Municipal Solid Waste Metabolism in Bangkok

Miss Saravanee Singtong

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การศึกษากระบวนการเมตาบอลิซึมขยะชุมชนในกรุงเทพมหานคร

นางสาวศรวณีย์ สิงห์ทอง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ปีการศึกษา 2558

Thesis Title	Municipal Solid Waste Metabolism in Bangkok
By	Miss Saravanee Singtong
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Thesis Advisor	Associate ProfessorChanathip Pharino, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Doctoral Degree

____________________________________Dean of the Graduate School

(Associate ProfessorSunait Chutintaranond, Ph.D.)

THESIS COMMITTEE

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(Assistant ProfessorChantra Tongcumpou, Ph.D.)

____________________________________Thesis Advisor

(Associate ProfessorChanathip Pharino, Ph.D.)

____________________________________Examiner

(Assistant ProfessorPichaya Rachdawong, Ph.D.)

____________________________________Examiner

(Associate ProfessorTawan Limpiyakorn, Ph.D.)

____________________________________Examiner

(Assistant ProfessorManaskorn Rachakornkij, Ph.D.)

____________________________________External Examiner

(Assistant ProfessorTrakarn Prapaspongsa, Ph.D.)

____________________________________External Examiner

(ProfessorChongrak Polprasert, Ph.D.)

ศรวณีย์ สิงห์ทอง : การศึกษากระบวนการเมตาบอลิซึมขยะชุมชนในกรุงเทพมหานคร (Municipal Solid Waste Metabolism in Bangkok) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร.ชนาธิป ผาริโน, 205 หน้า.

ในการศึกษานี้เพื่อสำรวจกระบวนการเมตาบอลิซึมของขยะชุมชนกรุงเทพมหานครโดยวิเคราะห์การไหลของวัตถุ (Material Flow Analysis, MFA) และระบบสารสนเทศภูมิศาสตร์ (Geographic Information System, GIS) เพื่อพัฒนาแผนผังการจัดการขยะชุมชนกรุงเทพมหานครในรูปแบบการปลดปล่อยคาร์บอนต่ำและนโยบายการจัดการขยะชุมชนอย่างมีประสิทธิภาพ ผลจากการวิเคราะห์การไหลของวัตถุสามารถระบุถึงจุดปัญหาของกระบวนการจัดการขยะชุมชน และพบว่าขยะชุมชนส่วนมากถูกสะสม/เก็บโดยการฝังกลบ กระบวนการจัดการขยะชุมชนของกรุงเทพมหานครที่ปลดปล่อยก๊าซเรือนกระจกสูงสุดคือฝังกลบ ซึ่งมีสัดส่วนถึง 88 เปอร์เซ็นต์ของการปลดปล่อยทั้งหมด และกระบวนการที่ใช้พลังงานสูงที่สุดคือกระบวนการเก็บขนขยะชุมชน ซึ่งมีสัดส่วนถึง 82 เปอร์เซ็นต์ของการใช้พลังงานทั้งหมด ในขณะเดียวกันผลการวิเคราะห์โดยระบบสารสนเทศภูมิศาสตร์ด้วยพารามิเตอร์การจัดการขยะ (ปริมาณขยะชุมชนที่ถูกเก็บขน ปริมาณการปลดปล่อยก๊าซเรือนกระจกรวม ปริมาณการปลดปล่อยก๊าซเรือนกระจกต่อขยะเก็บขน ปริมาณการใช้พลังงานรวม และปริมาณการใช้พลังงานต่อขยะเก็บขน) แสดงถึงพื้นที่เขตที่เป็นปัญหาหรือควรได้รับการแก้ไขในลำดับต้น พบว่าเขตปทุมวันและวัฒนาเป็นเขตที่เป็นปัญหาในหลายพารามิเตอร์มากที่สุด ยกเว้นพารามิเตอร์ปริมาณการปลดปล่อยก๊าซเรือนกระจกต่อขยะเก็บขนและปริมาณการใช้พลังงานต่อขยะเก็บขน จากผลการวิเคราะห์กระบวนการเมตาบอลิซึมของขยะชุมชนกรุงเทพมหานครดังกล่าวแสดงถึงโอกาสการปรับปรุงและปัจจัยที่มีนัยยะสำคัญในการพัฒนาแผนผังการจัดการขยะชุมชนกรุงเทพมหานครในรูปแบบการปลดปล่อยคาร์บอนต่ำ ในงานวิจัยได้เสนอ 4 ทางเลือกการปฏิบัติเดี่ยวและอีก 7 ทางเลือกสำหรับการปฏิบัติทางเลือกเดี่ยวหลายๆอันพร้อมกัน พบว่านโยบายการลดการเกิดขยะชุมชนที่ต้นกำเนิดร้อยละ 25 ของการเกิดขยะชุมชนในปัจจุบัน ส่งผลให้ลดการปลดปล่อยก๊าซเรือนกระจกได้ร้อยละ 24.5 และพบว่าทางเลือกสำหรับการปฏิบัติทางเลือกเดี่ยวหลายๆอันพร้อมกันอันได้แก่ การหมักปุ๋ยในพื้นที่เขต การเปลี่ยนประเภทพลังงานเชื้อเพลิงในรถขนขยะ และนโยบายการลดการเกิดขยะชุมชน มีศักยภาพลดการปลดปล่อยก๊าซเรือนกระจกสูงสุด อย่างไรก็ตามทางเลือกที่เหมาะสมต่อการเป็นแผนผังการจัดการขยะชุมชนกรุงเทพมหานครในรูปแบบการปลดปล่อยคาร์บอนต่ำมากที่สุดคือการดำเนินการการเปลี่ยนประเภทพลังงานเชื้อเพลิงในรถขนขยะ และนโยบายการลดการเกิดขยะชุมชน ซึ่งสามารถลดการปลดปล่อยก๊าซเรือนกระจกได้ 0.29 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในช่วงพ.ศ.2563 ในงานวิจัยนี้ได้พัฒนาโปรแกรมเพื่อสนับสนุนเขตในการตัดสินใจต่อการจัดการขยะชุมชนในรูปแบบการปลดปล่อยคาร์บอนต่ำ โดยโปรแกรมช่วยบุคคลากรในระดับพื้นที่เขต/ท้องถิ่นสามารถประเมินการปลดปล่อยก๊าซเรือนกระจกของการจัดการขยะชุมชนและเปรียบเทียบการปลดปล่อยนี้กับค่าเฉลี่ยทั้งกรุงเทพมหานคร เพื่อประเมินการดำเนินการจัดการขยะชุมชนของพื้นที่ตนเอง และโปรแกรมสามารถให้ทางเลือกการจัดการขยะชุมที่พัฒนาจากผลการวิเคราะห์แผนผังการจัดการขยะชุมชนกรุงเทพมหานครในรูปแบบการปลดปล่อยคาร์บอนต่ำพร้อมปริมาณการลดการปลดปล่อยก๊าซเรือนกระจก การศึกษานี้ได้เสนอนโยบายแนะนำและเครื่องมือสำหรับกรุงเทพมหานครและบุคคลากรระดับท้องถิ่นในการดำเนินงานการจัดการขยะชุมชนกรุงเทพมหานครในรูปแบบการปลดปล่อยคาร์บอนต่ำ ซึ่งพัฒนาจากกระบวนการเมตาบอลิซึมของขยะชุมชนกรุงเทพมหานคร อีกทั้งแสดงถึงศักยภาพของการลดการปลดปล่อยก๊าซเรือนกระจกจากภาคการจัดการของเสีย

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต ....

