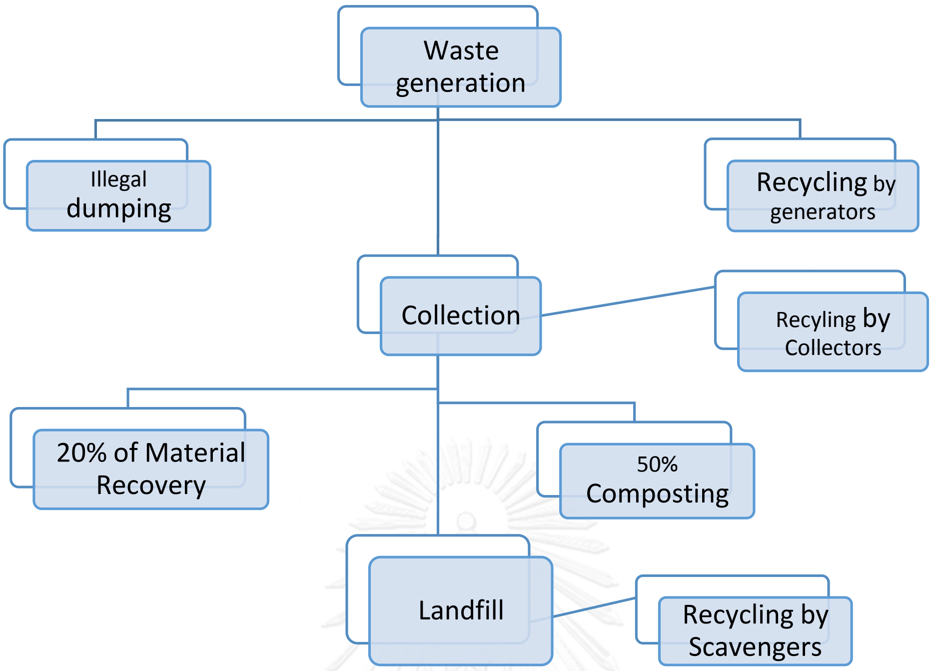


Figure 25: Flow Flow in Scenario 3

To calculation the greenhouse emission in this scenario, like in scenario one and two, US EPA emission factors is used. Table show about the emission factor that is compulsorily used in this scenario.

Table 15: Emission Factor

Material	Recycling (EPA)	Composting (EPA)	Landfilling (Own Data)
Mixed Paper	-0.96	-	0.905224
Mixed Metal	-1.43	-	0
Mixed Plastic	-0.41	-	0
Mixed Organic	-	-0.05	0.3409091

This scenario 3 is the combination of scenario 1 and scenario 2. As a result, it can be calculated simply sum the potential reduction of greenhouse emission in Scenario 1 with the potential reduction of greenhouse gas emission in Scenario 2. Table show the result of the reduction of greenhouse emission in this scenario comparing to the current waste management system, baseline scenario.

Table 16: Summary of GHG Emission

Scenario 3: Scenario 1 + Scenario 2 (Tons CO2 eq.)		
	Reduction	GHG Emission
Scenario 1	-10,666	203.806
Scenario 2	-53,329	

The potential reduction of Greenhouse gas emission in scenario one is 178,355 tons CO2 equivalent. Meanwhile, the potential reduction of GHG emission in Scenario 2 is 30,623 tons CO2 equivalent. As a result, the total greenhouse gas emission in scenario 3, the combination of scenario 1 and scenario 2, is 203,806 tons CO2 equivalent. The figure below demonstrates the greenhouse gas emission by categories.

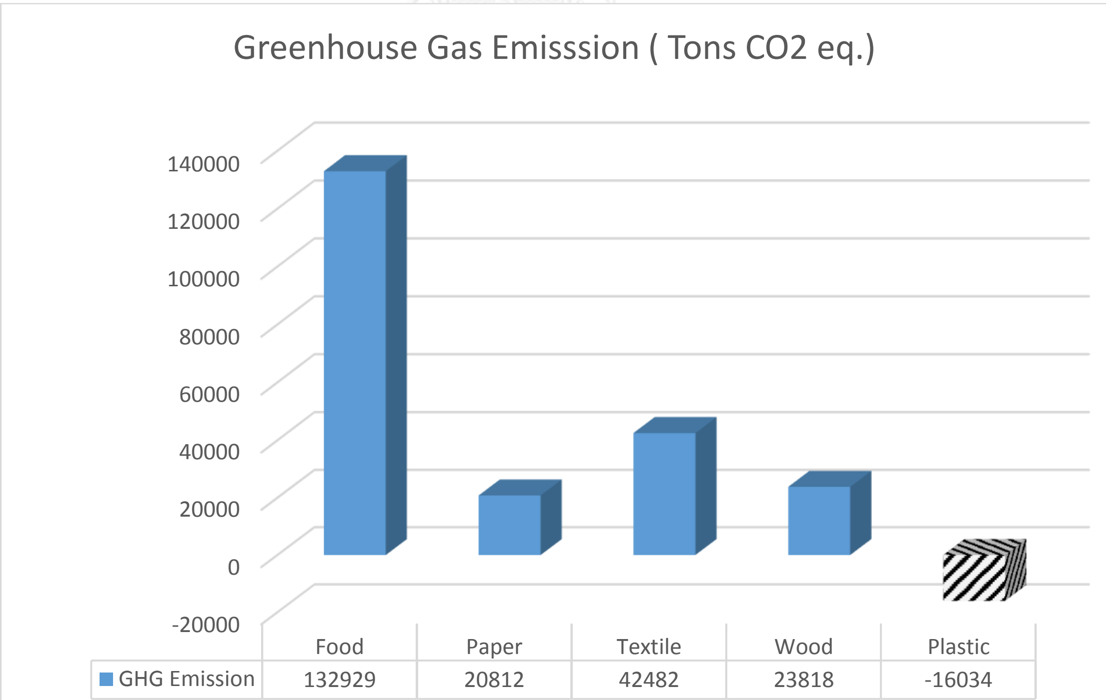
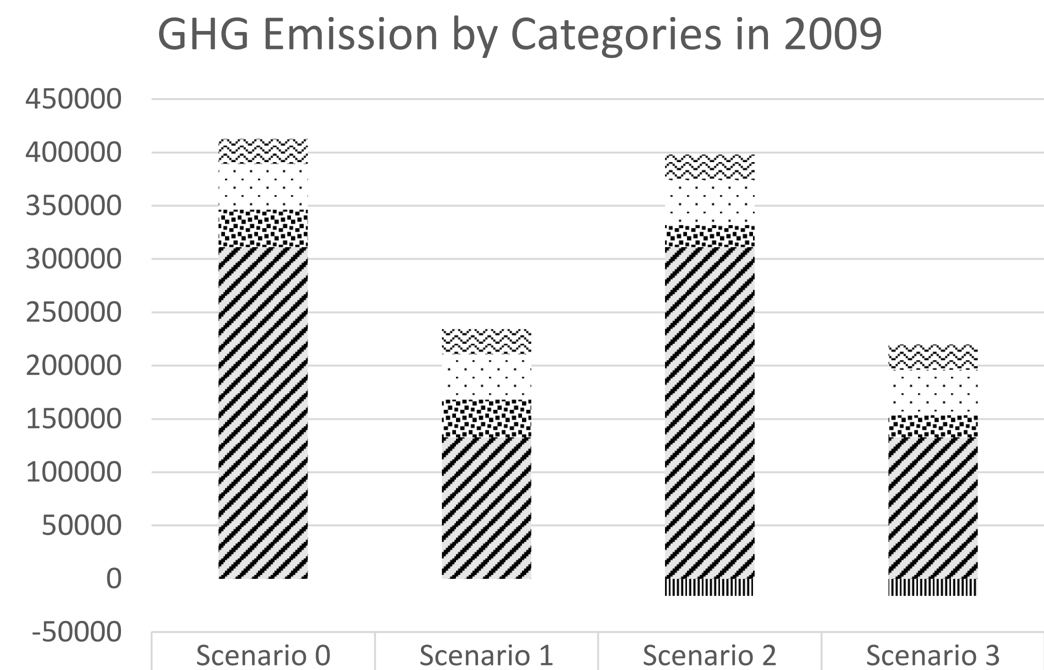


Figure 26: GHG Reduction

Figure 27 shows the emission and reduction of GHG by categories in each scenario. In scenario 1 where the food waste is transporting to composting facility, the emission of GHG from food waste is reduced. In Scenario 2, we can see the negative result. It illustrates the substitution of recycled plastic production. We assume that plastic waste do not release the GHG while doing recycling of GHG can reduce the GHG from producing plastic from raw material. Scenario 3 is the combination of Scenario 1 and scenario 2.



	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Plasctic	0	0	-16034	-16034
Wood	23818	23818	23818	23818
Textile	42482	42482	42482	42482
Paper	35401	35401	20812	20812
Food	311084	132729	311084	132729

Figure 27: GHG Reduction by Categories

To make it easy to evaluate and compare the result, Figure 28 illustrates the GHG reduction of GHG of scenario 1, scenario 2 and the combination comparing to the baseline scenario.

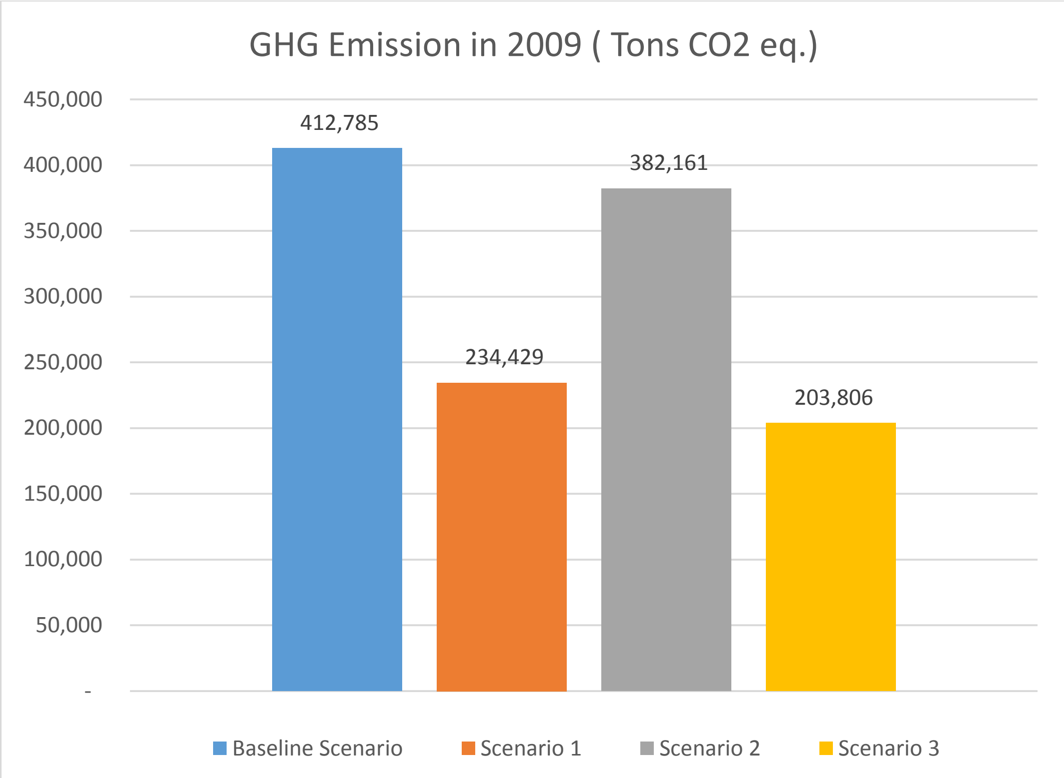


Figure 28: GHG Reduction

According to the figure above, in Baseline scenario, which is the current waste management system, releases the GHG emission 412,785 ton CO2 equivalent during the year 2009-2100. In Scenario 1, 50% of food waste, the GHG emission reduces to 234,429 ton CO2 equivalent in the same year timeframe. To simply put, scenario 1 can reduce the emission about 43 percent from the baseline scenario. But If 20% of material recovery, in scenario 2, plastic and paper recovery, is implemented, the GHG emission is only 382,161 tons CO2 equivalent in the same timeframe. In this scenario, the GHG emission is decreased by 8 percent from the current waste management. But if the scenario 3 is implemented, the combination of scenario 1 and scenario 2, taking advantages of composting and recycling strategies, the GHG emission is reduced significantly to approximately 203,806 ton CO2 equivalent, which is about 48% comparing to the scenario 0, baseline scenario 0. After seeing the result, we can see that composting method can be significantly reduced the GHG emission from the system. Recycling activity is reduced small amount of GHG emission comparing to the composting. But if the source separation is enhanced, the composting and recycling efficiency can be increased, the amount of GHG emission is decreased accordingly.

IV.3.2.2 Estimation of GHG Emission in the future (from 2009-2030)

After getting the result of GHG emission in 2009, it is important to estimate the GHG emission in the future. The calculation of Greenhouse gas emission is done by starting evaluating the emission from 2009 up to the year 2100. The reason that it is chosen to start at 2009 because the new landfill start its operation at 2009. It is assumed that the waste are transferred to the landfill from 2009 to 2030. From the year 2030 later, the landfill cease its operation. In other word, there is no waste disposed in landfill anymore. The waste that already disposed from 2009 to 2030 are left to emit the greenhouse emission without gas collection system. The data of waste collection are available from 2009 to 2013. And from 2013 to 2030, the amount of waste transferred to landfill is estimated by the estimation of the population growth done by the government multiplied by the waste per capita per day. It is assumed that the composition of waste remain the same from 2013 until 2030. The table below is shown the estimation of the population growth of Cambodia from 2008 to 2030 done by National Institute of Statistic (**NIS 2012**).

Table 17: Estimation of Population Growth in Cambodia (NIS 2012)

YEAR	CAMBODIA					
	TOTAL	MALE	FEMALE	ANNUAL GROWTH	SEX RATIO	MEDIAN AGE
2008	13,868,227	6,745,592	7,122,635		94.7	21.9
2009	14,085,324	6,859,756	7,225,568	1.57	94.9	22.3
2010	14,302,779	6,973,994	7,328,785	1.54	95.2	22.6
2011	14,521,275	7,088,691	7,432,584	1.53	95.4	23.0
2012	14,741,414	7,204,166	7,537,248	1.52	95.6	23.4
2013	14,962,591	7,320,112	7,642,479	1.50	95.8	23.8
2014	15,184,116	7,436,178	7,747,938	1.48	96.0	24.2
2015	15,405,157	7,551,944	7,853,213	1.46	96.2	24.6
2016	15,626,444	7,667,790	7,958,654	1.44	96.3	25.0
2017	15,848,495	7,783,987	8,064,508	1.42	96.5	25.4
2018	16,069,921	7,899,824	8,170,097	1.40	96.7	25.8
2019	16,289,270	8,014,562	8,274,708	1.36	96.9	26.2
2020	16,505,156	8,127,496	8,377,660	1.33	97.0	26.6
2021	16,717,422	8,238,593	8,478,829	1.29	97.2	27.1
2022	16,925,995	8,347,859	8,578,136	1.25	97.3	27.5
2023	17,129,834	8,454,760	8,675,074	1.20	97.5	27.9
2024	17,327,917	8,558,773	8,769,144	1.16	97.6	28.3
2025	17,519,272	8,659,399	8,859,873	1.10	97.7	28.7
2026	17,704,090	8,756,659	8,947,431	1.05	97.9	29.1
2027	17,883,061	8,850,832	9,032,229	1.01	98.0	29.5
2028	18,056,858	8,942,266	9,114,592	0.97	98.1	29.9
2029	18,226,073	9,031,264	9,194,809	0.94	98.2	30.3
2030	18,390,683	9,117,812	9,272,871	0.90	98.3	30.7

Because we do the estimation of GHG emission of Waste management system of Phnom Penh municipality. So, the estimation of the population growth of the city itself is compulsory.

This table 18 illustrates the population growth of Phnom Penh Municipality from 2008 to 2030. It is also done by National Institute of Statistic **(NIS).**

Table 18: Estimation of Population Growth in Phnom Penh (NIS 2012)

YEAR	Phnom Penh						
	TOTAL	MALE	FEMALE	ANNUAL GROWTH	SEX RATIO	MEDIAN AGE	% OF THE TOTAL
2008	1,374,451	647,577	726,874		89.1	24.7	9.9
2009	1,438,765	677,056	761,709	4.68	88.9	25.2	10.2
2010	1,504,361	707,320	797,042	4.56	88.7	25.8	10.5
2011	1,570,791	738,159	832,631	4.42	88.7	26.3	10.8
2012	1,637,473	769,288	868,186	4.25	88.6	26.8	11.1
2013	1,704,071	800,534	903,537	4.07	88.6	27.3	11.4
2014	1,770,131	831,668	938,463	3.88	88.6	27.7	11.7
2015	1,835,090	862,403	972,687	3.67	88.7	28.2	11.9
2016	1,898,407	892,463	1,005,944	3.45	88.7	28.7	12.1
2017	1,959,621	921,612	1,038,009	3.22	88.8	29.2	12.4
2018	2,018,312	949,634	1,068,678	3.00	88.9	29.6	12.6
2019	2,074,099	976,336	1,097,764	2.76	88.9	30.1	12.7
2020	2,126,617	1,001,530	1,125,087	2.53	89.0	30.6	12.9
2021	2,175,636	1,025,107	1,150,529	2.31	89.1	31.1	13.0
2022	2,221,011	1,046,999	1,174,011	2.09	89.2	31.5	13.1
2023	2,262,593	1,067,132	1,195,461	1.87	89.3	32.0	13.2
2024	2,300,287	1,085,457	1,214,831	1.67	89.4	32.6	13.3
2025	2,334,053	1,101,953	1,232,101	1.47	89.4	33.1	13.3
2026	2,364,023	1,116,677	1,247,346	1.28	89.5	33.6	13.4
2027	2,390,417	1,129,731	1,260,686	1.12	89.6	34.1	13.4
2028	2,413,511	1,141,253	1,272,258	0.97	89.7	34.7	13.4
2029	2,433,557	1,151,371	1,282,186	0.83	89.8	35.2	13.4
2030	2,450,717	1,160,169	1,290,548	0.71	89.9	35.8	13.3

After getting information about the estimation of the population growth, it is possible to estimate the growth of waste generation in the future. Table below shows the increase of amount of waste from 2009 to 2013 according to the increase of population increase estimated by the national institute of statistic. The amount of waste increased is estimated by categories because it is easy to do the evaluation and comparison of each scenario. The composition of each category of waste is based on the composition of waste in 2013.