ปีการศึกษา 2558 ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

5387874220 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: BANGKOK, ENERGY INTENSITY, GHG EMISSION, MASS FLOW ANALYSIS, MUNICIPAL SOLID WASTE METABOLISM

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The main objective of this research is to identify low carbon municipal solid waste management (MSWM) schemes and policy recommendations for Bangkok. The study analyzed Bangkok's municipal solid waste metabolism using Material Flow Analysis (MFA) and Geographic Information System (GIS). MFA of Bangkok's MSWM indicated that landfill is the GHG hot spot. Landfills are the largest GHG emission source (88%) in Bangkok's waste metabolism. Waste collection system is the energy consumption hot spot (82%). In addition, GIS displayed based on MSWM parameters (MSW_c volume, net and intensity of GHG emission and energy consumption) revealed hot spot areas of each parameter. Among 50 districts, Pathumwan and Wattana districts are the highest hot spot areas in term of MSW_c volume, net, and intensity of GHG emission. Analyses of Bangkok's MSW metabolism provides insights for key factors and potential improvement to help developing a low carbon MSWM system. The study examined eleven scenarios to improve the performance of current Bangkok's MSW metabolism. An approach on reducing 25% waste generation at sources has the highest potential to reduce GHG emission by approximately 24.5% and energy consumption by 24.21%. Multiple actions, comprising of (1) decentralized composting facility, (2) changing fuel type in the vehicles for waste collection, and (3) campaign for reducing 25% waste generation, showed the highest potential in GHG reduction (30.01%). The scheme that can yield the highest reduction of energy consumption approximates 36.58% is multiple actions comprising of (1) changing fuel type in the vehicles for waste collection, and (2) campaign for reducing 25% waste generation. Changing fuel types in waste collection truck and waste reduction campaign are practical options to promote a low carbon scheme in Bangkok which can help reducing GHG emission (0.29 $MtCO_2e$) by 2020. The research developed a program that can help estimate emission of MSWM in local districts. Recommended options/policies of MSWM present with potential GHG reduction as the output of the developed program. The program can help provide informaiton for decision making at a district or provincial level toward low carbon waste management.

Field of Study: Environmental Management	Student's Signature ....
Academic Year: 2015	Advisor's Signature ....

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LIST OF ABBREVIATIONS

Abbreviation	Term
BMA	Bangkok Metropolitan Administration
CS	Collection System
CEI	Carbon Emission Intensity
EC	Energy Consumption
EFA	Emission Flow Analysis
EI	Energy Consumption Intensity
ENFA	Energy Flow Analysis
GIS	Geographic Information System
LCD	Low Carbon Cevelopment
LCS	Low Carbon Society
MFA	Material Flow Analysis
MSW_c	Collected Municipal Solid Waste of Bangkok
MSWM	Municipal Solid Waste Management
TS	Transfer Station
UMSW	Unsorted Municipal Solid Waste
WTL	Waste to Landfill

CHAPTER I

INTRODUCTION

1.1 Rationale of Study

Urban growth has become a key driver causing environmental quality degradation. Thailand is one of high urbanization countries with an increase of total population index of 48% from 1990 to 2013. Increased urbanized areas of Bangkok based on construction index from 1950 to 2002 are 99.5 percent or 4.8 percent per annum. Based on household income index, a trend of urbanization in Bangkok has continued to increase significantly about 500% increase in 2011 as compared to that of 1991 (United Nations Population Fund Country Office in Thailand, 2011). Urbanization spreads to suburbs around Bangkok along the development of transportation network that connects people to the inner commercial areas (central zone of Bangkok). With an increase in urbanization came an increase in natural resource consumption and pollution emission to the environment including municipal solid wastes. An unmanaged urban transformation can impact networks of urban infrastructure such as waste, energy, water, and transport. An effective waste management is a critical factor for healthy urban development. Transformation of waste management in Manchester, UK is a good example of the urban transition from simple landfills to an implementation of multi-technologies to move toward sustainable development in response to fast urbanized growth (Uyarra & Gee, 2013).

Municipal waste has been a serious environmental concern for a long time (Othman, Zainon Noor, Abba, Yusuf, & Abu Hassan, 2013). Particularly, the rapid urban transformation is an accelerating factor straining existing waste management program. Waste generation continuously increases from urbanization. Several concepts of sustainable waste management have been developed and implemented to address the problems including zero emission systems, close loop management, and symbiosis. One of the significant initiatives of modern waste management concept is a combination of waste treatment and waste prevention approaches (Ngoc & Schnitzer, 2009). Waste management system analysis has become an important element in helping communities to achieve sustainable waste management planning. It provides an interdisciplinary basis for the handling of rapidly increasing wastes. There are many models and analysis options that are suitable for analyzing issues for waste management. For instance, Material flow analysis (MFA) can be used to quantify mass flow within a system in a space and time. MFA is used as a tool of urban metabolism analysis (A. Pires, G. Martinho, & N. B. Chang, 2011; Sendra, Gabarrell, & Vicent, 2007; X. Zhang, Shen, Feng, & Wu, 2013). The combination of system analysis and various conceptual models of waste management planning can lead to an effective and practical solution.

There are many evidences that Greenhouse Gas (GHGs) is causing the world's climate change (Babel & Vilaysouk, 2016). GHG emission of Municipal Solid Waste

Management (MSWM) is a part of a contributor with significant impacts on climate change especially on the disposal aspect which is the largest source of emission (Intergovernmental Panel on Climate Change, 2006b). The rapidly increasing amounts of MSW (Yu & Zhang, 2016). The issue of emission in MSWM has increasingly received considerable attention. GHG emission of MSWM is one of the most widely used indicators to investigate an effective MSWM (K. S. Woon & Lo, 2013). Low carbon concept is a procedure recently adopt in MSWM in a global attempt to achieve sustainable development (Papargyropoulou, Colenbrander, Sudmant, Gouldson, & Tin, 2015; United Nations Department of Economic and Social Affairs, 2012). The amount of GHG emission can imply how MSWM performance is in every stage and show climate co-benefits from GHG reduction from good waste management practice (Menikpura, Sang-Arun, & Bengtsson, 2013). Many studies have reported the mitigation GHG emission of MSWM by improving currently waste treatment technologies, waste management policies and reducing waste generation (Babel & Vilaysouk, 2016; Chen & Lo, 2016).

Low carbon development (LCD) refers to using less carbon for growth with an aim to mitigate climate change and a part of rooted sustainable development. The policy seeks to balance the development (economic growth) with low impacts to the environmental (Mulugetta & Urban, 2010). Many cities adopt the policy to shift toward low carbon society (LCS) according to the agreement in sixteenth session of the

Conference of the Parties (COP16). LCS defined as “actions that are compatible with the principles of sustainable development allowing for deep emissions cuts using low carbon energy sources and technologies, at high levels of energy efficiencies, without imposing any cost to the developing needs” (Pew Center on Global Climate Change, 2010; Subash Dhar, 2013).

Bangkok is one of the major cities with rapid urbanization growth. MSW generation, as a consequence, increases at a high rate in relation to the urbanization growth. Most studies of waste management in Bangkok mainly focused on assessment of impacts and options of treatment techniques (Chiemchaisri, Juanga, & Visvanathan, 2007; Inazumi, Ohtsu, Shiotani, & Katsumi, 2011). Also, most studies in waste management have been carried out with a large number of impact assessment options on treatment technologies (Eriksson et al., 2005; Kok Sin Woon & Lo, 2014; Yi, Kurisu, & Hanaki, 2011). The MSWM system analysis seems lack of study. It contributes to point out what MSWM system can be improved.

Bangkok Metropolitan Administration (BMA) set targets to move toward LCS in 2050 which the waste sector is a part of the program. The goal in 2020 of emission reduction summation is 7.29 MtCO2e with 3% contribution by the waste sector. Even though a definite plan in waste management in order to be successful in moving toward LCS has existed, the details in action plans and potential impacts from various alternatives have not much. Meanwhile, the trend of MSW generation in the cities is increasing (Bhada-Tata, 2012). Inazumi (2011) shows that the current Bangkok's MSWM stream is high emission and environmental load, however; the result demonstrates that there are opportunities to improve the system to become more efficient and environmentally friendly. Then, Bangkok's MSWM has high potential to reduce the emission, and it needs to do immediately.

Bangkok's MSWM is in crisis with the rapid amount of MSW, and it is also high impact on GHG emission. However, BMA has launched the plan to move forward low carbon society which contains a part of MSWM to contribute the emission reduction. The low carbon MSWM action in the plan seems not much with details to implement and practice, even though; GHG emission of Bangkok's MSWM has high potential to decrease. The low carbon MSWM is the co-benefit of GHG emission reduction and improvement Bangkok's MSWM. But how to design Bangkok's low carbon MSWM with matching the waste metabolism and under the constraints.

1.2 Objectives

There are three main objectives in this research including;

1. To analyze current situation of Bangkok's MSW metabolism through Material Flow Analysis (MFA) and Geographic Information System (GIS)

2. To evaluate GHG emission and energy intensities on MSWM system in different district areas and different management stages at collection system, at transfer stations, and at disposal sites (including transportation) in Bangkok
3. To investigate sustainable Bangkok's MSWM schemes and recommend policies to achieve low carbon solid waste management

Overall objectives of this study are to evaluate the status of Bangkok's MSW metabolism and the efficiency of MSWM in various levels through MFA and GIS and indicators development in term of emission and energy intensities. The results from environmental indicators, MSWM system, and diagram MSW flows in different scales can indicate hot spots of pollution in MSWM in each stage and geographic area. The framework of low carbon MSWM scheme in Bangkok was designed by scenarios development. Finally, the research provided recommendations for Bangkok to promote low carbon MSWM.

1.3 Expected Outcomes

1. Understand Bangkok's MSW metabolism in different district areas and management stages. GIS map provides information about the current situation of wastes and its management in Bangkok.

2. Information regarding energy and carbon emission intensity of Bangkok MSWM help to assess and identify hot spots and levels of the burden on the environment.
3. Recommendations to promote low carbon MSWM in local areas of Bangkok.

1.4 Hypothesis

1. Different local areas of the city should have different MSW metabolism about municipal solid wastes generation and management. Emission and energy intensities can be good indicators and evidence for assessing performance on waste metabolism.
2. The collection system should be the highest GHG emission contributor (the highest CEI) and also the highest energy intensity stage in MSWM in Bangkok.

1.5 Scope of Study

The MSW metabolism study in Bangkok is divided based on 50 districts. The scopes of study are as follow:

1. MSW stream in this study only generates from urban activities, and municipality locates in Bangkok (50 districts) as describe in Table 1-1.
2. The scope of analysis starts from unsorted municipal solid waste (UMSW) from disposal stage then transfer by collection system to transfer station, and disposal site as shown in Figure 1-1.
3. The transfer stations in this study are On-Nuch, Sai-Mai, and Nong-Kham and including two disposal sites at Chachoengsao and Nakhornpathom provinces.
4. Duration of MSW is from 2008 to 2013 as recorded by BMA. Mass flows express in term of weight per year.

Table 1-1 Agents involve in MSW management in Bangkok

Waste management stage	Materials	Agent	Scope of waste generation
Generation	Unsorted MSW (UMSW)	Municipalities in each district of Bangkok	50 Districts
Transfer station and intermediate treatment	Food waste (project) (FW)	Districts biological treatment by composting	50 Districts

Waste management stage	Materials	Agent	Scope of waste generation
	Pruning waste (PW)	Districts biological treatment by composting	50 Districts
	Unsorted MSW (UMSW)	Transfer station	3 Sites
	Unsorted MSW (UMSW)	Composting plant	1 Site
Disposal	Wrapped MSW, Municipal unsorted waste, and waste from composting plant	Sanitary landfill	2 Sites
Products	Soil amendment	District composting plant	50 Districts
	Soil amendment	Composting plant	1 Site
	Biogas	Sanitary landfill	2 Sites

This study focuses on investigating Bangkok's MSW metabolism in various management stages and geographic areas using Material Flow Analysis (MFA) and Geographic Information System (GIS), explored waste utilization, and the combination of emission and energy consumption analysis. The results can help identifying hot spots of Bangkok's MSW metabolism and areas which can be used to identify a suitable direction for improvement that supports sustainable urbanization growth. It also analyzes the comprehensive design for Bangkok's low carbon MSWM scheme including a consideration of implementation with issues of concerns in Bangkok's MSWM system. Finally, the recommendation options to promote low carbon MSWM is proposed for policy makers to decide which policies will help promote low carbon MSWM scheme and should be implemented in the hot spot areas (Figure 1-2).