Table 19: Estimation of Waste Generation

Year	Food	Paper	Textile	Wood	Amount of Waste
2009	248868	10666	21332	7111	355525
2010	268623	11512	23025	7675	383747
2011	286146	12263	24527	8176	408780
2012	323177	13850	27701	9234	461682
2013	353567	15153	30306	10102	505095
2014	384428	16475	32951	10984	549183
2015	398535	17080	34160	11387	569336
2016	412286	17669	35339	11780	588980
2017	425580	18239	36478	12159	607971
2018	438327	18785	37571	12524	626181
2019	450442	19305	38609	12870	643489
2020	461848	19793	39587	13196	659783
2021	472494	20250	40499	13500	674991
2022	482348	20672	41344	13781	689069
2023	491378	21059	42118	14039	701969
2024	499565	21410	42820	14273	713664
2025	506898	21724	43448	14483	724140
2026	513407	22003	44006	14669	733439
2027	519149	22249	44498	14833	741641
2028	524154	22464	44927	14976	748791
2029	528508	22650	45301	15100	755011
2030	532235	22810	45620	15207	760336

In this section, we want to know about the greenhouse gas emission in the future by making use of the increasing of population. Moreover, it is also interesting what will happen if the new technology like gas collection is equipped in the future. GHG emission will be evaluated using the same methodology. In this section, 7 scenarios will be raised to do the evaluation and comparison. Those 7 scenarios are: Baseline scenario, Material Recovery scenario, Composting scenario, waste prevention scenario, waste composition changed scenario, gas collection scenario and high-efficiency gas collection scenario.

- **S0 Scenario – Baseline Scenario**

In this scenario, it is assumed that the waste management system in 2030 remains the same as the current waste management system. It simply means that all waste are transferred to landfill without pretreatement or posttreatment. The equation, based on IPCC and U.S. EPA, that used in the previous section is applied in this calculation as well. The same DOC and K values are used in this calculation too. Table below is the calculation of food waste disposed in landfill from 2009-2030. All the waste emitte the GHG emission to 2100.

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
2009	0																					
2010	2101.633	0																				
2011	1746.676	2268.463	0																			
2012	1451.67	1885.329	2416.442	0																		
2013	1206.489	1566.905	2008.315	2729.164	0																	
2014	1002.718	1302.262	1669.119	2268.22	2985.793	0																
2015	833.3634	1082.315	1387.212	1885.127	2481.506	3246.412	0															
2016	692.6119	899.5168	1152.918	1566.737	2062.39	2698.107	3365.543	0														
2017	575.6327	747.5923	958.195	1302.122	1714.061	2242.408	2797.117	3481.667	0													
2018	478.4108	621.3271	796.36	1082.199	1424.564	1863.675	2324.696	2893.628	3593.932	0												
2019	397.6093	516.3876	661.8582	899.4204	1183.961	1548.908	1932.065	2404.907	2986.932	3701.578	0											
2020	330.4548	429.172	550.0732	747.5122	983.995	1287.304	1605.747	1998.728	2482.452	3076.397	3803.886	0										
2021	274.6424	356.6867	457.1682	621.2606	817.8024	1069.884	1334.543	1661.152	2063.177	2556.807	3161.426	3900.207	0									
2022	228.2565	296.4438	379.9544	516.3323	679.6791	889.1853	1109.145	1380.59	1714.715	2124.973	2627.475	3241.479	3990.111	0								
2023	189.7049	246.3757	315.7818	429.126	564.8842	739.0058	921.815	1147.415	1425.107	1766.074	2183.706	2694.007	3316.198	4073.326	0							
2024	157.6646	204.7639	262.4476	356.6485	469.4777	614.1908	766.1244	953.6211	1184.412	1467.792	1814.887	2239.001	2756.106	3385.358	4149.582	0						
2025	131.0357	170.1802	218.1213	296.4121	390.1849	510.4566	636.7292	792.5586	984.3703	1219.888	1508.36	1860.843	2290.612	2813.586	3448.735	4218.719	0					
2026	108.9043	141.4375	181.2816	246.3493	324.2844	424.2427	529.1884	658.6989	818.1144	1013.854	1253.605	1546.555	1903.737	2338.383	2866.259	3506.196	4280.645	0				
2027	90.51086	117.5493	150.6639	204.742	269.5141	352.5899	439.8107	547.4474	679.9383	842.6186	1041.876	1285.348	1582.204	1943.44	2382.16	2914.014	3557.662	4335.612	0			
2028	75.22396	97.69572	125.2174	170.1619	223.9943	293.039	365.5286	454.9859	565.0997	700.3039	865.9079	1068.258	1314.977	1615.202	1979.823	2421.85	2956.788	3603.346	4384.102	0		
2029	62.51896	81.19533	104.0687	141.4223	186.1627	243.546	303.7924	378.1407	469.6568	582.0256	719.6597	887.8342	1092.883	1342.401	1645.44	2012.81	2457.4	2994.756	3643.646	4426.368	0	
2030	51.95977	67.48179	86.49195	117.5367	154.7206	202.4121	252.4831	314.2744	390.3337	483.724	598.1123	737.8828	908.2996	1115.675	1367.532	1672.855	2042.355	2488.955	3028.25	3678.774	4463.137	0
2031	43.18399	56.0844	71.88383	97.68525	128.5889	168.2256	209.8398	261.1948	324.408	402.025	497.0937	613.2576	754.8917	927.2424	1136.562	1390.317	1697.41	2068.581	2516.791	3057.445	3709.332	4494.611
2032	35.8904	46.61199	59.74296	81.18663	106.8708	139.813	174.3988	217.0801	269.6169	334.1247	413.1367	509.681	627.3937	770.6351	944.6012	1155.498	1410.725	1719.206	2091.716	2541.055	3082.842	3735.49
2033	29.82866	38.73942	49.65263	67.47456	88.82079	116.1992	144.9436	180.4162	224.0798	277.6925	343.3597	423.5981	521.4296	640.4782	785.0621	960.3395	1172.46	1428.84	1738.434	2111.882	2562.163	3104.582
2034	24.79073	32.1965	41.26651	56.07839	73.81934	96.57363	120.4632	149.9447	186.2337	230.7914	285.3677	352.0542	433.3624	532.3041	652.4685	798.1423	974.4361	1187.515	1444.82	1755.194	2129.425	2580.231
2035	20.60368	26.75865	34.29678	46.60699	61.35157	80.26276	100.1175	124.6197	154.7796	191.8117	237.1703	292.5937	360.1693	442.4003	542.2694	663.3395	809.8581	986.9487	1200.796	1458.749	1769.774	2144.441
2036	17.12381	22.23923	28.5042	38.73527	50.98955	66.70672	83.20808	103.5719	128.638	159.4156	197.1133	243.1759	299.3383	367.6807	450.6824	551.3043	673.0765	820.2573	997.9869	1212.373	1470.867	1782.254
2037	14.23167	18.48312	23.68996	32.19305	42.37764	55.44024	69.1546	86.07909	106.9116	132.491	163.8217	202.1045	248.7813	305.581	374.5641	458.1914	559.3968	681.7194	829.4312	1007.608	1222.444	1481.239
2038	11.828	15.3614	19.68883	26.75578	35.22023	46.07662	57.47468	71.5407	88.85467	110.1138	136.1529	167.9699	206.7632	253.9697	311.3018	380.8048	464.917	566.5799	689.3438	837.4275	1015.978	1231.064
2039	9.830304	12.76692	16.36347	22.23684	29.27169	38.29448	47.76745	59.45778	73.8475	91.51605	113.1573	139.6005	171.8418	211.0753	258.7243	316.4885	386.3945	470.887	572.9166	695.9896	844.3838	1023.143
2040	8.170007	10.61064	13.59975	18.48114	24.32783	31.8267	39.69973	49.41562	61.37497	76.05938	94.04548	116.0226	142.8184	175.4256	215.0268	263.0349	321.1342	391.3562	476.1534	578.4399	701.771	850.3383
2041	6.790128	8.818552	11.30281	15.35975	20.21896	26.45131	32.99462	41.06953	51.009	63.21328	78.1616	96.42688	118.697	145.797	178.7097	218.6095	266.896	325.2578	395.7331	480.7439	583.2449	706.7198
2042	5.643305	7.329137	9.393814	12.76556	16.80406	21.9838	27.42197	34.13306	42.3938	52.53683	64.96044	80.14079	98.64961	121.1725	148.5264	181.6873	221.8184	270.3231	328.8955	399.5483	484.7373	587.3579
2043	4.690175	6.091277	7.807239	10.60951	13.96593	18.27083	22.79052	28.36813	35.23367	43.66358	53.9889	66.60536	81.98811	100.707	123.4409	151.0011	184.3542	224.6667	273.3465	332.0663	402.8673	488.1556
2044	3.898024	5.062486	6.48863	8.817608	11.60714	15.18496	18.9413	23.57688	29.28285	36.28899	44.87041	55.356	68.14067	83.698	102.5923	125.4976	153.2176	186.7215	227.1794	275.9817	334.8247	405.7083
2045	3.239665	4.207454	5.392728	7.328351	9.646747	12.62029	15.74219	19.59484	24.3371	30.15994	37.29199	46.00661	56.632	69.56176	85.2649	104.3016	127.3398	155.185	188.8098	229.3696	278.2742	337.1859
2046	2.692499	3.496833	4.481919	6.090624	8.017453	10.48878	13.0834	16.28536	20.22667	25.06605	30.99353	38.23629	47.0671	57.81308	70.86402	86.68552	105.8326	128.9749	156.9206	190.6301	231.2749	280.2366
2047	2.237748	2.906233	3.724942	5.061944	6.663339	8.717266	10.87367	13.53483	16.81047	20.8325	25.75886	31.77834	39.11767	48.0487	58.89539	72.04471	87.95796	107.1916	130.4174	158.4335	192.2136	232.9059
2048	1.859802	2.415383	3.095815	4.207003	5.53793	7.244957	9.037156	11.24886	13.97126	17.31398	21.4083	26.41112	32.51086	39.93348	48.94821	59.87667	73.10224	89.08742	108.3905	131.6747	159.7495	193.5691
2049	1.545689	2.007435	2.572946	3.496458	4.602597	6.021315	7.510819	9.348973	11.61157	14.38972	17.79253	21.95039	27.01992	33.18889	40.68107	49.76375	60.75558	74.04093	90.08378	109.4354	132.7685	160.8761
2050	1.284629	1.668388	2.138386	2.905922	3.825238	5.004341	6.242274	7.769971	9.650427	11.95936	14.78744	18.24307	22.45637	27.58342	33.81021	41.35887	50.49423	61.53574	74.86901	90.95226	110.3445	133.7048
2051	1.067661	1.386604	1.777222	2.415124	3.179172	4.159129	5.187981	6.457656	8.020511	9.939477	12.28991	15.16189	18.66358	22.9247	28.09981	34.37353	41.96597	51.14261	62.22396	75.59081	91.70777	111.1226
2052	0.887337	1.152413	1.477057	2.00722	2.642223	3.45667	4.311753	5.366986	6.665881	8.260742	10.2142	12.60111	15.51138	19.05282	23.35387	28.56799	34.8781	42.50485	51.7146	62.82385	76.21872	92.35449
2053	0.73747	0.957775	1.227588	1.668209	2.195963	2.872853	3.583516	4.460525	5.540042	6.865538	8.489062	10.47284	12.89158	15.83488	19.4095	23.74298	28.98733	35.32596	42.98022	52.21317	63.34571	76.75621
2054	0.612914	0.796011	1.020254	1.386456	1.825074	2.387641	2.978276	3.707161	4.604353	5.705978	7.055296	8.70402	10.71425	13.16044	16.13132	19.73289	24.0915	29.35956	35.72105	43.39459	52.64689	63.79242
2055	0.509396	0.661568	0.847937	1.152289	1.516827	1.984378	2.475258	3.081038	3.826697	4.742263	5.863687	7.233949	8.904656	10.93769	13.40681	16.40009	20.02255	24.40085	29.68792	36.06543	43.75505	53.01815
2056	0.423361	0.549832	0.704724	0.957673	1.260642	1.649225	2.057197	2.560664	3.180385	3.941315	4.873335	6.012166	7.400697	9.090365	11.14246	13.63019	16.64082	20.27965	24.67375	29.97413	36.36501	44.06361
2057	0.351857	0.456968	0.585699	0.795926	1.047725	1.370678	1.709745	2.128179	2.643231	3.275644	4.05025	4.996737	6.150751	7.555041	9.260545	11.32811	13.83026	16.85451	20.50646	24.91163	30.22312	36.62146
2058	0.29243	0.379788	0.486777	0.661497	0.870768	1.139177	1.420977	1.768738	2.196801	2.722401	3.36618	4.152809	5.111916	6.279027	7.696478	9.414838	11.49439	14.00785	17.04301	20.70416	25.11856	30.43625
2059	0.24304	0.315643	0.404563	0.549773	0.723699	0.946775	1.18098	1.470006	1.825771	2.2626	2.797646	3.451418	4.248535	5.218526	6.396576	7.824712	9.553036	11.64199	14.16452	17.20732	20.87615	25.2957
2060	0.201991	0.262333	0.336234	0.456919	0.60147	0.786868	0.981517	1.221728	1.517406	1.880456	2.325136	2.868488	3.530976	4.33714	5.316222	6.503152	7.939569	9.675705	11.77219	14.30108	17.35025	21.02336
2061	0.167876	0.218026	0.279445	0.379747	0.499884	0.65397	0.815743	1.015384	1.261122	1.562855	1.93243	2.384013	2.934609	3.604615	4.418335	5.404797	6.59861	8.04152	9.783919	11.88568	14.41987	17.47261
2062	0.139522	0.181202	0.232248	0.31561	0.415456	0.543517	0.677968	0.84389	1.048124	1.298896	1.606051	1.981363	2.438966	2.995811	3.672097	4.49195	5.484133	6.683342	8.131457	9.878244	11.98442	14.52156
2063	0.115958	0.150598	0.193022	0.262304	0.345287	0.451719	0.563462	0.70136	0.871101	1.079518	1.334796	1.646719	2.027035	2.489831	3.051896	3.733279	4.557886	5.554554	6.758089	8.209851	9.960299	12.06893
2064	0.096373	0.125163	0.160422	0.218002	0.28697	0.375426	0.468296	0.582904	0.723975	0.897192	1.109355	1.368595	1.684678	2.06931	2.536443	3.102744	3.788079	4.616413	5.616677	6.823242	8.278047	10.03054
2065	0.080096	0.104023	0.133327	0.181183	0.238502	0.312018	0.389203	0.484454	0.601699	0.74566	0.921989	1.137446	1.400143	1.719812	2.108049	2.578704	3.148289	3.836721	4.668044	5.670826	6.879921	8.336424
2066	0.066568	0.086454	0.110809	0.150582	0.19822	0.25932	0.323468	0.402631	0.500075	0.619721	0.766269	0.945336	1.163665	1.429343	1.752009	2.143172	2.616556	3.188715	3.879631	4.713047	5.717932	6.928437
2067	0.055325	0.071852	0.092094	0.125149	0.164741	0.215522	0.268836	0.334629	0.415614	0.515053	0.63685	0.785673	0.967127	1.187933	1.456102	1.781199	2.174631	2.650155	3.224378	3.917034	4.752197	5.758254
2068	0.045981	0.059717	0.076539	0.104012	0.136917	0.179121	0.22343	0.278111	0.345419	0.428063	0.529289	0.652976	0.803783	0.987296	1.210172	1.480362	1.807345	2.202555	2.679795	3.255464	3.949572	4.78571
2069	0.038215	0.049631	0.063612	0.086445	0.113792	0.148868	0.185694	0.23114	0.287079	0.355765	0.439894	0.542691	0.668028	0.820546	1.00578	1.230336	1.502092	1.830553	2.227189	2.70563	3.282506	3.977424
2070	0.031761	0.041248	0.052868	0.071845	0.094573	0.123725	0.154331	0.192101	0.238593	0.295678	0.365598	0.451033	0.555201	0.68196	0.835908	1.022537	1.248395	1.52138	1.851026	2.248661	2.728105	3.305654
2071	0.026396	0.034282	0.043939	0.05971	0.0786	0.102828	0.128265	0.159656	0.198295	0.245739	0.30385	0.374855	0.46143	0.566779	0.694726	0.849835	1.037547	1.264426	1.538396	1.868871	2.26734	2.747343
2072	0.021938	0.028492	0.036518	0.049626	0.065325	0.085461	0.106602	0.132691	0.164804	0.204235	0.252531	0.311544	0.383496	0.471053	0.57739	0.706301	0.86231	1.05087	1.278567	1.553227	1.884396	2.283329
2073	0.018233	0.02368	0.03035	0.041244	0.054292	0.071027	0.088597	0.11028	0.136969	0.16974	0.20988	0.258925	0.318725	0.391494	0.479871	0.58701	0.716669	0.873382	1.062623	1.290894	1.566129	1.897684
2074	0.015153	0.01968	0.025224	0.034278	0.045122	0.059031	0.073633	0.091654	0.113836	0.141072	0.174432	0.215194	0.264894	0.325372	0.398823	0.487867	0.595627	0.725872	0.88315	1.072867	1.301617	1.577173
2075	0.012594	0.016356	0.020964	0.028489	0.037501	0.049061	0.061197	0.076174	0.094609	0.117245	0.144971	0.178849	0.220154	0.270418	0.331464	0.405468	0.495028	0.603275	0.73399	0.891665	1.081779	1.310796
2076	0.010467	0.013594	0.017423	0.023677	0.031168	0.040775	0.050861	0.063309	0.07863	0.097443	0.120486	0.148642	0.182971	0.224746	0.275481	0.336986	0.41142	0.501385	0.610022	0.741066	0.899071	1.089408
2077	0.008699	0.011298	0.014481	0.019678	0.025903	0.033888	0.042271	0.052616	0.06535	0.080985	0.100136	0.123537	0.152068	0.186787	0.228953	0.280071	0.341933	0.416703	0.506992	0.615903	0.747222	0.905412
2078	0.00723	0.00939	0.012035	0.016355	0.021528	0.028164	0.035132	0.043729	0.054313	0.067307	0.083224	0.102672	0.126385	0.15524	0.190284	0.232768	0.284182	0.346324	0.421363	0.51188	0.621019	0.752491
2079	0.006009	0.007804	0.010002	0.013592	0.017892	0.023408	0.029198	0.036344	0.045139	0.055939	0.069168	0.085331	0.105039	0.12902	0.158146	0.193454	0.236185	0.287831	0.350197	0.425426	0.516132	0.625399
2080	0.004994	0.006486	0.008313	0.011297	0.01487	0.019454	0.024267	0.030205	0.037516	0.046492	0.057486	0.070919	0.087298	0.107229	0.131436	0.160781	0.196294	0.239218	0.29105	0.353573	0.428959	0.519772

2081	0.00415	0.00539	0.006909	0.009389	0.012359	0.016168	0.020168	0.025104	0.031179	0.038639	0.047776
2082	0.003449	0.00448	0.005742	0.007803	0.010272	0.013438	0.016762	0.020864	0.025913	0.032113	0.039707
2083	0.002867	0.003723	0.004772	0.006485	0.008537	0.011168	0.013931	0.01734	0.021537	0.026689	0.033001
2084	0.002383	0.003094	0.003966	0.00539	0.007095	0.009282	0.011578	0.014411	0.017899	0.022182	0.027427
2085	0.00198	0.002572	0.003296	0.004479	0.005897	0.007714	0.009622	0.011977	0.014876	0.018435	0.022795
2086	0.001646	0.002137	0.00274	0.003723	0.004901	0.006411	0.007997	0.009954	0.012364	0.015322	0.018945
2087	0.001368	0.001776	0.002277	0.003094	0.004073	0.005328	0.006647	0.008273	0.010275	0.012734	0.015745
2088	0.001137	0.001476	0.001892	0.002572	0.003385	0.004429	0.005524	0.006876	0.00854	0.010583	0.013086
2089	0.000945	0.001227	0.001573	0.002137	0.002813	0.003681	0.004591	0.005715	0.007098	0.008796	0.010876
2090	0.000785	0.00102	0.001307	0.001776	0.002338	0.003059	0.003816	0.004749	0.005899	0.00731	0.009039
2091	0.000653	0.000848	0.001086	0.001476	0.001943	0.002542	0.003171	0.003947	0.004903	0.006076	0.007512
2092	0.000542	0.000704	0.000903	0.001227	0.001615	0.002113	0.002636	0.003281	0.004075	0.005049	0.006243
2093	0.000451	0.000585	0.00075	0.00102	0.001342	0.001756	0.00219	0.002727	0.003386	0.004197	0.005189
2094	0.000375	0.000487	0.000624	0.000847	0.001116	0.001459	0.00182	0.002266	0.002814	0.003488	0.004313
2095	0.000311	0.000404	0.000518	0.000704	0.000927	0.001213	0.001513	0.001883	0.002339	0.002899	0.003584
2096	0.000259	0.000336	0.000431	0.000585	0.000771	0.001008	0.001257	0.001565	0.001944	0.002409	0.002979
2097	0.000215	0.000279	0.000358	0.000487	0.00064	0.000838	0.001045	0.001301	0.001616	0.002002	0.002476
2098	0.000179	0.000232	0.000298	0.000404	0.000532	0.000696	0.000869	0.001081	0.001343	0.001664	0.002058
2099	0.000149	0.000193	0.000247	0.000336	0.000442	0.000579	0.000722	0.000899	0.001116	0.001383	0.00171
2100	0.000123	0.00016	0.000206	0.000279	0.000368	0.000481	0.0006	0.000747	0.000928	0.001149	0.001421
	12443.37	13431.14	14307.3	16158.87	17678.32	19221.4	19926.75	20614.3	21279	21916.34	22522.09

2081	0.058941	0.072554	0.089119	0.109237	0.133626	0.163141	0.198815	0.241893	0.293856	0.35651	0.431984
2082	0.048986	0.0603	0.074067	0.090787	0.111057	0.135587	0.165236	0.201038	0.244225	0.296297	0.359024
2083	0.040713	0.050115	0.061557	0.075454	0.0923	0.112687	0.137328	0.167084	0.202976	0.246254	0.298386
2084	0.033837	0.041651	0.051161	0.06271	0.076711	0.093655	0.114134	0.138864	0.168695	0.204663	0.24799
2085	0.028122	0.034616	0.04252	0.052118	0.063755	0.077837	0.094857	0.115411	0.140203	0.170096	0.206106
2086	0.023372	0.02877	0.035338	0.043316	0.052987	0.06469	0.078836	0.095918	0.116523	0.141367	0.171295
2087	0.019425	0.023911	0.02937	0.036	0.044038	0.053765	0.065521	0.079718	0.096843	0.117491	0.142364
2088	0.016144	0.019872	0.024409	0.02992	0.0366	0.044684	0.054455	0.066254	0.080487	0.097647	0.11832
2089	0.013417	0.016516	0.020287	0.024866	0.030418	0.037137	0.045258	0.055064	0.066893	0.081155	0.098336
2090	0.011151	0.013727	0.01686	0.020667	0.025281	0.030865	0.037614	0.045764	0.055595	0.067448	0.081727
2091	0.009268	0.011408	0.014013	0.017176	0.021011	0.025652	0.031261	0.038035	0.046205	0.056057	0.067924
2092	0.007702	0.009481	0.011646	0.014275	0.017462	0.021319	0.025981	0.031611	0.038401	0.046589	0.056452
2093	0.006402	0.00788	0.009679	0.011864	0.014513	0.017719	0.021593	0.026272	0.031915	0.03872	0.046917
2094	0.00532	0.006549	0.008044	0.00986	0.012062	0.014726	0.017946	0.021835	0.026525	0.032181	0.038993
2095	0.004422	0.005443	0.006686	0.008195	0.010025	0.012239	0.014915	0.018147	0.022045	0.026745	0.032407
2096	0.003675	0.004524	0.005557	0.006811	0.008331	0.010172	0.012396	0.015082	0.018322	0.022228	0.026934
2097	0.003054	0.00376	0.004618	0.005661	0.006924	0.008454	0.010302	0.012535	0.015227	0.018474	0.022385
2098	0.002538	0.003125	0.003838	0.004704	0.005755	0.007026	0.008562	0.010418	0.012655	0.015354	0.018604
2099	0.00211	0.002597	0.00319	0.00391	0.004783	0.005839	0.007116	0.008658	0.010518	0.012761	0.015462
2100	0.001753	0.002158	0.002651	0.00325	0.003975	0.004853	0.005914	0.007196	0.008742	0.010605	0.012851
	23092.39	23624.69	24117.39	24568.88	24978.23	25344.88	25670.32	25957.41	26207.66	26425.35	26611.69

Figure 29: Calculation Sheet

The same calculation is applied for paper, wood, and textile waste; as a result, the same table of paper, wood, and textile waste can be found in the annex.

After calculating all the waste categories from 2009-2100, the table below illustrates the summarization of the emission of GHG from each waste category from 2009-2100.

Table 20: GHG Emission Result

Year	Food	Paper	Textile	Wood	Total
2009	311,084	35,401	42,482	23,818	412,785
2010	335,779	38,201	45,842	25,654	445,475
2011	357,682	40,682	48,818	27,267	474,450
2012	403,972	45,933	55,120	30,726	535,751
2013	441,958	50,236	60,284	33,537	586,015
2014	480,535	54,603	65,524	36,376	637,037
2015	498,169	56,586	67,904	37,616	660,275
2016	515,357	58,517	70,220	38,814	682,908
2017	531,975	60,379	72,455	39,959	704,768
2018	547,909	62,161	74,593	41,042	725,705
2019	563,052	63,850	76,620	42,057	745,579
2020	577,310	65,435	78,522	42,995	764,262
2021	590,617	66,909	80,291	43,852	781,670
2022	602,935	68,267	81,921	44,626	797,749
2023	614,222	69,505	83,406	45,314	812,448
2024	624,456	70,620	84,744	45,915	825,734

2025	633,622	71,610	85,931	46,427	837,590
2026	641,758	72,479	86,974	46,854	848,065
2027	648,935	73,235	87,882	47,202	857,255
2028	655,191	73,883	88,660	47,475	865,209
2029	660,634	74,435	89,322	47,679	872,069
2030	665,292	74,893	89,872	47,818	877,876
Total	11,902,444	1,347,823	1,617,387	883,022	15,750,677

This kind of table is very beneficial since it shows very in detail about the important information. It can be seen the annual GHG emission from 2009 to 2030. Moreover, there is information regarding the GHG emission by categories. For example, according to the table about, food waste in 2009 release the GHG emission 311,084 ton CO2 equivalent. Food waste from 2009-2030 release the GHG emission 11,902,444 tons CO2 equivalent. In the same year frame, we can also realize that the total GHG emission is 412,785 ton CO2 equivalent. This kind of table is very important to scientist, policy maker and so on. Figure below shows the GHG emission the disposal of waste from 2009-2030.

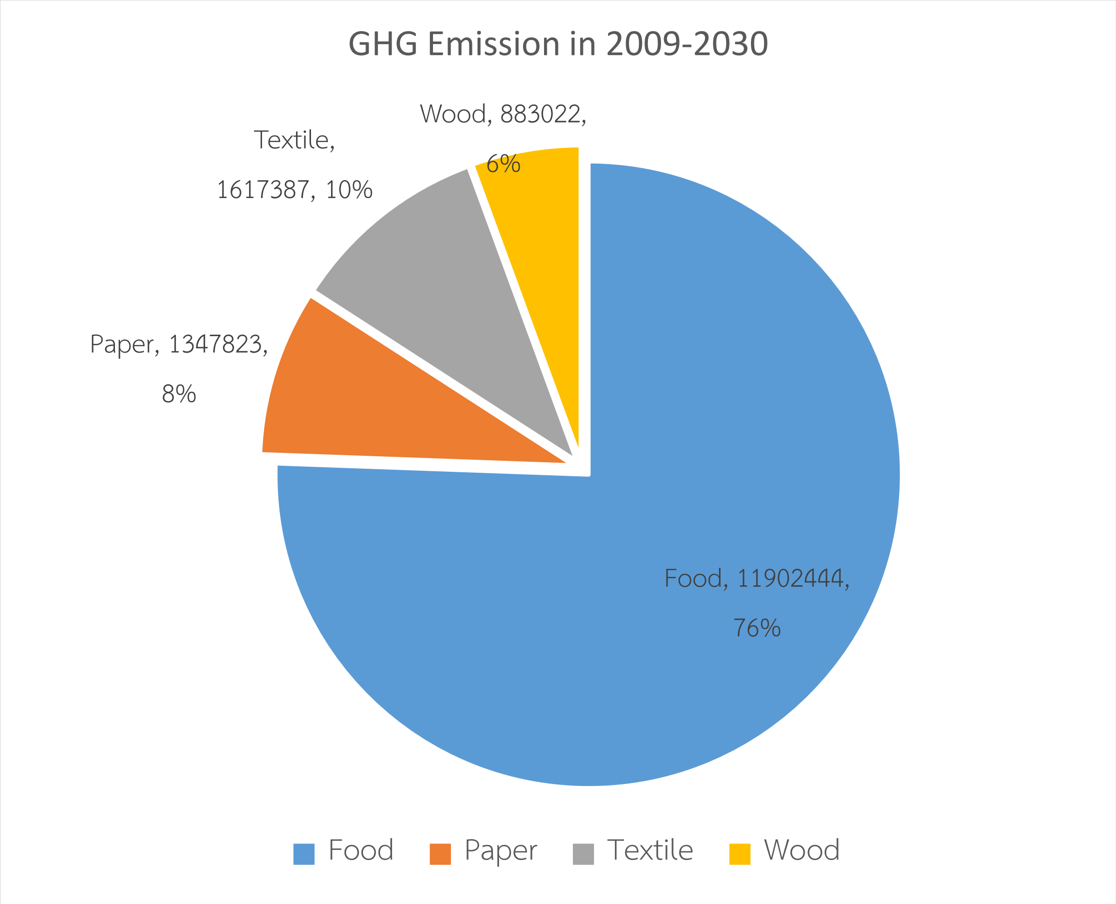


Figure 30: GHG Emission

In the chart above, the food waste will release the GHG emission 11,902,444 ton CO2 equivalent, which takes account for 80% of the overall GHG emission from landfill. GHG emission from textile take account for 10% while Paper waste release the GHG 8%. Last but not least, Wood emit the GHG only 6% of the all GHG emission from 2009-2030.

- **Scenario 1: 50% Composting**

In this scenario, food waste is separated at source, and transported to the composting facility to do composting from food waste composition. The calculation of GHG emission in this scenario is calculated as it is done in the scenario in 2009. Emission factor from U.S. EPA is used in this scenario. Table shows about the potential GHG emission reduction.

Table 21: GHG Factor and Emission

Scenario 1: 50% Composting (Tons CO2 eq.)				
Category	Amount (Tons)	Emi. Factor	Reduction	GHG Emission
Food	9,521,692	-0.390909	-6,823,879	8,926,798

According to the above table, the total amount of wood waste from 2009-2030 is 9,521,692 tons. After implementing the 50% composting of food waste, GHG emission can be reduced 6,823,879 ton CO2 equivalent. The total emission of GHG is reduced to only 8,926,798 ton CO2 emission.

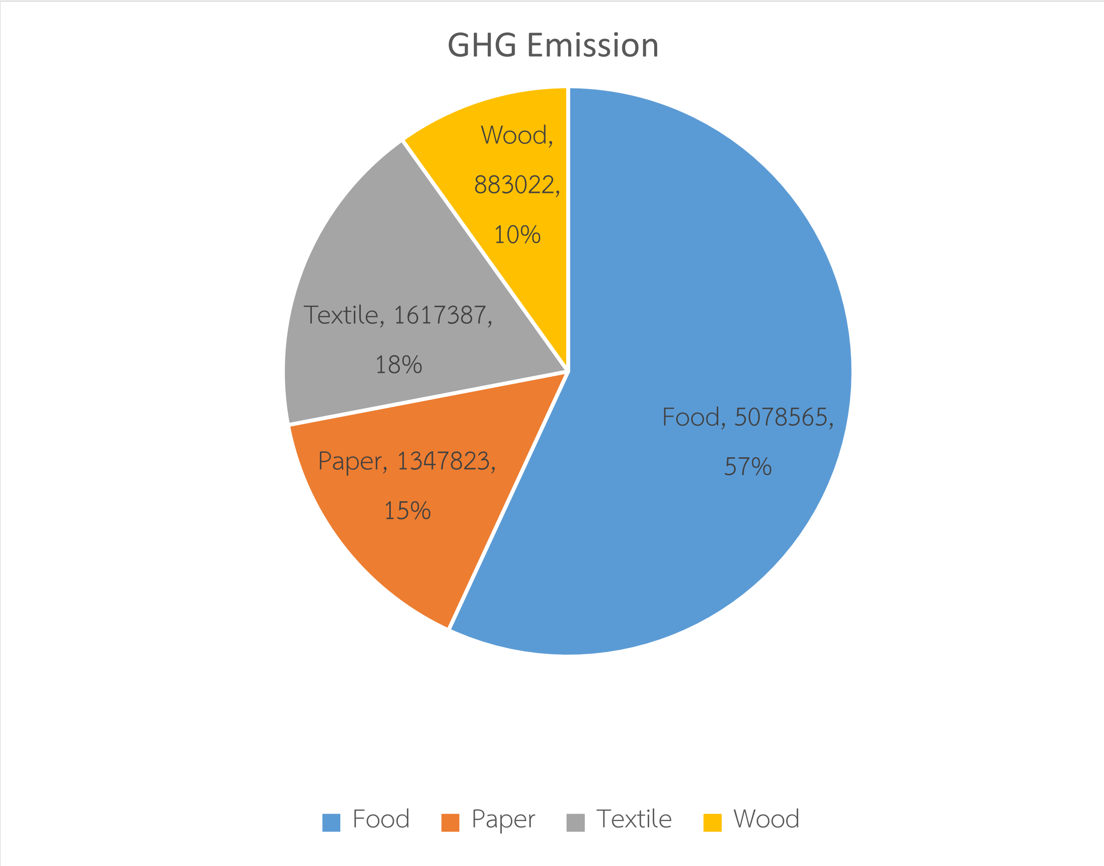


Figure 31: GHG Emission by Categories

According to the figure, after implementing 50% composting facility, food waste alone release greenhouse gas 5,078,565 ton CO2 equivalent which is 57% of an overall GHG emission in the system. For, Paper, Textile and wood are remain the same because composting activity is only make use of organic waste.

- **Scenario 2: 20% of Material Recovery**

In this scenario, Recyclable waste is separated at source, and transported to the recycling facility to do material recovery from recyclable waste composition. The calculation of GHG emission in this scenario is calculated as it is done in the scenario in 2009. Emission factor from U.S. EPA is used in this scenario. Table shows about the potential GHG emission reduction.

Table 22: GHG Factor and Emission

Scenario 2: Material Recovery (Tons CO2 eq.)				
Category	Amount (Tons)	Emi. Factor	Reduction	GHG Emission
Paper	408,084	-1.86522404	-558,190	14,579,000
Plastic	2,040,420	-0.41	-613,486	

The total amount of Paper waste disposed in landfill from 2009-2030 is 408,084 tons. After doing the 20% of material recovery, GHG emission decrease 558,190 tons CO2 equivalent. For Plastic waste, the total amount transfer to landfill from 2009-2030 is 2,040,420 tons. The GHG emission reduce 613,486 ton CO2 equivalent if 20% recycling is achieved. The total amount of GHG release in this scenario is 14,579,000 ton CO2 equivalent.