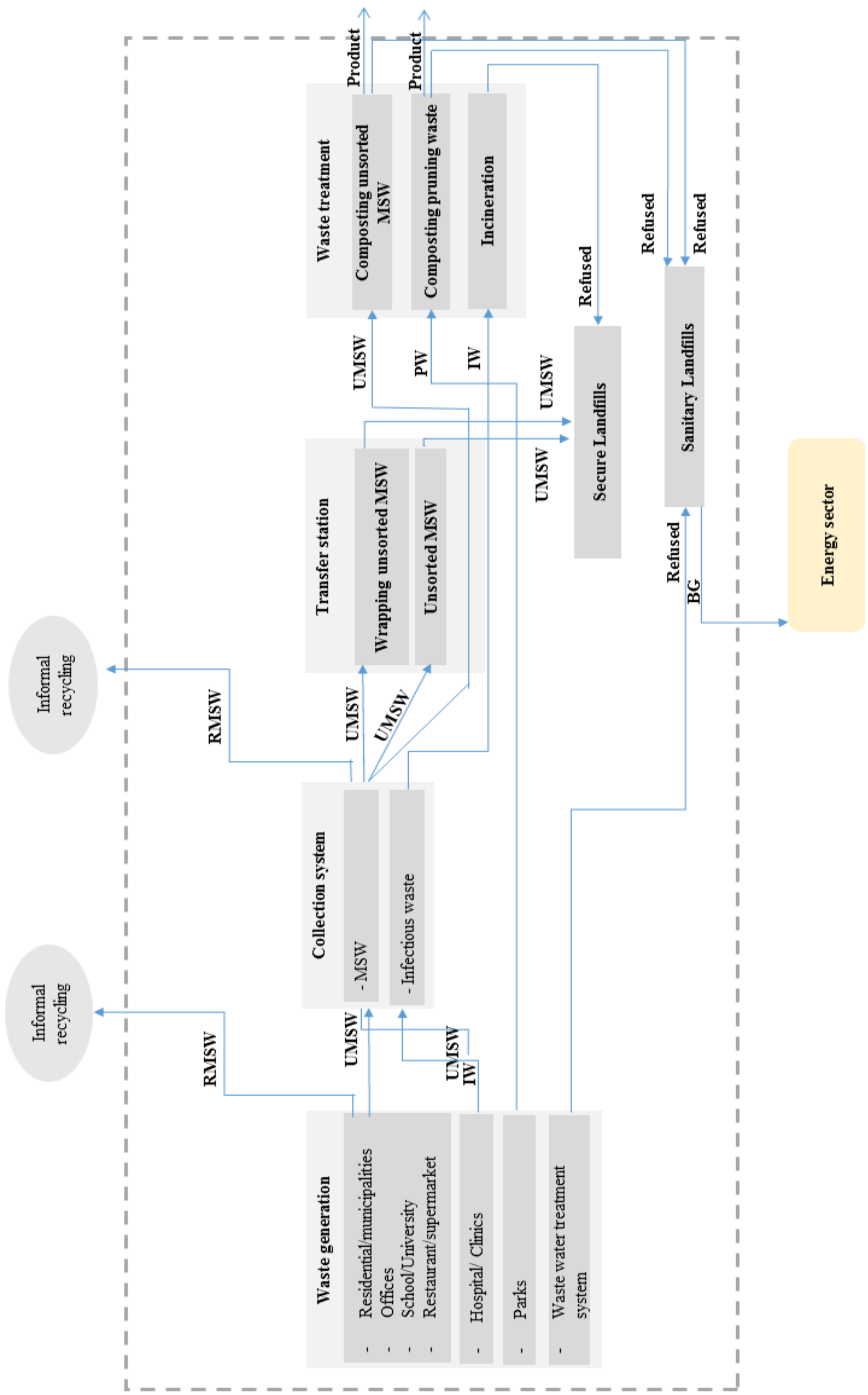


Figure 1-1 Overview of waste flow in Bangkok

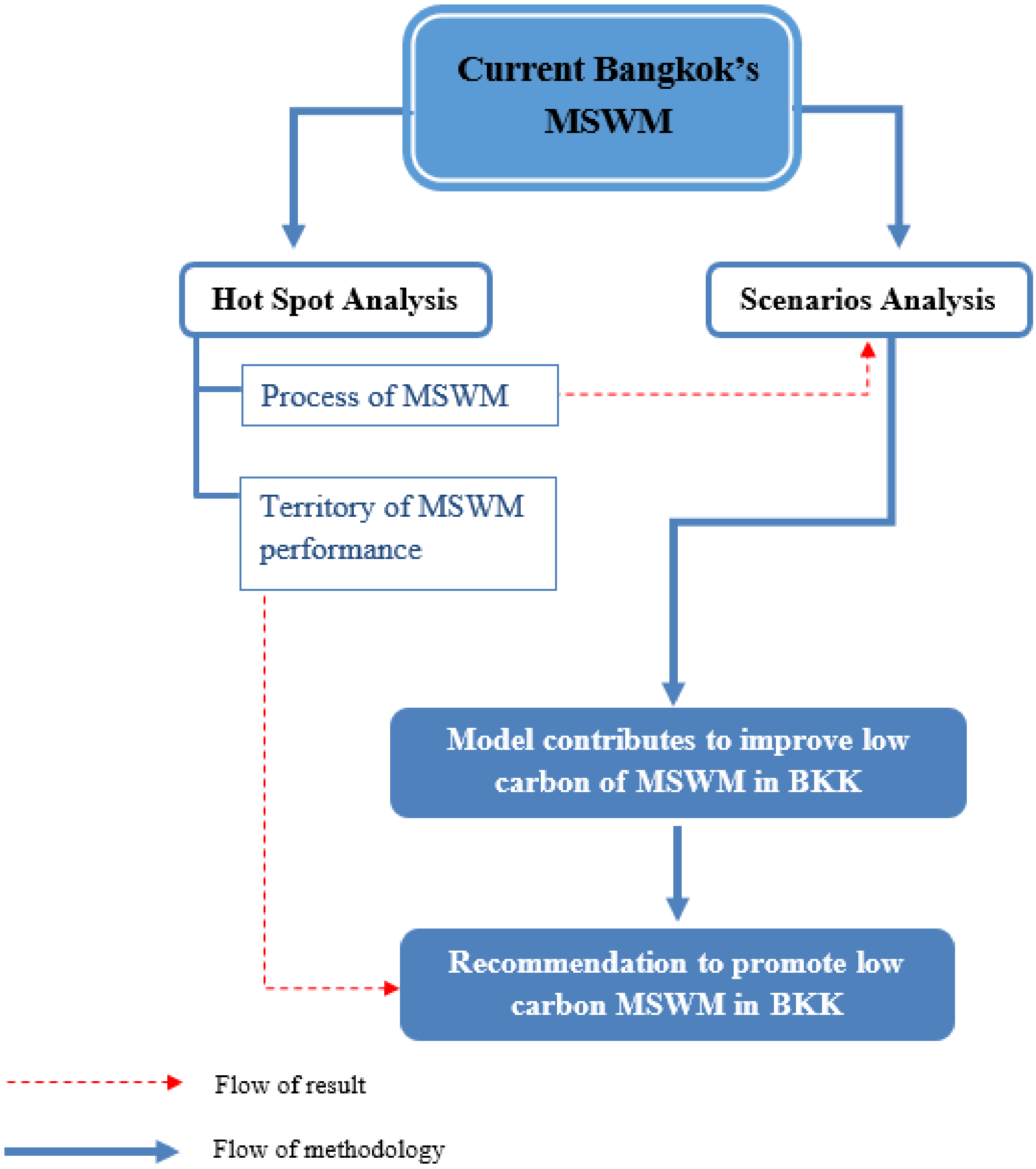


Figure 1-2 Overview of the study

CHAPTER II
LITERATURE REVIEW

2.1 Low Carbon Municipal Solid Waste Management (MSWM)

2.1.1 Low Carbon Development Concept

The low carbon development (LCD) is an indefinite internationally explanation. It is a broad adaptation by development countries for planning and policies of economic and social to use less carbon for growth. However, the aim of LCD is similarity using to reduce poverty, economic growth, and improvement wellbeing which climate change mitigation is the main dominant. The development pattern is involvement the reducing energy intensity as India and China attempt. Then, LCD is a variety of tactics for achieving clean development, and it depends on the program development by the different countries (Mulugetta & Urban, 2010). United States is a one of LCD implementation policy which it emits in the second largest in the world. It launched a national legal framework of reducing GHG emission to attain a low carbon society in term of regional and state levels (Garber, 2010). The similar wording of LCD is low carbon society, low-emission development/strategies, climate compatible development, low emission climate-resilient development, and green growth. Their target is the same that are to avoid the impact of climate change in short and long-term by a complex of socio-economic context (Fisher, 2013; International Research Network for Low Carbon Societies, 2014).

2.1.2 Emission of MSWM

Not only, the production and usage by human activities emit GHG to ambient air, but also the end of life such as waste treatment and disposal is. Global accounts waste sector emission in 3-4% of anthropogenic GHG emission which it composes of several steps. Normally, methane is the largest emission from the solid waste disposal of waste sector. The incineration and open burning is also the important source of carbon dioxide emission. The biological treatments emit methane and nitrous oxide (Intergovernmental Panel on Climate Change, 2006b). Consideration on the far side of waste treatment, waste transportation is the significant source of emission such as collection system. It has many works to study the carbon sink, waste recovery, and renewable energy from waste sector to mitigate GHG emission (Chen & Lo, 2016). The estimation emission is quite high uncertainties, but it can be reduced by national definition, data collection, standardizes, and validation of models. The inventory emission can provide information for the effective GHG emission mitigation, protection of public health and environmental, and sustainable development. The direct emission can be reduced by changing treatment technologies, while; indirect emission can be reduced by waste hierarchy principles such as waste minimization, recycling, and re-use (Bogner, 2007).

2.1.3 Low Carbon MSWM