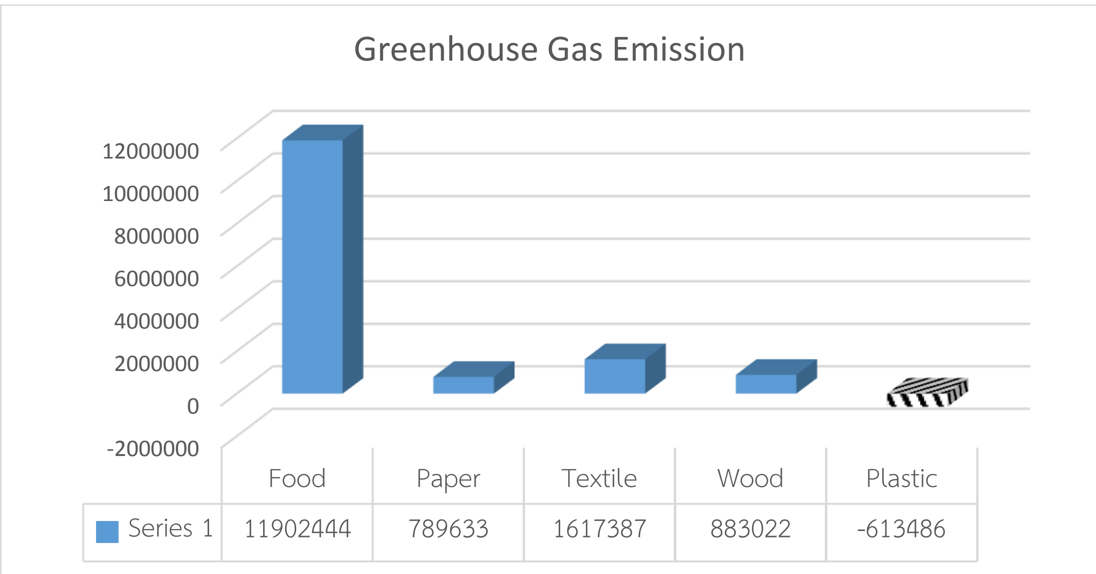


Figure 32: GHG Emission by Categories

After seeing the result, it is clearly shown that the paper fraction is reduced to 789,633 ton CO2 equivalent if the 20% of paper is going to recycling facility. For plastic waste, it is beneficial to environment as it can reduced 613,486 ton CO2 equivalent. If source separation is improve to 40 or 50%, the potential reduction of GHG will be increased accordingly.

- **Scenario 3: 50% of Composting + 20% of Material Recovery**

In this scenario, 50% of Composting and 20% Material recovery are assumed to evaluate the potential reduction of GHG emission. Recyclable waste is separated at source, and transported to the recycling facility to do material recovery from recyclable waste composition. 50% of food waste is separated at source and transported to the composting facility. The calculation of GHG emission in this scenario is calculated as it is done in the scenario in 2009. Emission factor from U.S. EPA is used in this scenario. Table shows about the potential GHG emission reduction.

Table 23: GHG in Scenario 3

Scenario 3: Scenario 1 + Scenario 2 (Tons CO2 eq.)		
	Reduction	GHG Emission
Scenario 1	-6,823,879	7,755,121
Scenario 2	-1,171,676	

In scenario 1, the potential reduction of GHG emission is 6,823,879 ton CO2 equivalent. In scenario 2, the potential reduction of GHG emission in the year is 1,141,676 ton CO2 equivalent. As a result, the total emission of the waste disposed in landfill from 2009-2030 reduces to 7,755,121 ton CO2 equivalent. The figure shows the total GHG emission by categories.

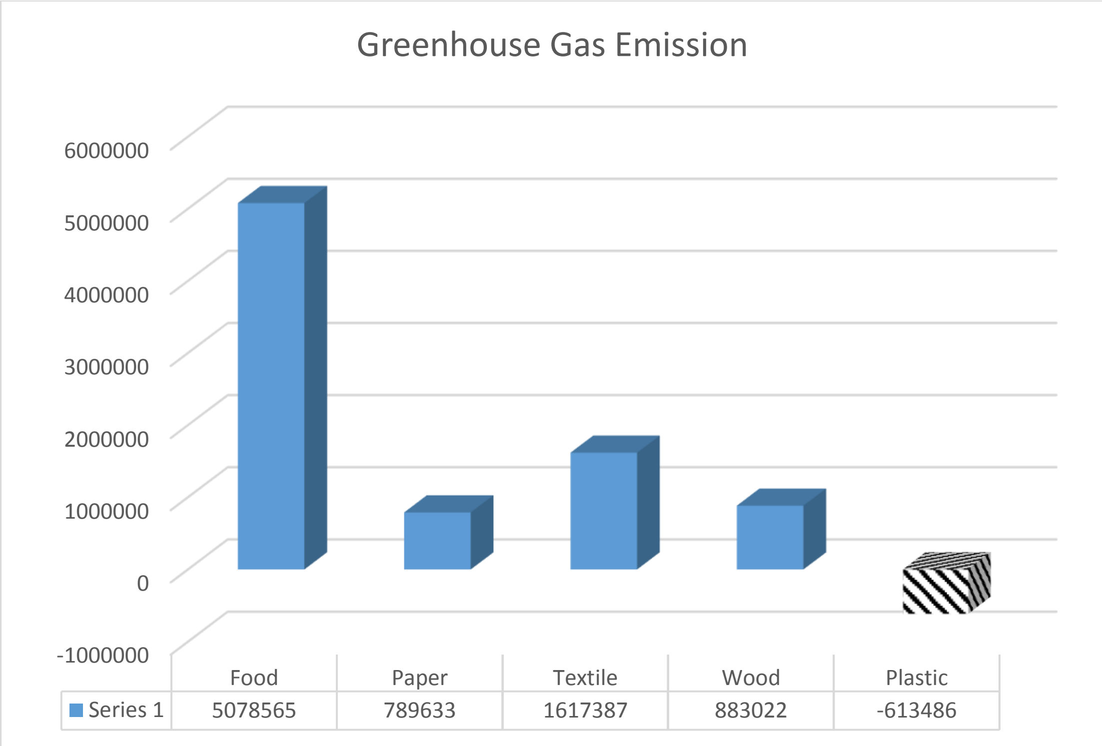


Figure 33: GHG Reduction in Scenario 3

- **Scenario 4: Implementing of Waste Reduction (2% each year from 2016)**

In this scenario, it is assumed that from 2016 onward, the government will implement a new regulation to reduce the waste generation at source by 2% each year from 2016. It simply means that all categories of waste are assumed to reduce by 2% accumulatively from 2016 onward until reaching the goal of prevention 20% of waste generation in 2025. After 2025, the waste is decreased by 20% constantly without any change. Table shows about the calculation of GHG emission from food waste. As we can see, the amount of GHG emission from 2009 to 2015 remains the same because the waste reduction policy will be implemented in 2016 onward. For the GHG from 2016 onward, as shown in the blue box, will be reduced because the amount of the waste generation is decreased.

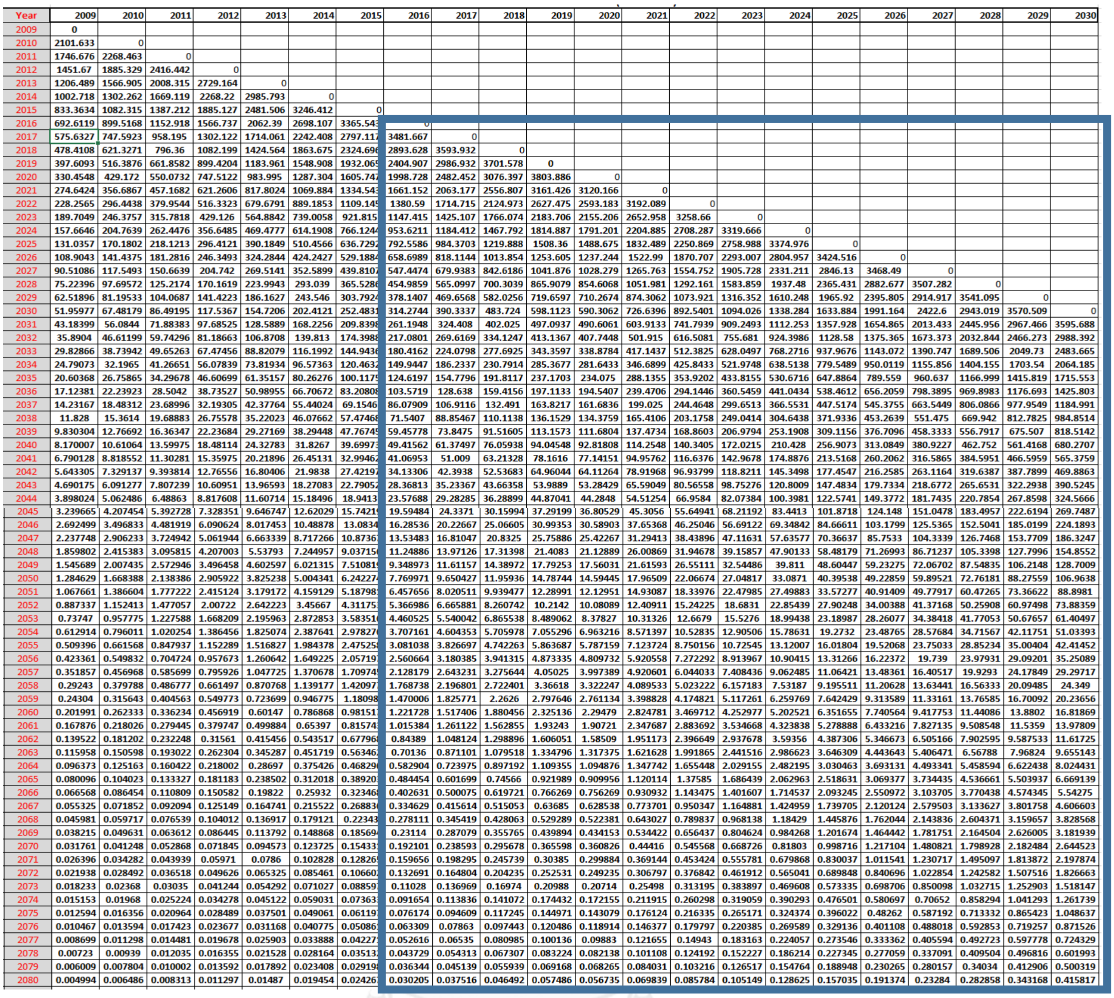


Figure 34: Calculation Sheet

Table 24: GHG Emission

Year	Food	Paper	Textile	Wood	Total
2009	311084	35401	42482	23818	412785
2010	335779	38201	45842	25654	445475
2011	357682	40682	48818	27267	474450
2012	403972	45933	55120	30726	535751
2013	441958	50236	60284	33537	586015
2014	480535	54603	65524	36376	637037
2015	498169	56586	67904	37616	660275
2016	515357	58517	70220	38814	669250
2017	531975	60379	72455	39959	676577
2018	547909	62161	74593	41042	682163

2019	563052	63850	76620	42057	685933
2020	461848	52348	62818	34396	687836
2021	472494	53527	64233	35082	687870
2022	482348	54614	65537	35701	686064
2023	491378	55604	66725	36251	682456
2024	499565	56496	67795	36732	677102
2025	506898	57288	68745	37141	670072
2026	513406	57983	69580	37483	678452
2027	519148	58588	70306	37762	685804
2028	524153	59107	70928	37980	692167
2029	528507	59548	71457	38143	697656
2030	532234	59915	71898	38254	702301
Total	10519450	1191568	1429882	781791	12,574,295

Comparing this table of result with the baseline scenario, we can see that the GHG emission from 2009-2019 is the same, but from 2020-2030, as shown in blue box, the GHG emission in each year is not the same, it is because the waste in 2020 is reduced by 20%.

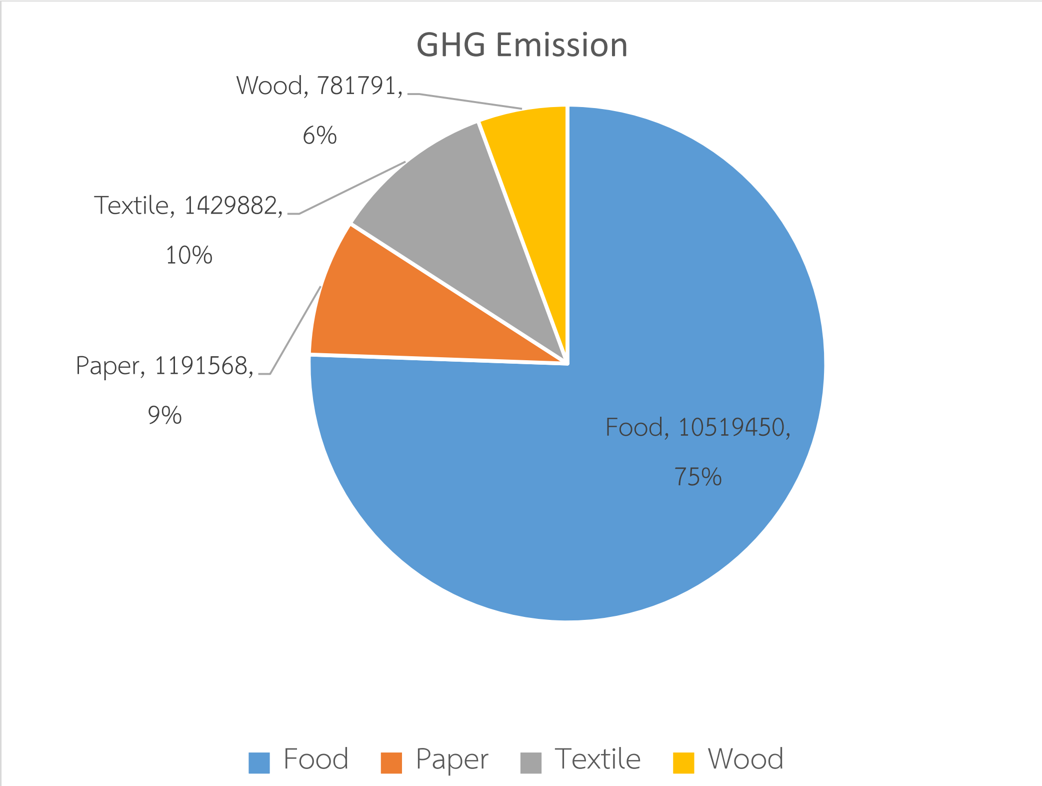


Figure 35: GHG Emission by Categories

Scenario 5: Change waste Composition in 2020 (Paper increase 20%, Food Waste decrease 20%)

In most developed countries where the economic is advanced, the dominant group of waste is not food waste, but paper waste. So it is meaningful to see what the difference is if the paper waste increases while the food waste decreases. In this scenario, it is assumed that the food waste, which accounts for about 70%, which is the dominant group of waste in the current waste management system, decrease 20%. It means that the food waste remains only 50% in 2020. In the meantime, paper waste, which is only 3% in the current waste management system, increase 20%. In other word, in 2020, the paper waste fraction takes account for 23% while the other wastes fraction are assumed to remain the same.

The table illustrates the GHG emission in each year by categories in Scenario 5.

Table 25: GHG Emission

Year	Food	Paper	Textile	Wood	Total
2009	311,084	35,401	42,482	23,818	412,785
2010	335,779	38,201	45,842	25,654	445,475
2011	357,682	40,682	48,818	27,267	474,450
2012	403,972	45,933	55,120	30,726	535,751
2013	441,958	50,236	60,284	33,537	586,015
2014	480,535	54,603	65,524	36,376	637,037
2015	498,169	56,586	67,904	37,616	660,275
2016	515,357	58,517	70,220	38,814	682,908
2017	531,975	60,379	72,455	39,959	704,768
2018	547,909	62,161	74,593	41,042	725,705
2019	563,052	63,850	76,620	42,057	745,579
2020	412,365	501,671	78,522	42,995	1,035,553
2021	421,870	512,971	80,291	43,852	1,058,985
2022	430,669	523,384	81,921	44,626	1,080,600
2023	438,731	532,873	83,406	45,314	1,100,325
2024	446,040	541,418	84,744	45,915	1,118,116
2025	452,587	549,007	85,931	46,427	1,133,952
2026	458,399	555,670	86,974	46,854	1,147,898
2027	463,524	561,470	87,882	47,202	1,160,079
2028	467,993	566,438	88,660	47,475	1,170,566
2029	471,880	570,668	89,322	47,679	1,179,549
2030	475,209	574,183	89,872	47,818	1,187,082
Total	9,926,739	6,556,303	1,617,387	883,022	18,983,452

- **Scenario 6: 50% of Gas Collection implementation in 2020**

In most sanitary landfills, landfill gas collection system is necessarily installed to capture the landfill gas emitted to the atmosphere. Methane (CH_4) is collected at site, and transfer to the facility to generate electricity. This process is called the waste to energy process. The system is very useful. It not only reduces the greenhouse gas emission from landfill to the atmosphere, it also can generate electricity for people around the landfill site. The electricity generated from landfill gas collection is considered as green energy as it can replace the use of fossil fuel. In this system, we assume that the gas collection system with the efficiency of 50% will be installed at site to collect the methane in 2020 onward.

Table 26: GHG Calculation Sheet

Year	Food	Paper	Textile	Wood	Total
2009	311084	35401	42482	23818	412785
2010	335779	38201	45842	25654	445475
2011	357682	40682	48818	27267	474450
2012	403972	45933	55120	30726	535751
2013	441958	50236	60284	33537	586015
2014	480535	54603	65524	36376	637037
2015	498169	56586	67904	37616	660275
2016	515357	58517	70220	38814	682908
2017	531975	60379	72455	39959	704768
2018	547909	62161	74593	41042	725705
2019	563052	63850	76620	42057	745579
2020	461848	52348	62818	34396	382131
2021	472494	53527	64233	35082	390935
2022	482348	54614	65537	35701	398875
2023	491378	55604	66725	36251	406224
2024	499565	56496	67795	36732	412867
2025	506898	57288	68745	37141	418795
2026	513406	57983	69580	37483	424033
2027	519148	58588	70306	37762	428628
2028	524153	59107	70928	37980	432605
2029	528507	59548	71457	38143	436035
2030	532234	59915	71898	38254	438938
Total	10519450	1191568	1429882	781791	11,180,713

- **Scenario 7: 70% of Gas Collection implementation in 2025**

This scenario continue from the scenario 6. It means that the government implement the high efficiency, 70% of efficiency, of landfill gas collection in 2025 upgraded to 50% efficiency landfill gas collection installed in 2016. In other word, from 2010 to 2025, the gas collection system with the efficiency of 50% is installed in the landfill, but from the year 2025 onward, 70% efficiency landfill gas collection system is install to replace the 50% efficiency of landfill gas collection.

Table 27: GHG Emission Calculation

Year	Food	Paper	Textile	Wood	Total
2009	311084	35401	42482	23818	412785
2010	335779	38201	45842	25654	445475
2011	357682	40682	48818	27267	474450
2012	403972	45933	55120	30726	535751
2013	441958	50236	60284	33537	586015
2014	480535	54603	65524	36376	637037
2015	498169	56586	67904	37616	660275
2016	515357	58517	70220	38814	682908
2017	531975	60379	72455	39959	704768
2018	547909	62161	74593	41042	725705
2019	563052	63850	76620	42057	745579
2020	461848	52348	62818	34396	382131
2021	472494	53527	64233	35082	390935
2022	482348	54614	65537	35701	398875
2023	491378	55604	66725	36251	406224
2024	499565	56496	67795	36732	412867
2025	506898	57288	68745	37141	251277
2026	513406	57983	69580	37483	254420
2027	519148	58588	70306	37762	257177
2028	524153	59107	70928	37980	259563

2029	528507	59548	71457	38143	261621
2030	532234	59915	71898	38254	263363
Total	10519450	1191568	1429882	781791	10,149,100

It is obvious that the amount of GHG emission is reduced significantly because of the installation of gas collection in the landfill.

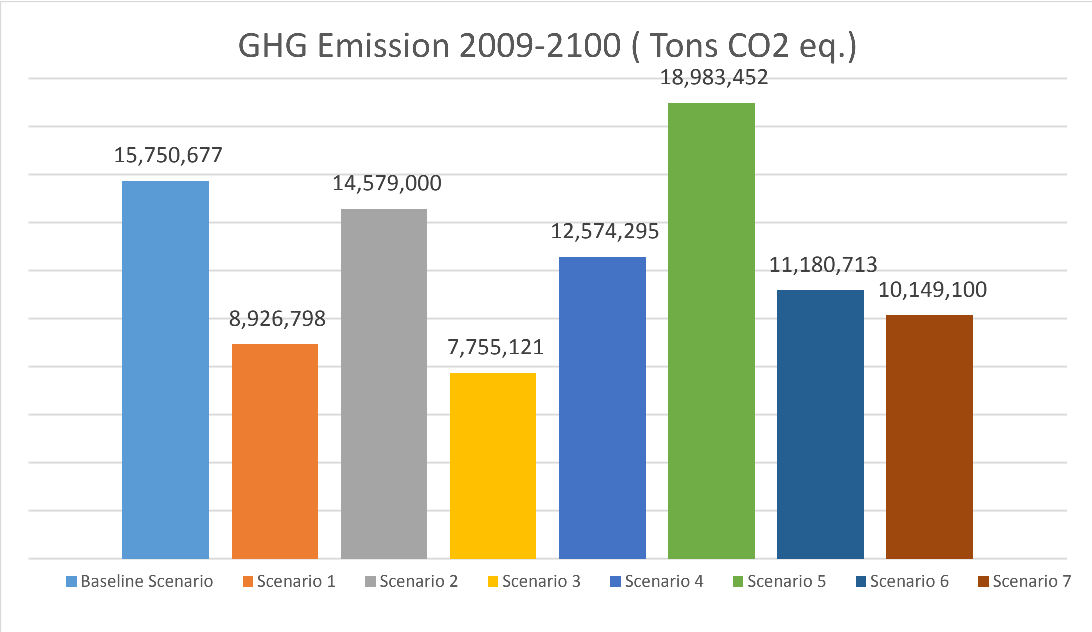


Figure 36: GHG Emission in Each Scenario

Figure below illustrates the accumulation the GHG emission of each scenarios in yearly basis. According to the Figure, it is obvious that the Gas collection scenario will reduce the GHG emission dramatically whilst the GHG emission will be increased drastically in 2020 if the increasing of Paper waste occur. This kind of graph is very important especially for decision maker and policy maker as it gives the insight of each system scenarios.

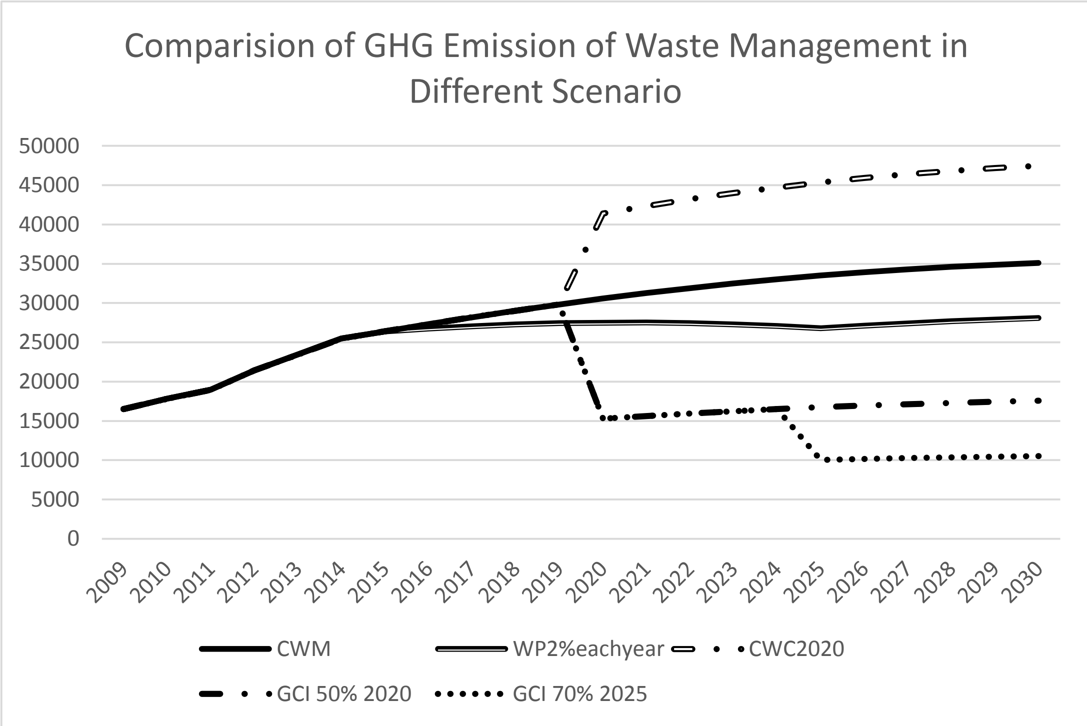


Figure 37: GHG Emission in Yearly Basis

- **Priority on GHG Reduction**

According to the result shown in the last chapter, some scenarios are seen to be more beneficial to the environment than other scenarios regarding the potential reduction of greenhouse gas emission to the atmosphere. This can be done by comparing to the current waste management system, scenario S0. In this section, these scenarios will be listed from the most favorable to the least favorable choice according to its potential reduction of greenhouse gas emission comparing to the scenarios S0. In other word, the scenario that stays at the top of the list is the prioritized scenario that should be implemented as soon as possible:

1. **Scenario 3 - The combination of 50% composting and 20% of material recovery:** according to the result, the implementation of this scenario is the most favorable system to the environment in term of the GHG emission reduction. In scenario 0, the GHG emission is 15,750,677 tons CO_2 equivalent. If the government implement and achieve 50% of composting and 20% of material recovery, the GHG will emit only 8,926,798 tons CO_2 equivalent. The

greenhouse gas emission can be reduced up to 52 percent if scenario 3 successfully implemented. It is worth to mention that the GHG emission can be further reduced if the government enhance the efficiency of source separation. Material recovery can be increased the revenue if the recycling facility is properly handled. Composting is also beneficial to the farmers as the product of composting is used to enhance the soil condition.

2. **Scenario 1 – 50% of composting:** composting is the most popular waste management system in developing countries. It is because the majority of waste composition is food waste, which is beneficial for doing composting. According to the result, by doing 50% of composting alone can reduce the GHG emission from 15,750,677 tons CO_2 equivalent in the current waste management S0 to only 8,926,798 tons CO2 equivalent. It reduces up to 44 percent of GHG emission. It not only reduces the GHG emission to the atmosphere, but also reduces the amount of solid waste that need to transfer to the disposal site to a great extend. It helps extend the landfill life. Economic benefic can be also obtained by this scenario implemented by selling the composting products. Good quality of composting can be used as fertilizer to increase the crop yield of the farmer. It is very benificial to the economy.

3. **Scenario 6 and 7 – Gas Collection System Installation:** gas collection is commonly used in developed countries, but not for developing countries because it need a lot of budgets for equipment, installation, maintenance and so on. According to the result, if the installation of gas collection with 50% recovery in 2020 succeeded, the GHG emission would be reduced from 15,750,677 tons CO_2 equivalent in baseline scenario, scenario 0, to only 11,180,713 tons CO_2 equivalent. It potentially reduced 30%. But if it is possible to implement the gas collection system with 70% efficiency in 2025, the GHG will be continuously reduced to only 10,149,100 tons CO_2 equivalent. The GHG emission is reduced approximately 35 percent. The benefits of landfill gas

collection is not only the potential reduction of GHG emission, but it is also possible to generate electricity providing to people living around that area.

4. **Scenario 4 - 2% of Waste Prevention Accumulatively in Each Year:** Assuming that 2 percent of waste can be prevented accumulatively from 2016 onward, the result illustrated that the GHG emission in this scenario is about 12,574,295 tons CO_2 equivalent. It reduces 20 percent of GHG emission from that of baseline scenario, which is 15,750,677 tons CO_2 equivalent. If more percent could be achievable, waste prevention surely is the best option as it is stated in hierarchy of waste management. Waste prevention is stayed on the top of the waste hierarchy.

5. **Scenario 2 – 20% of Material Recovery:** If 20% of material can be separated for collection and transfer to the recycle facility to do the material recovery, it is also beneficial to the environment as well. As shown in the result, the potential reduction of GHG emission is 9 percent. It reduces from 15,750,677 tons CO_2 equivalent from baseline scenario to 14,579,000 tons CO_2 equivalent in this scenario. The efficiency of material recovery is depended on the efficiency of the source separation of recyclable waste. It simply means that if it is possible to enhance the source separation, the efficiency of material recovery is increased accordingly.

6. **Scenario 5 - Change of Waste Composition:** Out all of the scenarios in this study, only this scenario is not beneficial to the environment in terms of the GHG emission reduction. According to the result, if the paper waste increases in proportion instead of food waste, the GHG emission is not only not decreased, but it will, on the other hand, be considerably increased. It is because of the fact that the degradable organic carbon (DOC) existing in paper is much bigger than DOC existing in food waste.

The list of priority above is provided only based on the potential reduction of greenhouse gas emission, GHG, comparing to the net emission of GHG in the baseline scenario. In the next chapter, recommendations as well as strategic plan for GHG reduction to improve the waste sector in Phnom Penh will be provided. Moreover, the advantages and disadvantages of each scenarios will be elaborated as well. Furthermore, the stakeholders and the strategic plans in each scenarios will be identified to make the implementation of each scenario feasible.

IV.4 Questionnaire Survey Result

After assessing the environmental impact of each scenario strategies of waste management, behavioral analysis is proceeded to evaluate people behavior and willingness to separate. The distribution of questionnaire survey is carefully done to obtain the reliability as much as possible. Plan and targeted area have been carefully made and chosen before doing the survey. Mostly the questionnaire survey is done by using house to house approach and distributing at crowded area like market area. To conduct the survey faster, two people that have experiences in doing this kind of survey were hired to help. In prior to doing the survey, two session of training were conducted. The first session is to explain the material in the questionnaire survey and question that might be asked during doing the real survey. The second session is a mock survey. Several people of about thirty years old are asked to answer the questionnaire survey. They asked many questions what they are not cleared about the question in the survey. After making sure that they understand about each question in the survey, the real survey has been launched. The survey has been done from June 2, 2015 to June 12, 2015 (10 days). To determine the sample size, Yamane formula is used for the calculation. According to Yamane principle, 400 samples are needed for the population more than 100,000 to obtain the precision levels with confidence level 95% and P=5%. However, because of the unreliability and inconsistence of the answer of the respondents, some samples have to be cut off. The finalized sample that using for analyze is 300 samples (table 28). 58 percent of the respondents are female while 42 percent are male. The majority of the respondent has age between 15 to 29 years old, accounting for 42 percent. 30-40 years old respondents are the second leading group as it consists of 33 percent. The respondent whose age is between 40-50 is 20 percent. The rest is the elder respondent whose age is 50-60+. The simple descriptive analysis is deployed in this study.

Table 28: Information of the Respondents

Information	Percentage
Sex:	
Female	58%
Male	42%
Age:	
15-29	42%
30-40	33%
40-50	20%
50-60+	5%

IV.4.1 Environmental Awareness

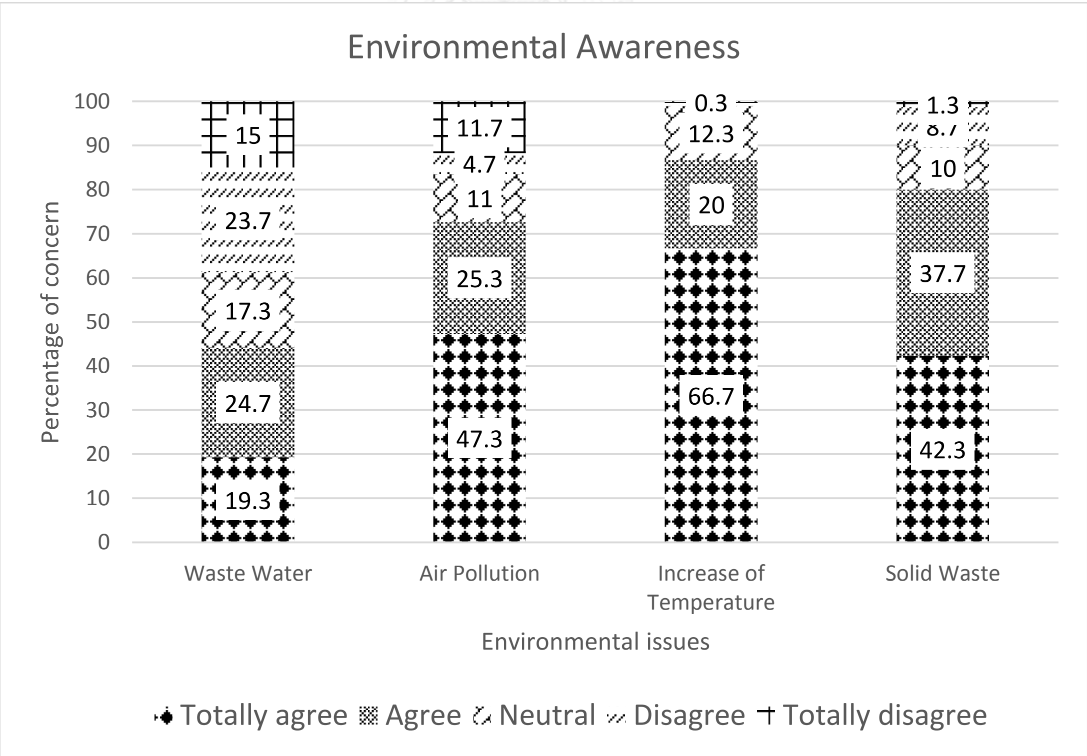


Figure 38: Environmental Awareness

This question asks about how the respondents about what environmental impacts that they concern nowadays. Unsurprisingly, people seem to concern about temperature rise as nowadays it become a lot hotter comparing to about ten years before, rather than other environmental impacts. 66.7 percent of people totally agree that global warming is the most concerning problem. While 20 percent of respondents agree that the increase of the temperature is a problem. 12 percent is neutral toward temperature raising. Less than 1 percent do not feel the urgency of the climate change effect to the environment as well as the society. Air pollution is also the environmental issue that the majority of people considers as the serious problem as well. 47.3 percent of overall respondent totally agree that it is the problem that should take an immediate action as the amount of transportation is rapidly increasing in Phnom Penh, and the air quality is not good for them and family. 25 percent agree that it is the problem but it is not as urgent to solve as the previous group. 11 percent of the people feel neutral towards air pollution issue, and 5 and 12 percent are disagree and totally disagree, respectively. For MSW issue is considered to be a serious issue amongst global warming and air pollution. 42 percent of the total respondents totally agree that MSW issue must be taken into consideration while 38 percent agree that it is the issue. 10 percent neutrally think that MSW is not a big problem. Only 9 percent and 1 percent disagree and totally disagree on MSW issue, respectively. Last but not least, it seem like Waste Water issue is the least concerned of the respondent. According to the questionnaire, only 19 percent totally agree on waste water issue. 25 percent agree, 17 percent is neutral, 23 percent disagree and 15 percent is totally agree. Looking to the chart, global warming or temperature rising is the issue that people concern the most. It also illustrates that people are well aware of the issues regarding MSW management.

IV.4.2 Issue of municipal Solid Waste Management

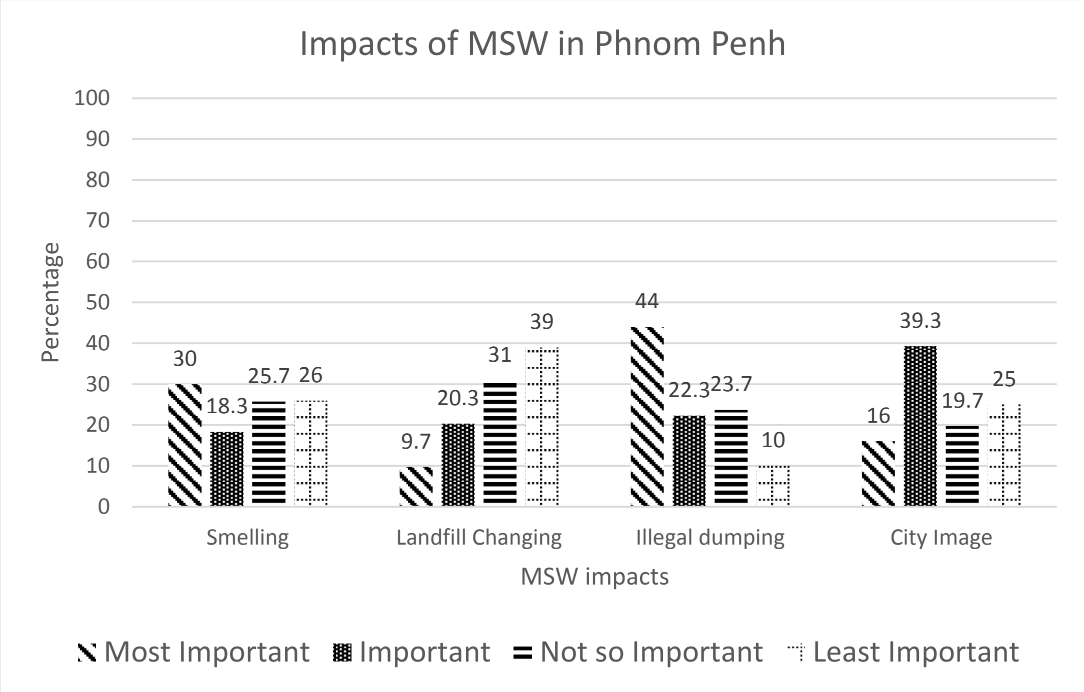


Figure 39: Impacts that People Concern

This question is to find out the issue occurred related to MSW management system concerning by people in Phnom Penh, Cambodia. According to the bar chart, it is illustrated that 30 percent of the respondents think that the smelling problem is the most important issue, will 10 percent think that landfill changing is the serious problem to consider. 44 percent stress on the illegal dumping as the most important issue. 16 percent is considered city image as the most concerning factor. On contrary, 26 percent of the people think that smelling is the least important factor among the others. Landfill changing is considered least important by 39 percent of overall respondent. 10 percent think that illegal dumping is not a problem occurring nowadays. 25 percent consider city image as least important issue. 18 percent think that smelling is important, while 20% think that Landfilling changing is important. Another 22 percent, believe that illegal dumping in the city is important while the last 39 percent categories the effect of the image of the city as the important factor among the others. Moreover, 26 percent think that smelling issue is not so important to consider as the problem. 31 percent thinks that landfill changing is not so important, and the other 24% thinks that illegal dumping is not so serious issue while the rest 20% thinks that the city image is not so important to take into consideration for the current municipal solid waste management. The chart demonstrates that illegal dumping and smelling are the most concerning issues that people in Phnom Penh municipality consider as serious problems.