The obscure definition of LCD influences on the freestyle of low carbon MSWM. There are the strategies to reduce the emission from the current MSWM. In the case of Malaysia, the forecasting of MSW generation expected 57% is increasing of organic solid waste generation by the year 2020 from the based the year 1990-2008. The emission will also increase approximately 54%. The community composting in a village is an option to achieve a low carbon and self-sustainable society. The potential reduction from the centralized composting plant is 77.64% when compares with landfilling. Malaysia launched LCS blueprint in 2012 which effective MSWM is a key pillar to achieve (Bong et al., 2016). In the case of Venezuela represent as developing countries, the report shows populations lack of energy access 10% and waste collection 12%. The waste to energy (WTE) technology can be a part of energy matrix to serve the needed, and it also decreases emission 3-5.4 million tCO_2e. However, the result of the study shows carbon tax policy should also implement with WTE for financial of waste management improvement. The combination actions can succeed in the goal of emission reduction 20% and LCD (Cuberos Balda, Furubayashi, & Nakata, 2016). Consideration two cases study, the design low carbon MSWM, depends on the goal emission reduction, waste characteristics, lifestyle the populations, and points of enhancement. The effective waste management can signify the climate change as a co-benefit (Dominic Hogg, 2015).

2.2 Municipal Solid Waste Management (MSWM) in Bangkok

Bangkok is the capital of Thailand which has an administrative area of 1,568.737 km^2 and comprises of 50 districts as shown in Figure 2-1. The registered-population is approximately 5.7 million (Bangkok Metropolitan Administration, 2011). The collected municipal solid waste (MSW) in Bangkok in 2010 was 8,700 ton/day. These wastes were collected separately from infectious wastes. The local government (districts officers) is responsible for collecting MSW from receptacles typically placed in front of households, buildings, and at predetermined locations. The majority of MSW in Bangkok is unsorted and mostly comprises of biodegradable solid wastes (54.87%). All of the MSW in Bangkok after being collected are sent to 3 transfer stations located in Bangkok including On-Nuch, Sai-Mai, and Nong-Khaem stations. The capacity of the On-Nuch transfer station is the largest (4,300 ton/day). At the On-Nuch transfer station, 1,200 ton/ day of MSW is treated by composting and 3,100 ton/ day of MSW goes to landfill at Chachoengsao province. The capacity of the Sai-Mai and Nong-Khaem transfer stations are 2,000 and 3,600 ton/ day, respectively. Beside, incineration plant at Nong Khame was test operation on 10 May, 2016. The capacity is 300 ton/day, however; it has not operated fully. Approximately 89% of Waste management in Bangkok is through sanitary landfills. Wastes from both of Sai-Mai and Nong-Khaem transfer stations go to landfills at Nakhonpathom Province. A schematic drawing in 2010 illustrated the framework of waste management in Bangkok is shown in Figure 2-

2. The cost per ton of waste management also displayed in the diagram. All wastes treatment technologies are MSW exception incineration is an infectious waste which is the highest cost. However, the main responsibility waste management cost is BMA, while population pays only collective service in 20 Thai Baht per month. Interestingly, the composting cost is cheaper than landfilling 2 US$ per ton, however; it offsets approximately 63 US$ per ton. The composting is the cheapest of waste treatment cost and the best option for waste utilization.