IV.4.3 Waste Separation

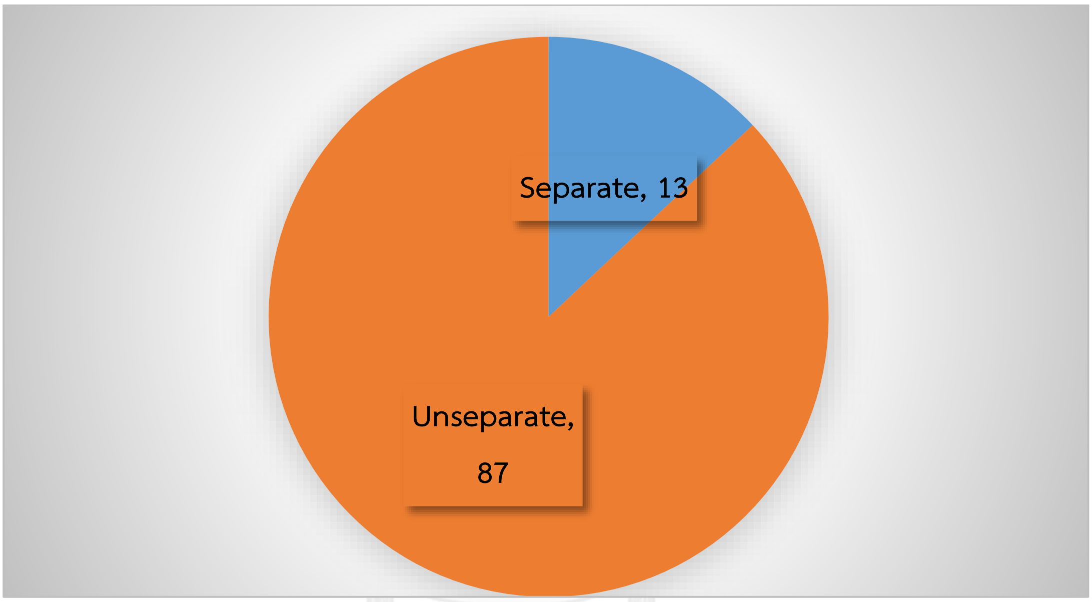


Figure 40: Waste Separation

Waste separation in Phnom Penh municipality is not generally practiced. The government seem not to be actively promote the waste separation method. This question aim to measure the percentage of people who separate their waste before discharge for collection and disposal to landfill. The pile chart above shown the result about the waste separation before discharging, or in other word, it is called at source separation. According to the pile chart, up to 87 percent of 350 samples answers that they did not separate at all before they discharge them. They mix everything in the bag and discharge for collection. The other 13 percent answers that they separate it before they discharge for collection. The result clearly illustrates that waste separation method in Phnom Penh municipality is so minor. The majority of the population does not separate waste before dispose it.

IV.4.4 Reasons of not separate waste

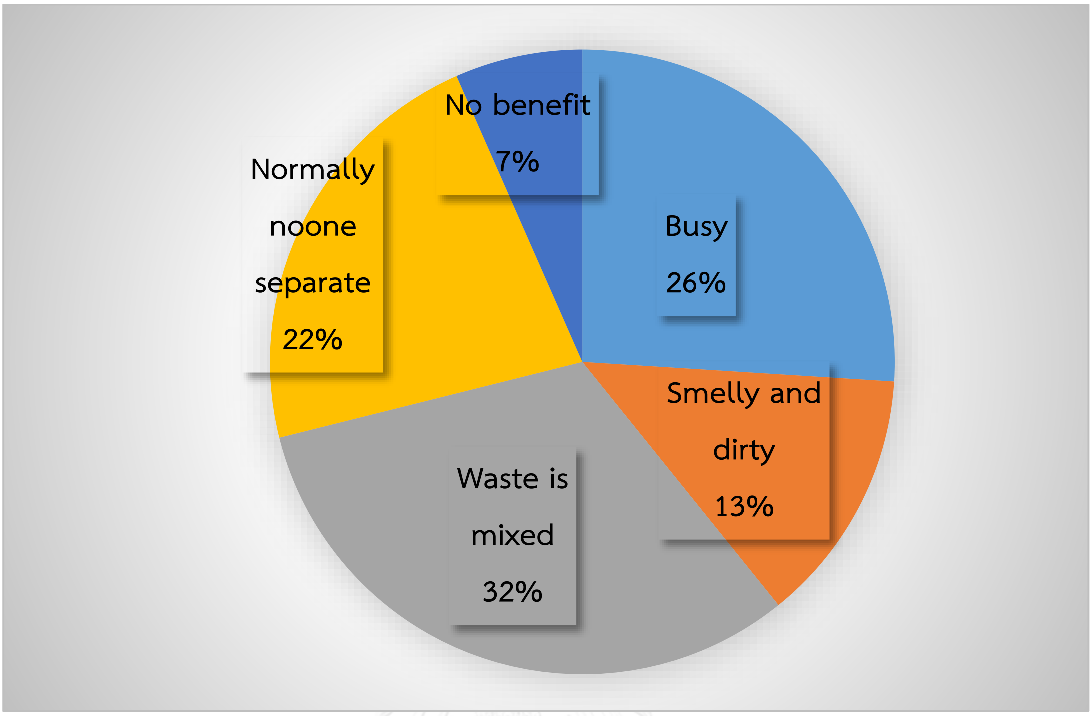


Figure 41: Reason of Not Separation

After knowing the amount of people who separate and not separate their waste before discharging, it is very important to know the root why people do not separate waste at source or home. The main goal of this question is to find out the reason why people do not separate waste. The results of the unseparated behavior of waste are as shown in the figure 4. The vast majority of people, take account for 32 percent, said that waste is mixed, and it is very difficult to do the separation. It is the reason why they do not separate into categories because wet waste is very difficult for them to do the separation. 26 percent said that they do not separate waste into categories because they are busy with their study or work, so they do not have time to do the separation. 22 percent of the respondent claims that normally no one separate before discharging; as a result, they do not separate as well because even though they separate at their house, the waste will be mix at the end. 13 percent answered that waste are smelly and dirty, so they do not want to separate and leave it unseparated. The rest 7 percent claims that waste separation has no benefit, so they do not separate it. In short, wet waste, business and the unseparation of the majority are the main roots. If the government is able to find an effective method to deal with these roots, it is believed that the waste separation method will be able to be implemented in the system easily and successfully.

IV.4.5 Recyclable Waste Management

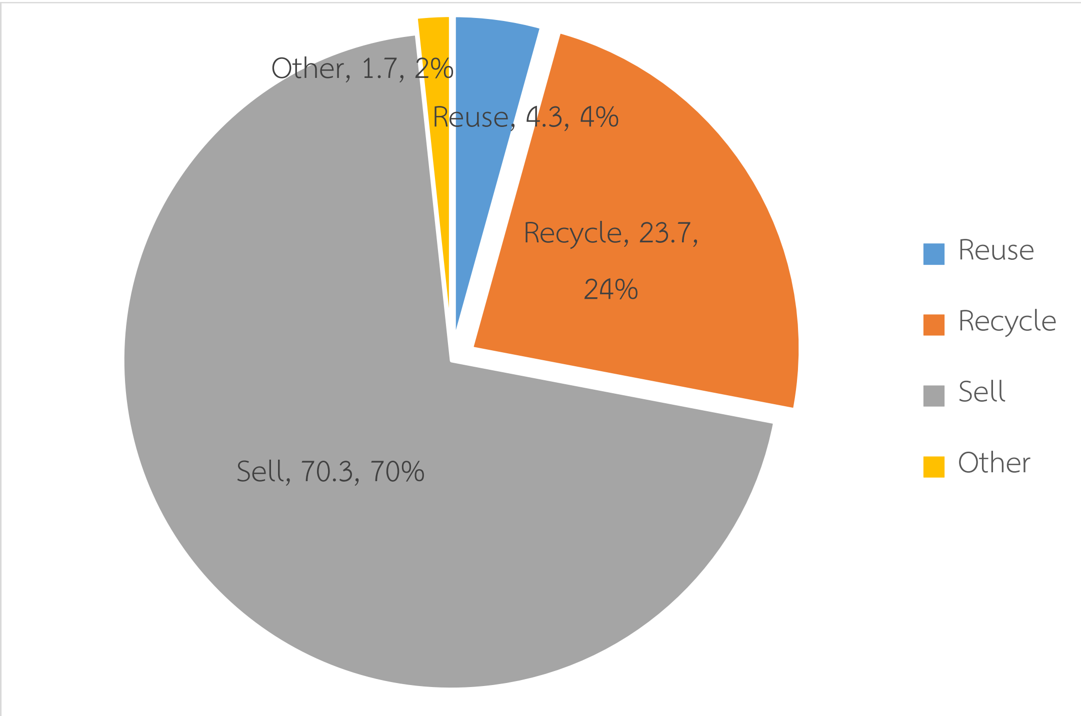


Figure 42: Recyclable Waste Management

For those who separate the waste, the following question to investigate how they manage their recyclable waste or valuable waste. The answer is shown in the pile chart above, among the 350 samples, 70 percent of the total respondent answer that they sell them to the scavenger for some profits. The material that are able to sell are aluminum material like aluminum can and so on, plastic bottle or paper. Other 24 percent answer that they recycle those material and use them again. 4 percent response that they reuse it again while the other 2% for different purposes

IV.4.6 People Behavior toward Separation and Willingness to Pay

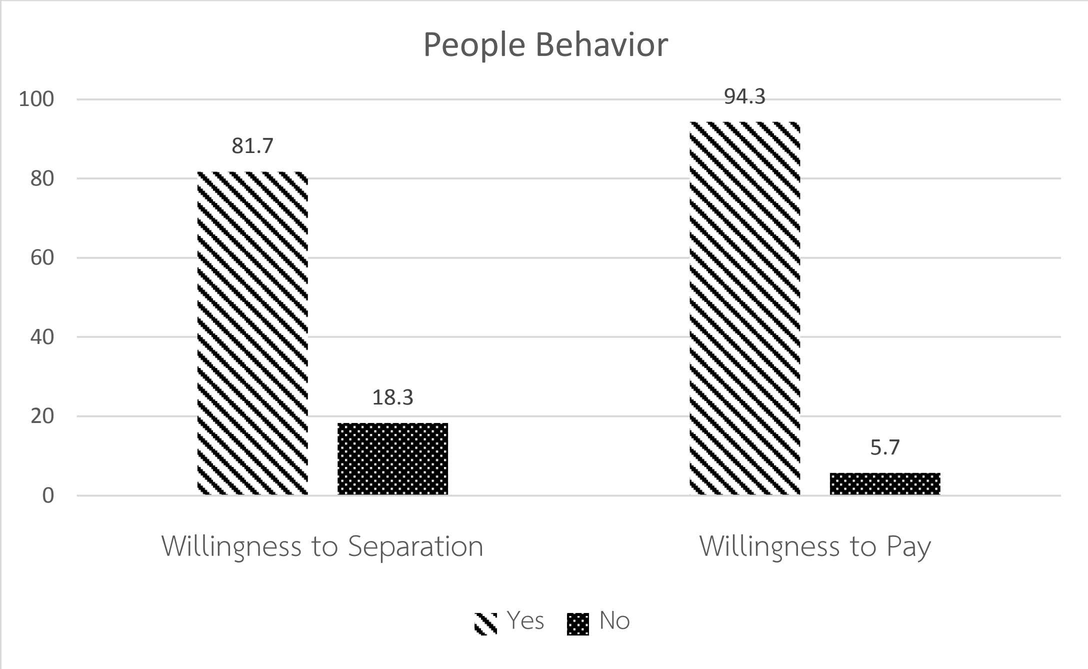


Figure 43: Willingness to Separate and Pay more

This section is to study about the people behavior and willingness of the people toward waste management to see whether people are willing to cooperate or nor. In this section, there are two questions that the respondents are asked. The first is that are you willing to separate your waste at home if you are asked to do so? And the second question is that are you willing to pay more for the improving of current waste management because to improve the management system, it need more money and those money to investigate. Satisfyingly, the result shown that the majority shown the positive answer to the question. As shown in the bar chart, more than 80 percent of the respondent said that they are willing to separate their waste before discharging if there is proper regulation or initiation from the government. Only less than 20 percent said that they are not willing to separate as they are busy and it has no benefit to do so. For the willingness to pay more, more than 90 percent answered that they are willing to pay more to improve the current waste management nowadays wile only less than 10 percent are not willing to pay more because they think that the money they monthly pay for the service is enough already. Currently, there is also a collection fee as well. The collection fee is included in the electricity bill. The amount of service fee varies according to the type of household and the area of the household. For the houses that do business or in the rich area, the service is higher than the common household. So this question is to ask whether people are willing to pay more in addition to their current paying or not. The amount of collection fee seem to be not well-defined. The collection fee of the same type of household might be varies. As a result, there are many people complain about this. The amount of pay more comes from the willingness of people without force. People can choose not to pay any more. After seeing the result shown above, it is optimistic that the implementation of the at source separation and other further treatment method are highly likely to be successful as people are willing to cooperate and pay more for a better improving of municipal solid waste management in Phnom Penh.

The figure illustrates the percentage of the citizen agree to pay more to improve the current waste management system in the currency of USD. According to the figure, the citizens that are willing to pay more 1 USD have 95%, but citizens that are willing to pay more 9 USD have only 2 percent. The average that citizen agree to pay more is between 3 USD and 4 USD. This kind of information is very important for government or policy maker to improve the current waste management because we have the information of the willingness to pay of people.

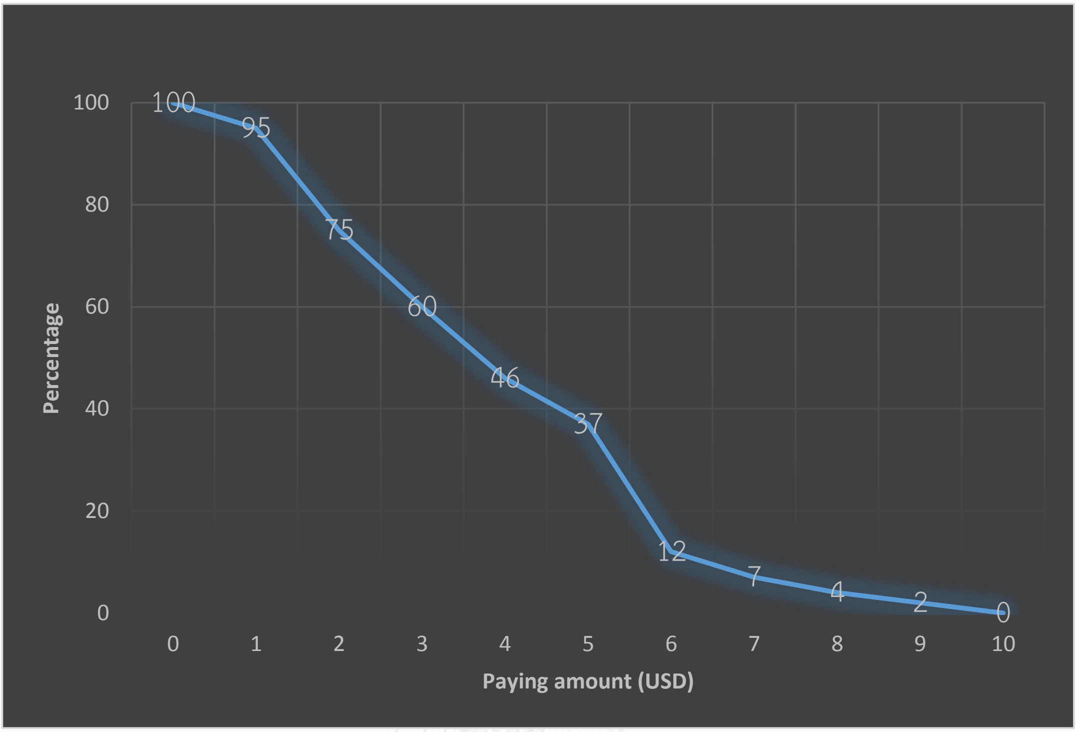


Figure 44: Amount of Money People are Willing to Pay (USD)

IV.4.7 Choices of Separation

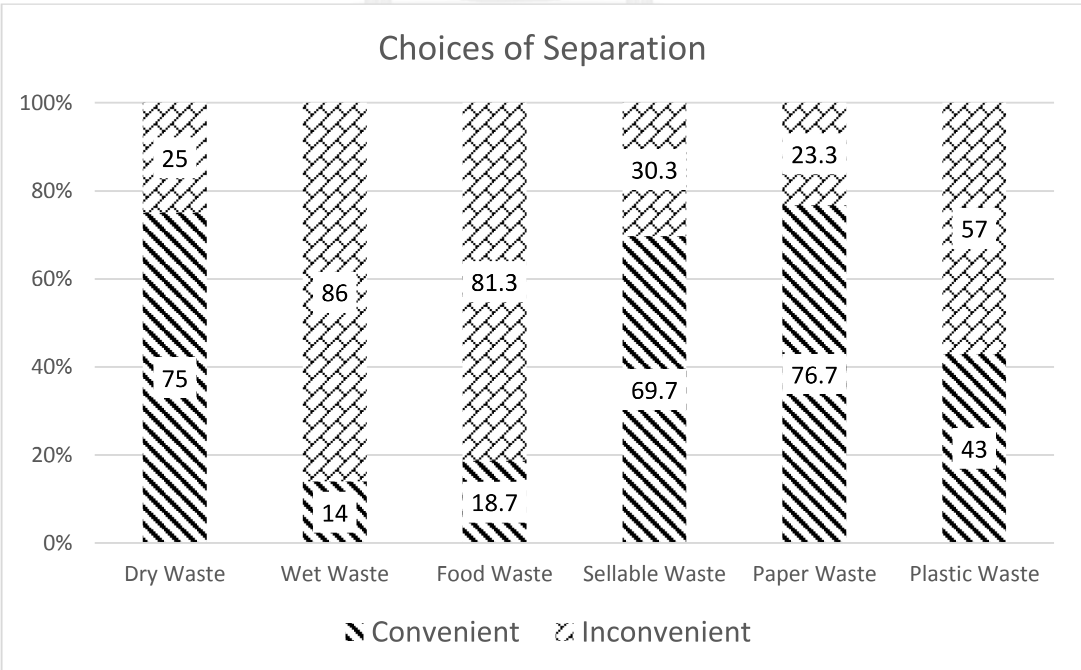


Figure 45: The Choices of Separation Methods

Last but not least, this question is to investigate what is convenient and inconvenient of material separation that people prefer over another. The question is asked the respondents to choose the three separation ways that they think that they are convenient for them if the separation method are initiated to implement. The result shown that people think dry waste separation from the overall waste is convenient as almost 80 percent choose this way, and only less than 20 percent do not choose it as a convenient method. For wet waste separation, less than 20 percent of the people think that it is the convenient method while more than 80% do not choose it as a convenient waste to do. Similarly, separation food waste from other waste is not a convenient to separate for the people as well. It is because only about 20 percent consider it as a convenient separation while almost 80 percent categories it as an inconvenient method for separation. For sellable waste like aluminum cans, plastic bottle and so on, 75 percent of the answer obtained from the questionnaire shows that it is a good method while only 25 percent consider it as an inconvenient method. Similarly, paper waste separation method is also the convenient separation method for the vast majority of people as well. As shown in the graph, almost 80 percent of overall respondents choose the paper waste separation method as a convenient method for them. Only around 20% do not choose this method as a convenient one. The last method separation is plastic waste separation, more than 50 percent do not choose plastic waste as a convenient separation method while only 40 percent of the respondent choose this as a convenient method for them.

Chapter V

Recommendations

This section provides recommendations to improve the current waste management system in Phnom Penh, Cambodia. There are recommendations given to the key stakeholders including the government officials, local governments, and citizens.

As shown in the problem section, the problems that exist in the current existing municipal solid waste management system in Phnom Penh mainly is coming from the poor of collection efficiency of waste and the low environmental awareness of the citizens. As a result, to improve the current waste management, firstly and foremost it is essential to improve the waste collection efficiency and raise people awareness.

Recommendations below are given based on the problems occurred in the current waste management system.

1. **Improve collection efficiency**

➢ **Short-term plan**

- **Government Role**
    - ✓ The storage system should be provided to as many places as possible because it can reduce the illegal dumping.
    - ✓ The schedule and collection time should be professionally planed in advance.
    - ✓ Collection service should be provided to every places in the city by enhance the collection schedule.
    - ✓ At-source separation, which is proven to be the successful management system in many countries, should be initiated and implemented by government because it helps improve resource recovery, extend landfill life, and composting activities.
    - ✓ Public awareness about environment, especially solid waste issue, should be promoted through education and short-course

training. Consequently, public participation will be significantly increased.

- **People Role**
  - ✓ Citizens should put waste in plastic bag, and put inside the waste container, avoiding putting outside the bin.
  - ✓ Prevent or reduce generating waste as much as possible.
  - ✓ Reuse or Recycle usable waste.
  - ✓ Try to separate waste in categories before disposal.
  - ✓ Illegal dumping or open burning is prohibited.

- **Long-term Plan**
  - **Government Role**
    - ✓ Strict regulations and laws regarding illegal dumping should be established, monitored, and enforced. Stringent penalties must be enforced to those who violate the law. Provides incentives to those who did well to encourage other people to follow the good deed.
    - ✓ The budget should be sufficiently provided by the government to the municipality to improve a current waste management.
    - ✓ Improve and enlarge the infrastructure for the accessibility of the truck should be taken into consideration.
    - ✓ Support the studies and researches regarding environmental issue, especially waste management.
  - **People Role**
    - ✓ Teaching children about the importance of environment.

2. **Raise People awareness**

People awareness is a key factor to improve the current waste management system, according to the questionnaire survey, people awareness seems to be still low. As a result, raising people awareness is very crucial before implementing a new system. Currently, the government also raise the environmental awareness through formal education. It means that in formal school curriculum includes the environmental study. But the curriculum seems to be not so effective because it includes in high school level. Moreover, students are also not interested and give no attention in those subjects. Sometimes, there is also a small group of people in the community try to promote people awareness regarding environment such as solid waste, waste water and forest. This campaign is in a small scale and lasts for several days only. It is normally ineffective. As a result, this section is to give the recommendations to raise people awareness.

- **Government Role**
  - ✓ Include environmental education from primary school. Outside activities such as growing tree and trip should be implemented in the curriculum to make students interest in this subject.
  - ✓ Provide short courses in rural areas.
  - ✓ Promote environmental campaign in the communities.
  - ✓ Improve the research in environmental area especially solid waste, and publish it for people to easily access to the information.
  - ✓ Raise people awareness through media like television, radio, social network and so on.
  - ✓ Implement the community approach, people in the community educate each other about environmental matters.
- **People role**
  - ✓ Participate in any activities such as campaign, training course and so on regarding environmental education.
  - ✓ Pay more attention to environmental issues occurring in the countries and the world by reading, watching or listening.

- ✓ Help educate and discuss with people in the same community about environmental issues.

After solving problems that exist in the current municipal solid waste management, it is important to improve the whole system to reduce the greenhouse gas emission. According to the LCA result, landfill gas collection system reduces the GHG emission the most; but because installing landfill gas collection needs to close the old landfill and build the closed landfill, it is considered that landfill gas collection system is in the long-term timeframe.

The recommendations below are given based on the result of the life cycle impact assessment in the short-term timeframe.

3. **Implement of Composting in the System**

Composting consists of many levels- from a household level to large-scale centralized level. For a large-scale centralized facilities need a wide geographic areas and need significant quantities of organic waste such as food waste. Neighborhood or community-level composting has many more benefits for example it improves the soil quality in the community, increase more job for locality. Moreover, if composting in neighborhood or communities succeed, it also reduce the amount of waste transported to the landfill. It means that it can reduce the garbage truck transportation hauling in the city. As a result, community-level composting is preferable over the large-scale centralized composting facilities. Composting can be achieved by:

- **Short-term plan**
  - **Government Role**
    - ✓ Provide composting land in the communities.
    - ✓ Instruct local community to the concept of food waste separation.
    - ✓ Storage system of food waste should be provided to local resident.
    - ✓ Study and choose the appropriate composting method that appropriate in each community.

- ✓ Allows for the local or neighborhood level operation.
- ✓ Promote local training, volunteering and employment opportunities.

○ **People Role**

- ✓ Separate food waste from other waste before dispose for collection.
- ✓ To improve the system, it need people involvement and financial support.
- ✓ Educate children and other residents in the community about composting, how it is done and how to incorporate in the system.
- ✓ Prepare the next generation for a full scale operation of composting.

➢ **Long-term Plan**

○ **Government Role**

- ✓ Increase the studies and researches in this area.
- ✓ The budget should be provided sufficiently.
- ✓ The role and responsibilities of each stakeholder such as ministry, local authority, collection service provider and community should be well defined and clearly allocated
- ✓ Strict regulations and laws should be established, monitored, and enforced from the national to local level. Stringent penalties must be enforced to those who violate the law.

○ **People Role**

- ✓ Voluntary approach by engaging in any environmental-related activities should be encouraged amongst the citizen.
- ✓ Educating children and general public about environment issues.

4. **Implementation of Recycling**

The recycling system of waste is very important. Many countries around the world implement the recycling system because it can reduce the GHG emission from the substitution of the primary production of the raw materials. Moreover, it can preserve the raw material from depletion. For example, if the recycling of paper is implemented, it not only reduces the GHG emission from the paper disposal, but it also help preserve the tree from deforestation. However, the improper waste recycling poses a lot of problems than dispose those waste in landfill. For example, the improper of plastic recycling and aluminum recycling. As a result, the government has to implement the proper recycling facility with the standard technology and operation.

- **Short-term plan**
  - **Government Role**
    - ✓ The collection and storage system should be provided to as many places as possible because it can reduce the illegal dumping.
    - ✓ At-source separation, recyclable waste such as aluminum can, plastic bottle and so on must do the separation before collection and transfer to recycling facilities.
    - ✓ Public awareness about environment, especially solid waste issue, should be promoted through education and short-course training. Consequently, public participation will be significantly increased.
    - ✓ Seeking an international fund to improve the system.
  - **People Role**
    - ✓ Separate the recyclable waste from other wastes and dispose it according to the instruction of the government.
    - ✓ Cooperate and pay more to improve the system.
    - ✓ Help and educate the residents to do the proper separation
- **Long-term Plan**
  - **Government Role**
    - ✓ Strict regulations and laws regarding illegal dumping should be established, monitored, and enforced. Stringent penalties must be enforced to those who violate the law.
    - ✓ The budget should be sufficiently provided by the government to the municipality to improve a current waste management.
    - ✓ Increase the studies and researches regarding environmental issue, especially waste management.
  - **People Role**

- ✓ Educate children about the importance of resource and environmental quality.

The recommendations below are given based on the result of the life cycle impact assessment in the long-term timeframe. As it is obviously shown in the life cycle impact assessment result, the landfill gas collection system can reduce the greenhouse gas emission dramatically; but due to the fact that installing landfill gas collection equipment requires money, expert, and time, landfill gas collection system is classified in the long-term system that need to be implement to reduce the greenhouse gas emit to the atmosphere and the environment.

5. **Landfill Gas Collection**

- **Short term plan**
  - **Government Role**
    - ✓ Start studying about the different types of gas recovery system that is suitable for the site conditions.
    - ✓ Find the technical and financial support and fund from the international agency or cooperation.
    - ✓ Install the landfill gas system according to the budget available.
  - **People Role**
    - ✓ Separate waste in categories before disposal as quality of source separation affect the efficiency of gas collection.
    - ✓ Engage in any activities that relate to environment.
    - ✓ Willing to cooperate and pay more money according to the government instruction.
- **Long term Plan**
  - **Government Role**
    - ✓ Improve the landfill gas recovery system efficiency.
    - ✓ Try to minimize the unnecessary spend by increasing the efficiency of the work.

- ✓ Consider generate electricity from waste as it can provide profit to reduce the financial burden for installation and maintenance.

- **People role**
  - ✓ Try to increase the separation to many categories.
  - ✓ Educate the local communities and public about environmental issue.

To ensure the success of the new system implementation, the engagement and involvement of people are very compulsory because only with the cooperation and willingness to separate waste before disposal for collection, the implementation of the new system to improve the current existing waste management is feasible. It is a common sense that to implement a new system, more budget are unavoidably needed to invest. The budget commonly come from the citizens, waste generators, to pay to improve the services of their waste disposal and management. According to the result of the survey study done above, people, positively, are willing to separate waste before disposal for collection, and they are willing to pay more in order to improve the current waste management. As a result, it is highly likely that the implementation of the recommended scenario is a success if the government or the policy maker make a decision to implement the above recommendations to improve the municipal solid waste management system in Phnom Penh, Cambodia.

Chapter VI
Conclusion

This section is to give the conclusion of this research study. This study is to apply the life cycle impact assessment method to improve the current municipal waste management system in Phnom Penh, Cambodia. Furthermore, questionnaire survey has been employed in this study to do the assessment in order to improve the current system from social perspective. Last but not least, recommendations as well as management strategies to improve the system are also presented. The key finding of this research is as below:

VI.1 Current Existing Waste Management System:

There is no storage system for the residents to store their waste. The waste is placed in front of the house waiting for collection. Because the collection service is not regularly provided, the free space area becomes the disposal point as people do not want to keep waste in their houses. The collection service is provided regularly to commercial or highly visible area. Waste collected is transported to the landfill, which approximately located 16 km from the central city. Almost all kinds of waste are seen transferred to the landfill without pretreatment and post treatment. There is currently no formal separation and recycling method.

VI.2 Existing Problems

There are a lot of problems existing in the current waste management system. First of all, the collection service efficiency is still low. Service is not provided regularly. Second, illegal dumping is still seen practicing in the city. Waste that clogs the drainage system is one of the factors that causes the floor when there is the heavy rain. Third, the level that people care or concern about the environment is still low. People has the idea of "no waste in my backyard". They do not want to see waste in their sight, so they just dispose waste everywhere as long as it is out of their sight, out of their houses.

VI.3 Life Cycle Impact Assessment:

Life cycle assessment illustrates that the current waste management system has a lot of environmental impact, in terms of greenhouse gas emission, rather than the other waste management scenarios. The current waste management emit the GHG gas 412,785 ton CO2 eq. for the waste disposed in 2009. The analysis is obviously shown that the GHG emission will be dramatically reduced to only 234,429 ton of CO2 eq. if we do the 50% composting while it slightly reduces to 382,161 ton CO_{2e}.if we implement the 20% of material recover. If we take the benefit of the composting combining with the material recovery, the trend will be continuously decreased to only 203,806 tons of CO_{2e}. in the same timeframe. To make it useful for the policy maker or decision maker, the estimation of the GHG emission in 2009 projected until 2030 is shown afterward. It is clearly shown that composting combine with material recovery is the best strategies because it can reduce the GHG emission from 15,750,677 ton CO2 eq. to only 7,755,121 ton CO_{2e}. The 50% composting of food waste comes to the second place because it reduces the GHG emission to only 8,926,798 ton CO_{2e}. It is worth to notice that the gas collection system plays an important role in reducing the GHG emission in the system. According to the result, in can reduce the GHG to 11,180,713 ton CO_{2e}. and 10,19,100 ton CO_{2e}. if we install the 50% and 70% of efficiency respectively. It is worth to mention that all of the scenario is benefit to the environment except for the changes of waste composition in the future. If the paper composition increases, the GHG emission will be increase from 15,750,677 ton CO_{2e}. to 18,983,452 ton CO_{2e}.

VI.4 Questionnaire Survey

Behavior study results illustrate that the majority of people concerns about the temperature rising of the globe. People also show the concern about the waste management problems occurring in Phnom Penh as well. According to survey, the majority of do not separate waste before disposal, The reason why they do not separate is because they think that waste is smelly and dirty, some people say that they are busy while the other mention that separation of waste is no use as they will be mixed up in the end. But fortunately, the majority of people are willing to do the separation if the government instruct them to, and they are willing to pay more to improve the current waste management.

VI.5 Recommendations

✓ Promote waste collection efficiency by:

- The technical arrangement such as storage, collection, transport and disposal need to be improved by improve the waste collection efficiency.
- The schedule and collection time should be professionally planed in advance.
- At-source separation, which is proven to be the successful management system in many countries, should be initiated and implemented because it helps improve resource recovery, extend landfill life, and composting activities.

✓ Implement Composting because it reduces GHG by:

- Installing the composting facility for community.
- Separate collection and transport the food waste to composting facility.
- Storage system of food waste should be provided to local resident.

✓ Implementing Waste Recycling by:

- Material recovery should be implemented because it not only reduces the GHG emission, but also makes profit.
- At-source separation, recyclable waste such as aluminum can, plastic bottle and so on must do the separation before collection.
- Strict regulations and laws should be established, monitored, and enforced from the national to local level. Penalties must be put to those who violate.

✓ Landfill gas collection should be installed by:

- Government should consider installing the landfill gas collection in the long-term goal. Study about landfill gas collection system should be initiated from now on.
- Start studying about the different types of gas recovery system that is suitable for the site conditions.

- Find the technical and financial support from the international agency or cooperation.
- Install the landfill gas system according to the budget available

Last but not least, this study only focuses on the environmental impacts of each system. Environmental impact is only one criterion to decide to implement a new system. From the point of view of the decision makers, economic side is very crucial in order to decide whether to implement the new system or not. As a result, I would recommend to do a further study about the cost and benefit of each new system. For example, this study finds the amount of methane emission from landfill. We can further our research study on how much the electricity can be generated from these amount of methane emission. Besides environmental impacts, economic return, investments, cost and benefits should take into account as well before decide to implement a new system to improve the current existing waste management system in Phnom Penh, Cambodia.

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APPENDIX

Appendix A: Questionnaire in English (Translated)

Section I: Respondent Background

1. Your age : ____________ years old

2. Your Sex :

   (a). Male (b). Female

3. Your address: District _____________________

4. Your profession:

   (a). Housewife (b). Do Business

   (c). Government officer (d). Unemployed

   (e). Student (f). Other ___________________

5. Your Income per month:

   (a). less than 200 $ (USD) (b). 200-400

   (c). 400-600 (d). more than 600$

6. Your education level:

   (a). Uneducated (b). Primary School

   (c).Secondary School (d). High School

   (e).Bachelor Degree (f). Master Degree

   (g). Doctor of Philosophy

7. Number of family member in your house: ____________ people

8. Kind of House you are living in:

(a). Condominium (b). Villa

(c). Flat (d). House

(e). Rent Room (f). others ____________

Section 2: Knowledge Regarding Environmental issue

9. Do you agree or disagree that the issues mentioned below are the problems that occur in the society.

Issues	Strongly agree	Agree	Neutral	Disagree	Total disagree
Waste water					
Air pollution					
Global warming					
Solid waste					

10. What kind of problems of waste management are you aware of? Please rank from 1-4 (1 the most problematic one)

Problems	Odor	Landfill life	Illegal dumping	City Image
Order				

Section 3: Current Waste Management

11. How often (times) do you discharge your waste per week?

(a). 1 time (b). 2 times

(c). 3 times (d). 4 times

(e). 5 times (f). .... times

12. Suppose you use waste container as below (Height=28cm, Width=26cm, Depth=26cm), Can you estimate how many bags you discharge per time?