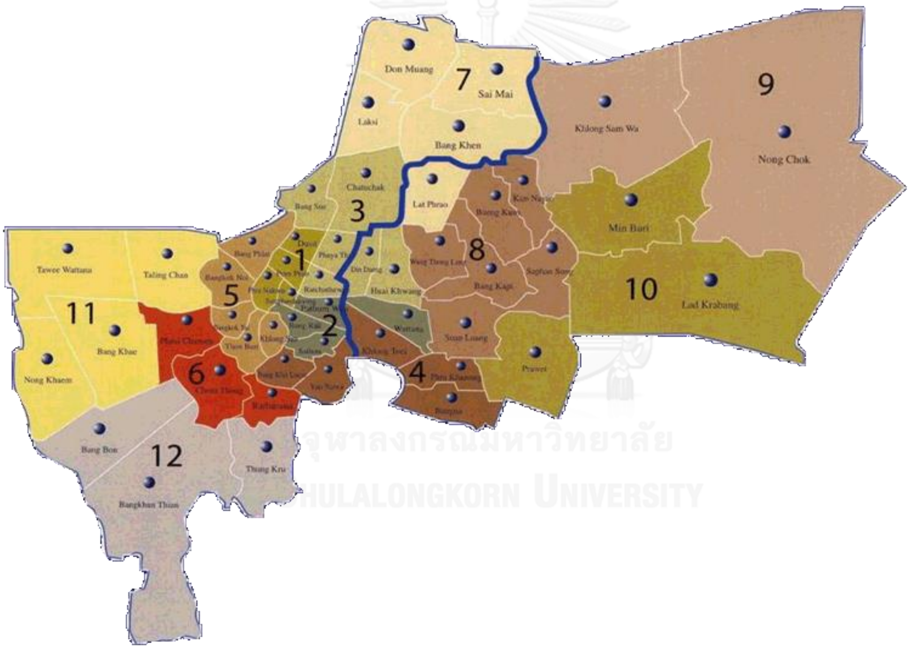


Figure 2-1 50 districts in Bangkok area

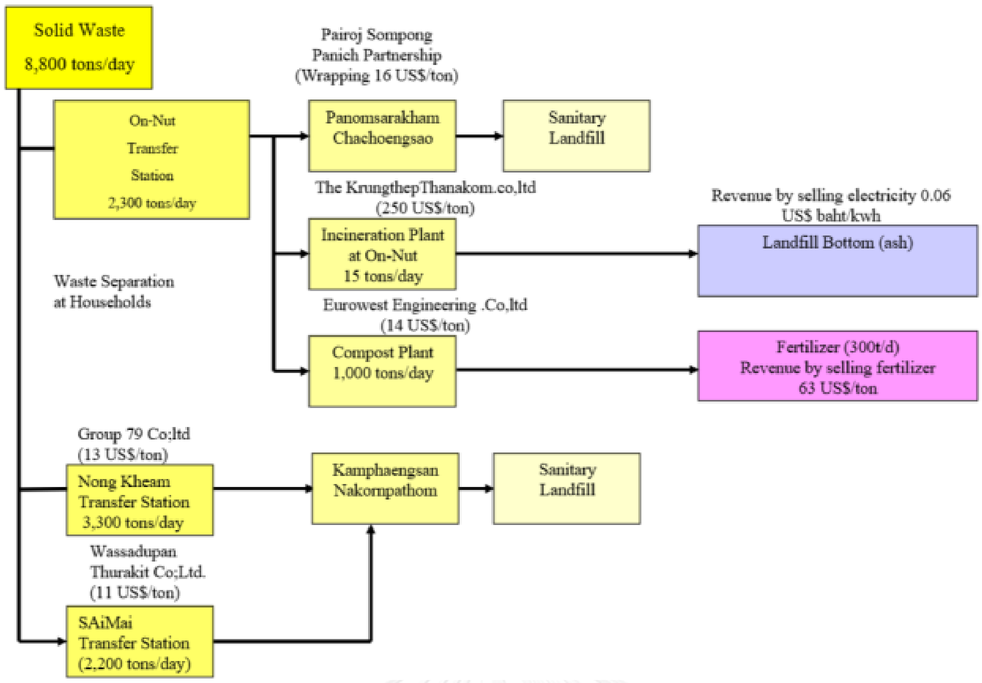


Figure 2-2 Structure of waste management (WM) in Bangkok (Bangkok Metropolitan Administration, 2010).

While the capacity of total transfer stations remains at 8,900 ton/day and landfill sites at 6,400,000 m^2 (Chiemchaisri et al., 2007). The population growth rate and immigration into the city trends are higher with more MSW generated in the same pattern as JBIC forecasting in 2001 (Bangkok Metropolitan Administration, 2013). An overloading capacity of MSWM, additional disposal sites must be found which can be very difficult. It can create health and environment impacts of using of open dumping as shown in cities across India (Sharholy, Ahmad, Mahmood, & Trivedi, 2008). Landfill site at Nakornpathom province was the first site to reach the limit of operation making it is unable to bury more MSW. It should be noted that the BMA contract also will expire in 2014. In Oahu, Hawaii, (Eckelman & Chertow, 2009) were conscious of the issue of limited disposal sites to support the quantity of waste generation. They implemented material recycle as a part of supporting the sustainability of long-term waste management on the island.

The current legislations related to MSWM in Bangkok including Bangkok Government Organization Act 1985, Public Health Act 1992, and Cleanliness and Tidiness of Country Act 1992. The MSWM policies in Bangkok have been set by BMA, which followed the Eleventh National Economic and Social Development Plan (2012-2016), with a goal to become a sustainable city. In addition, BMA has developed the Master Plan on MSWM in short, middle, and long terms (5, 10, and 20 years, respectively). The current master plan, Bangkok's 12-year BMA Development Plan (2009-2020), emphasizes on minimizing MSW at source by 10% annually through an implementation of 3Rs principle through many MSW projects. For example, this includes waste to energy, sorting MSW generated at source and Community Based Solid Waste Management (CBM), Polluter Pays Principle (PPP) for MSW, eco-friendly technology on MSWM with a goal of reducing landfill by 24% in 2026. The MSWM policy framework of Bangkok follows a waste hierarchy (Figure 2-3) as well as waste management to resource management concept, a public participant on MSWM and minimizing MSW transportation to achieve sustainable development (Bangkok Metropolitan Administration, 2010).

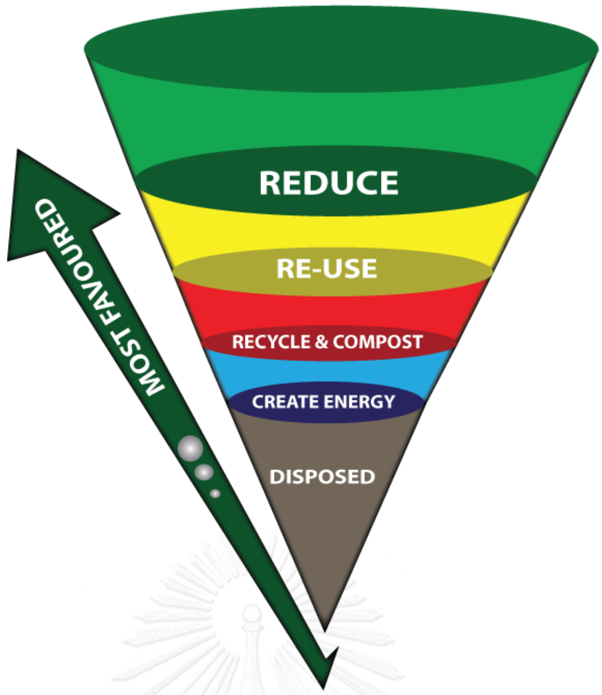


Figure2-3 Waste management hierarchies (BMA, 2013).

Considering the critical situation of MSWM in Hong Kong is the same Bangkok problem of limitation space of landfilling. The city is facing a problem of full landfill sites (6-10 years), while; increasing MSW generated. Despite the recovery/recycle rate of MSW in Hong Kong is more than that of Bangkok (40% of total MSW generated). The Department of Environmental Protection of Hong Kong launched a policy framework on MSWM aiming to achieve sustainable development. This framework includes throwing less pay less, the state of the art treatment (integrated MSW treatment), and community participation.

Table 2-1 shows the situation signifies Bangkok's MSW metabolism which the years are time during the study of this research. Only flooding crisis in 2011 affected the amount MSW. The impacts of situations displays in the right of table. Other years are normally according pattern Bangkok's MSWM and BMA planning.

Table 2-1 Significant situations affected on Bangkok's MSW metabolism

Year	Key incidents on Bangkok's waste	Impacts on waste management
2010	Implementation of CDM projects at Nakhonpathom landfill site.	Reducing biogas generation and energy consumption at the landfill site.
2011	Flooding crisis on the beginning of October 2011 (counted in the fiscal year 2012)	Increasing of waste generation from debris and ruin construction and belongings.
2012	Implementation of CDM projects at Chachoengsao landfill site.	Reducing biogas generation and energy consumption at the landfill site.

2.3 Urban Metabolism

Urban metabolism is similar to organisms in an ecosystem in that it consumes resources of the system as if uptake the nutrient, transforms it via socio-economic process and releases wastes to the environment. It can be considered as a big organism or as a superorganism as shown in Figure 2-4 (Y. Zhang, 2013) It is used to imply metabolic of materials and energy flow within the system. The rural areas are changing and becoming more cities at a fast pace. With conceiving of performance cluster, the urban metabolism process can imply that system informs uptake resources, transforms them in socioeconomic process and releases wastes to the environment. With rural areas fast changing and becoming cities, it produces impacts on the quality of ecology from improper management of problems including a rapidly increase in density of population in the region, depletion of resources, and environmental pollution. The majority of city’s problems come from human activities. It is important to consider how an urban ecosystem can persist on a higher level of resource consumption and pollution emission. To become a sustainable city, most of the urban metabolism studies show that innovations of society such as low-carbon city, ecological city, and environmentally friendly society concepts are very important. The methods of urban metabolism base on analysis of material and energy flow to characterize the urban system including Material flow analysis (MFA), Emergy (energy flow) analysis, and Ecological footprint analysis is the main tools. It should be noted that each method has unique pros and cons (X. Zhang et al., 2013). They rely on a formal mathematical framework and can be applied as a decision-making tool for assessment of the sustainability of a system.

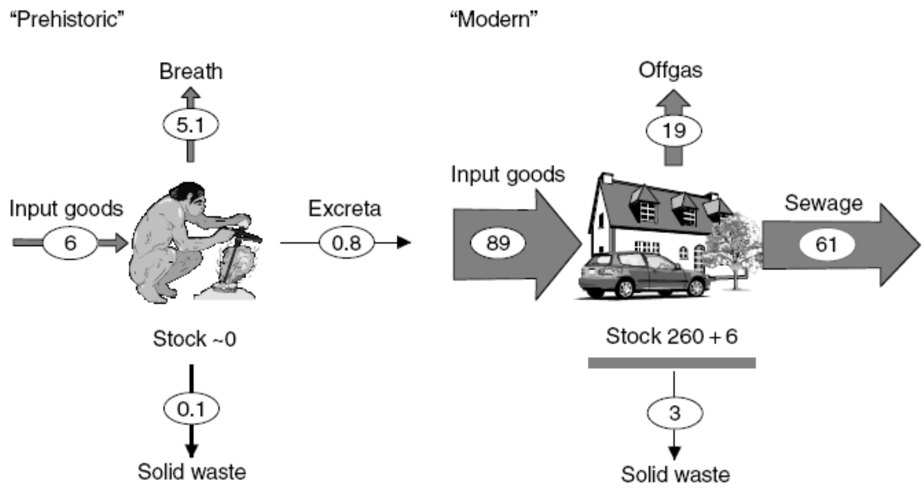


Figure 2-4 Overview urbanization concept (Rechberger, 2002)

(Yan Zhang, Yang, & Yu, 2009) evaluated Beijing's environment by energy synthesis indicator through urban metabolism concept. From the result, the energy value of Beijing metabolism showed an inefficiency of resource management from excessive dependent on non-renewable energy consumption and imported natural resources. This work provided a basis for the government to design policy for improvement of Beijing's energy consumption. Another example, an urban metabolism with nutrient substances flow in the Upper Chattahoochee Watershed, Metro Atlanta illustrated the interaction between human and nature and expanding to support policy making by (Villarroel Walker & Beck, 2012). On the study of N, P, and C substances flows, the problem level was identified where the most influencing nutrient movement is anthropogenic and qunatified each flow in term of input, stock, and output as shown in Figure 2-5.