(a). 1 bag (b). 2 bags

(c). 3 bags (d). ___ bags

13. Do you separate waste into different bag before discharging?

(a). yes (b). sometimes

(c). no

14. In case you do not separate waste, please give the reasons.

(a). I am very busy.

(b). It is dirty and smelly.

(c). I do not think it is useful to separate waste before discharging.

(d). Even I separate my waste, the waste will be mixed at when collection.

(e). The waste is wet, it is not easy to separate.

(f). others:___________________________

15. How do you manage recyclable waste like aluminum can, plastic bottle?

(a). Reuse (use again after it has been used)

(b). Recycle (change waste to new product and use it)

(c). Sell for profit.

(d). other:______________________________

16. You pay the fee of waste management:

(a). Never pay
(b). Every month
(c). Every 6 months
(d). Every years

17. How much you pay per month?

(a). 1 usd per month
(b). 2 usd per month
(c). 3 usd per month
(e). 4 usd per month
(f). others:_______________

18. Do you satisfy with the current waste management system?

(a). Yes, I like
(b). neutral
(c). No, I don’t like. Reason:_______________________________

19. Please rank top 3 of waste that you separate and recycle:

Materials	Recycle Waste
Aluminum Can	
Plastic bottle	
Paper	
Glass	
plastic bag	
other plastic	

20. What do you think the convenient way to sell recycled waste:

(a). Go to recycling shop
(b)Drop off at convenient store at your district
(c). Pickup by municipality service
(d). others:_______________

Section 4: Potential Future Improvement

In Phnom Penh, approximately 14 million tons of municipal solid waste have been generated every day. Almost all waste are directly transferred to the landfill without standard management. There is only one landfill site that is in operation nowadays. If the trend of waste generation is keeping going on without any proper measurements or actions taken. Solid waste issue will be more problematic. First example is the need of change of landfill site. The current landfill will be full soon, and the new one will be found and replaced. The second problem is the effect to the environment as well as the human health. According to many studies, at-source separation is the best management system that is popularly practiced in many developed countries that has a successful solid waste management system because it not only benefits to environment, but also the economic as well. It helps extend the landfill life. Moreover, it also helps reduce the price of waste treatment. More importantly, it can also make a profit from selling the recyclable waste. After getting the profit from this system, it will help reduce the service tax that you and your next generations have to pay in the long-term basis. But in order to achieve the success of this system implementation, it needs to invest a lot of money. Citizens' involvement to pay more is very crucial. If citizens do not take part in this process, the government will use national budget for developing the country like school, road, building construction if necessary. Otherwise, there is no improvement occurred.

Please take everything into consideration and answer the questions below:

21. Are you willing to cooperate in separate your waste before discharging?
    (a). Yes, I am happy to cooperate
    (b). No. please give reason:____

22. Are you willing to pay more to improve the current waste management?

(a). yes, I wish to pay

(b). No, I do not. Reason: ____.

23. What is the maximum fee that you are willing to pay?

1 USD	1.5 USD	2 USD	2.5 USD
3 USD	3.5 USD	4 USD	4.5 USD
5 USD	5.5 USD	6 USD	6.5 USD
7 USD	7.5 USD	8 USD	8.5 USD
9 USD	9.5 USD	10 USD	10.5 USD
11 USD	11.5 USD	12 USD	12.5 USD
13 USD	13.5 USD	14 USD	14.5 USD
15 USD	15.5 USD	16 USD	.... USD

24. Ranking the type of waste do you prefer to separate from 1-4. (1 is best)

Type of Waste	Ranking
a. Dry Waste	
b. Wet Waste	
c. Food Waste	
d. Sellable Waste	
e. Paper	
f. Plastic	

25. Please provide comments or Suggestions on how to improve Municipal Solid Waste Management in Phnom Penh.

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Appendix B: Questionnaire Survey in Khmer

ប្រវត្តិរូបសង្ខេប

១. អាយុ________ឆ្នាំ

២. ភេទ: ក. ប្រុស　　　　ខ. ស្រី

៣. អាស័យដ្ឋាន: ខ័ណ្ឌ:________________

៤. មុខរបររបស់អ្នក

ក. មេផ្ទះ　　　　ខ.ប្រកបអាជីវកម្ម

គ. ធ្វើការរាជកា　　　　ឃ. សិស្សនិស្សិត

ង.មិនមានការងារ　　　　ច. ផ្សេងៗ

៥. ប្រាក់ចំនូលប្រចាំខែ

ក. តិចជាង ២០០ដុល្លារ　　　　ខ. ២០០-៤០០ដុល្លារ

គ. ៤០០-៦០០ដុល្លារ　　　　ឃ. ច្រើនជាង៦០០ដុល្លារ

៦. កំរិតវប្បធម៌របស់អ្នក

ក. មិនបានចូលរៀន　　　　ខ. បឋមសិក្សា

ឃ. មធ្យមសិក្សាបឋមភូមិ(ថ្នាក់ទី៩)　　　　ង. មធ្យមសិក្សាទុតិយភូមិ(ថ្នាក់ទី១២)

ច. បរិញ្ញាប័ត្រ　　　　ឆ. អនុបណ្ឌិត-បណ្ឌិត

៧. ចំនួនសមាជិកក្នុងគ្រួសារ: ______________នាក់

៨. ប្រភេទលំនៅដ្ឋាន

ក. ខុនដូ　　　　ខ. ផ្ទះល្វែង

គ. ផ្ទះវីឡា　　　　ឃ. ផ្ទះជួល

ង. បន្ទប់ជួល　　　　ច. ផ្សេងៗ:______________________

II. ចំណេះដឹងទូទៅទាក់ទងបញ្ហាបរិស្ថាន

៩. តើអ្នកយល់ស្របឬមិនយល់ស្របចំពោះបញ្ហាបរិស្ថានដូចខាងក្រោម:

បញ្ហាបរិស្ថាន	យល់ស្រប ខ្លាំង	យល់ស្រប	ធម្មតា	មិនយល់ ស្រប	មិនយល់ស្រប ខ្លាំង
ទឹកកខ្វក់					
ខ្យល់ពុល					
ការឡើងកម្តៅ					
សំរាម					

១០. បញ្ហាសំណល់រឹង(សំរាម)ដែលអ្នកជ្រាប សូមរៀបលំដាប់ពី ១ដល់៤ (១ មានបញ្ហាបំផុត)

បញ្ហា	បញ្ហាក្លិន	ការផ្លាស់ប្តូរទីលានចោលសំរាម	ការចោលសំរាមគ្មានសណ្តាប់ធ្នាប់	ប៉ះពាល់សំរស់ទីក្រុង
លេខលំដាប់				

III. ការគ្រប់គ្រងសំរាមនាពេលបច្ចុប្បន្ន

១១. តើអ្នកបោះចោលសំរាមប៉ុន្មានដងក្នុងមួយសប្តាហ៍

ក. ១ ដង　　　　ខ. ២ ដង

គ. ៣ ដង　　　　ឃ. ៤ ដង

ង. ៥ ដង　　　　ច. ______ដង

១២. តើអ្នកបោះចោលសំរាមប៉ុន្មានថង់ក្នុងមួយសប្តាហ៍(ធុងដូចរូប កំពស់ ២៨សម មុខកាត់២៦សម)

ក. ១ថង់　　　　ខ. ២ថង់

គ. ៣ថង់　　　　ឃ. _______ថង់

១៣. តើអ្នកញែកសំរាមទៅតាមប្រភេទមុនពេលបោះចោលដែរឬទេ

ក. ញែក ខ. មិនញែក

១៤. ប្រសិនបើមិនញែកសូមជួយផ្តល់ហេតុផលដែលអ្នកមិនញែក

ក. រវល់ ខ. ក្លិនមិនល្អនិងកខ្វក់

គ. សំរាមសើមពិបាកញែក ឃ. ជាទូទៅគ្មានអ្នកញែក

ង. គ្មានអត្ថប្រយោជន៍និងមិនដឹងញែកធ្វើអ្វី ច.ផ្សេ
ងៗ____________________________________

១៥. តើអ្នកគ្រប់គ្រងដូចម្តេចទៅលើសំរាមដូចជាសំបកកំប៉ុងអាលុយមីញ៉ូម សំបកដបប្លាស្ទិច ។ល។

ក. ប្រើប្រាស់ឡើងវិញ ខ. កែច្នៃហើយប្រើប្រាស់ឡើងវិញ

គ. យកទៅលក់ ឃ. ផ្សេងៗ________________

១៦. តើអ្នកបង់ថ្លៃសេវាកម្មប្រមូលសំរាមយ៉ាងដូចម្តេច

ក. មិនដែលបង់ ខ. បង់រៀងរាល់ខែ

គ. បង់រៀងរាល់៦ខែ ឃ. បង់រៀងរាល់ឆ្នាំ

១៧. តើអ្នកបង់ថ្លៃសេវាកម្មប្រមូលសំរាមប៉ុន្មានក្នុង១ខែ

ក. ១ដុល្លារ ខ. ២ដុល្លារ

គ. ៣ដុល្លារ ឃ. ៤ដុល្លារ

ង. ៥ដុល្លារ ច. _________ដុល្លារ

១៨. តើអ្នកពេញចិត្តនឹងការគ្រប់គ្រងសំរាមពេលបច្ចុប្បន្នដែរឬទេ

ក. ពេញចិត្ត

ខ. ធម្មតា

គ. មិនពេញចិត្ត។ មូល
ហេតុ:____

១៩. សូមរៀបតាមលំដាប់ខ្ពស់មកទាបចំនួនបី(១ខ្ពស់បំផុត)នៃវត្ថុធាតុដែលអ្នកញែកនិងប្រើប្រាស់ឡើងវិញ

វត្ថុធាតុដែលអាចយកមកប្រើប្រាស់ម្តងទៀតបាន	លេខលំដាប់
សំបកកំប៉ុងអាលុយមីញ៉ូម	
សំបកដបប្លាស្ទិច	
ក្រដាស	
កែវ	
ថង់ប្លាស្ទិច	
ប្លាស្ទិចផ្សេងៗ	

២០. តើមធ្យោបាយណាមួយក្នុងចំណោមមធ្យោបាយខាងក្រោមដែលអ្នកយល់ថាងាយស្រួលក្នុងការលក់សំបកកំប៉ុងនិងសំបកដប

ក. យកទៅលក់នៅផ្សារ

ខ. មានមនុស្សមកទិញដល់ផ្ទះ(អេតចាយ)

គ. អ្នកប្រមូលសំរាមមកយក

ឃ. យកទៅចោលនៅតាមផ្សារទំនើប

IV. ការធ្វើឲ្យប្រសើរឡើងនាពេលអនាគត

នៅទីក្រុងភ្នំពេញសំរាមប្រជុំជនប្រមាណ១៤លានតោនត្រូវបានបង្កើតជារៀងរាល់ថ្ងៃ។ សំរាមស្ទើរតែទាំងអស់ត្រូវបានបញ្ជូនយកទៅចោលនៅទីលានចោលសំរាមដោយគ្មានវិធានការគ្រប់គ្រងតាមបែបមាត្រដ្ឋាន។ នៅទីក្រុងភ្នំពេញទីលានចោលសំរាមដែលដាក់ឲ្យដំណើរការសព្វថ្ងៃមានតែមួយប៉ុណ្ណោះ។ ប្រសិនបើសំរាមនៅតែបន្តរកើនឡើងដោយគ្មានវិធានការទប់ស្កាត់និងដោះស្រាយ បញ្ហាសំណល់រឹងនឹងក្លាយជាបញ្ហាកាន់តែស្មុគ្រស្មាញនិងពិបាកដោះស្រាយនៅថ្ងៃអនាគតដូចជាការផ្លាស់ប្តូរទីលានចោលសំរាមថ្មីជាញឹកញាប់ដែលត្រូវការដីទំនេរដ៏ធំ។ វាមានការប៉ះពាល់ជាច្រើនដល់ប្រជាពលរដ្ឋដែលរស់នៅក្បែរនោះ លើសពីនេះទៅទៀតការកើនឡើងនៃសំណល់រឹងដ៏លើសលប់នេះបង្កផលប៉ះពាល់ជាច្រើនដល់បរិស្ថានក៏ដូចជាសុខភាពប្រជាជនទាំងអស់។ យោងតាមការសិក្សាស្រាវជ្រាវជាច្រើនបានបង្ហាញថាការញែកសំរាមនៅតាមគេហដ្ឋាន (At-source Separation) ជាការគ្រប់គ្រងដ៏មានប្រសិទ្ធិភាពនិងជោគជ័យបំផុតដែលត្រូវបានប្រទេសអភិវឌ្ឍន៍ជាច្រើននៅលើសកលលោកកំពុងអនុវត្តន៍។ វាមិនត្រឹមតែផ្តល់អត្ថប្រយោជន៍ដល់បរិស្ថានប៉ុណ្ណោះទេ តែក៏ផ្តល់អត្ថប្រយោជន៍ដល់សេដ្ឋកិច្ចផងដែរ វាជួយពន្យារអាយុកាលទីលានចោលសំរាម ព្រមទាំងកាត់បន្ថយការចំនាយលើការចាត់ការសំរាម (Waste treatment)។ លើសពីនេះទៅទៀតនោះវាក៏អាចបង្កើតប្រាក់ចំណូលពីការលក់សំណល់ដែលអាចកែច្នៃឡើងវិញបាន(Recyclable Waste) ដូចជាសំបកកំប៉ុង សំបកដប ក្រដាស ។ល។ អ្វីដែលសំខាន់បំផុតបន្ទាប់ពីបានចំណូល វាក៏អាចជួយកាត់បន្ថយពន្ធអាករនិងថ្លៃសេវាកម្មផ្សេងៗដែលអ្នកនិងកូនចៅអ្នកត្រូវបង់នៅថ្ងៃអនាគតនៅរយៈពេលវែង។

ប៉ុន្តែដើម្បីទទួលបាននូវអ្វីដូចដែលបានរៀបរាប់ខាងលើត្រូវការចំណាយថវិការបន្ថែម ដែលថវិការទាំងនោះបានមកពីការយល់ព្រមបង់បន្ថែមពីសំណាក់អ្នកដែលបង្កើតសំរាម ដូចពាក្យមួយពោលថា "អ្នកចោលសំរាមជាអ្នកចាយ"

ដូចដែលបានអធិប្បាយខាងលើ សូមពិចារណាហើយឆ្លើយសំណួរដូចខាងក្រោម :

២១. តើអ្នកស្ម័គ្រចិត្តនឹងញែកសំរាមទៅតាមប្រភេទដែរឬទេប្រសិនបើមានការណែនាំឲ្យញែកសំរាមពីសំណាក់រាជរដ្ឋាភិបាល

ក. ស្ម័គ្រចិត្តនិងពេញចិត្តញែក

ខ. នឹងមិនញែក មូល
ហេតុ:____

២២. តើអ្នកយល់ស្របក្នុងការបង់ថ្លៃសេវាកម្មបន្ថែមដើម្បីទទួលបានការគ្រប់គ្រងប្រកបដោយនិរន្តរភាពឬទេ? (រាជរដ្ឋាភិបាលអាចនឹងយកថវិការសម្រាប់អភិវឌ្ឍន៍ដូចជាសាងសង់សាលានិងផ្លូវថ្នល់មកប្រើប្រាស់ជំនួសក្នុងករណីប្រសិនបើអ្នកមិនយល់ព្រម)

ក. ពេញចិត្តនឹងបង់បន្ថែមថ្លៃសេវាកម្ម

ខ. នឹងមិនព្រមបង់បន្ថែម មូល
ហេតុ:____

____

២៣. តើតម្លៃអតិបរមា(តម្លៃខ្ពស់បំផុត)ដែលអ្នកយល់ព្រមបង់ថ្លៃសេវាកម្មគឺប៉ុន្មាន?

១ ដុល្លារ	១.៥ ដុល្លារ	២ ដុល្លារ	២.៥ ដុល្លារ	៣ ដុល្លារ	៣.៥ ដុល្លារ
៤ ដុល្លារ	៤.៥ ដុល្លារ	៥ ដុល្លារ	៥.៥ ដុល្លារ	៦ ដុល្លារ	៦.៥ ដុល្លារ
៧ ដុល្លារ	៧.៥ ដុល្លារ	៨ ដុល្លារ	៨.៥ ដុល្លារ	៩ ដុល្លារ	៩.៥ ដុល្លារ
១០ដុល្លារ	១០.៥ដុល្លារ	១១ដុល្លារ	១១.៥ដុល្លារ	១២ដុល្លារ	១២.៥ដុល្លារ
១៣ ដុល្លារ	១៣.៥ ដុល្លារ	១៤ ដុល្លារ	១៤.៥ ដុល្លារ	១៥ ដុល្លារ	១៥.៥ ដុល្លារ
១៦ ដុល្លារ	១៦.៥ ដុល្លារ	១៧ ដុល្លារ	១៧.៥ ដុល្លារ	១៨ ដុល្លារ	…………. ដុល្លារ

២៤. សំរាមបីប្រភេទ ដែលអ្នកគិតថាងាយស្រួលក្នុងការញែកគឺ

ប្រភេទសំរាម	លេខលំដាប់
សំរាមស្ងួត	
សំរាមសើម	
សំរាមផ្ទះបាយ	
សំរាមលក់បាន (កំប៉ុង ដប។ល។)	
ក្រដាស	
ប្លាស្ទិច	

២៥. សូមផ្តល់ជាមតិក៏ដូចជាយោបលដើម្បីទទួលបានការគ្រប់គ្រងសំរាមសំណល់រឹងនៅរាជធានីភ្នំពេញកាន់តែ ប្រសើរឡើងនិងប្រកបដោយនិរន្តរភាព:

VITA

Srun Pagnarith was born on January 1st, 1991 in Kampongcham Province, Cambodia. He is the second child in a family with an older sister and two younger brothers. He spent his childhood and study life from elementary school to high school in his hometown. He continued his undergraduate degree, majoring in Water Resources and Infrastructure Engineering of Institute of Technology of Cambodia, Phnom Penh, Cambodia from 2003 to 2008. In July 2008, he successfully graduated his bachelor's degree in engineering. Then, He got a scholarship from AUN/Seed-Net and leave Cambodia to continue his higher education in Master's degree of Environmental Engineering, Department of Environmental Engineering, Chulalongkorn University, Bangkok, Thailand.