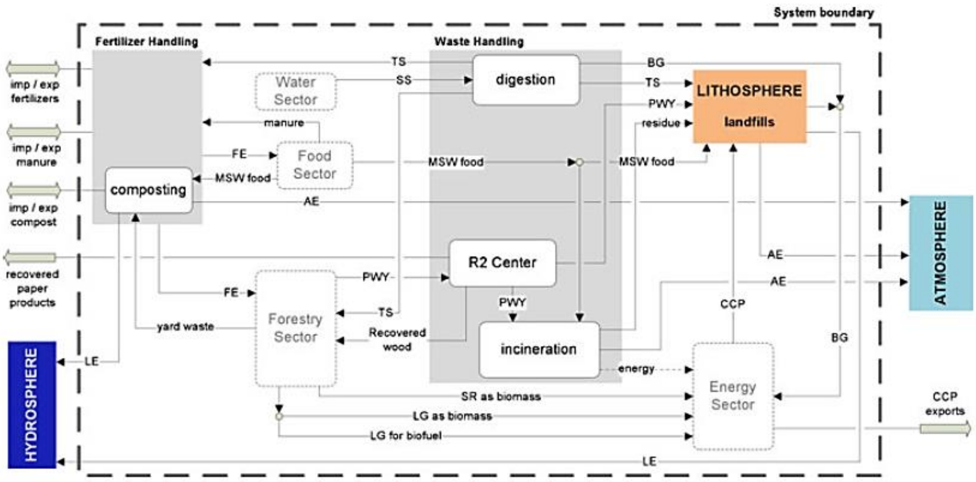


Figure 2-5 The flows of element N, P, and C, water, and energy transform in five sectors.

The urban metabolism concept provides the MSW metabolism information contributes to changing management procedure in sectors such as regulation, technologies, and policy and balance between human needs and impacts to the environment. Urban metabolism can also help identifying problem level and urgency for priority planning on MSWM improvement.

2.4 Material Flow Analysis (MFA)

To account and assess an urban metabolism, an MFA can be applied as decision-making tool on resource, waste, and environmental management relies on the law of conservation of material within a system and time. From the conservation basis, MFA can quantify the flow of material input, stock, and output to show accumulation and depletion of substance or good in the system and environment.

The harmful effects of their accumulation also present and can be set as a priority in a management plan the future. The behavior of materials can be designed through MFA. Moreover, MFA interprets result with evaluation method to specify the system of material, for example, material intensity per service unit, sustainable process index (SPI), and cost-benefit analysis (Reachberger, 2004).The variety of applications of MFA according an urban metabolism study can be in term of environmental management and engineering, industrial ecology, resource management, and waste management.

The steps of MFA, beginning with identification of terminologies in the MFA system are *material*, which is a word representative both of substance and goods. The substance is a chemical element or compound composed of uniform units as chemical science definition. Goods is none positive or negative economic value matter and comprise of one or several substances such as wood, waste, and concrete. *Process* is the transformation, transportation or storage of materials. *System* is boundaries of interaction between elements with other elements in a space of time. Secondly, the quantitative materials/substances transformed in the system based on the conservation law is shown as in Equation 1. Figure 2-5 symbolizes process and flow/flux of MFA, which is demonstrated in a rectangular box with the direction of input/output identified through arrows and expressed in the unit of weight per time.

$$\sum_{k_1} \dot{m}_{input} = \sum_{k_0} \dot{m}_{output} + \dot{m}_{storage}$$

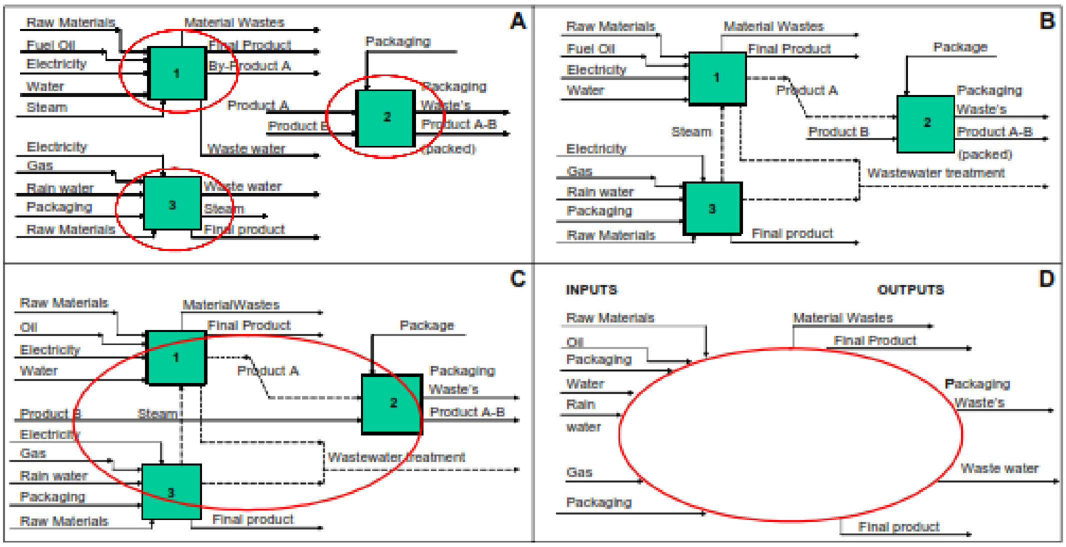


Figure 2-6 The MFA of 3 industrials (1, 2, and 3) with their own processes (A); for industrial symbiosis (close loop of waste management, MFA is shown the whole circle system (B, C, and D) which composes of summary input and output process from each industrial within fixed boundary (Sendra et al., 2007).

According to terminological of the MFA, material in an MFA of MSW can be expressed in term of goods transformed through MSWM process, and the spatial system boundary of studying. In this case is Bangkok area for MSW metabolism analysis. The mass balance of MSW metabolism provides full information for the subsequent investigation of environmental impacts. In the case of goods, the category of MFA calls Bulk-MFA for creating valuable information of turnover goods in economic perspective. The productive spatial system boundary should be individually carried out according to case and objective and selected small boundary, which contains all important materials flows and processes. From this condition, the MSW MFA of Bangkok is divided into various level scales for an effective representation of MSW metabolism.

The bio-waste MFA studied in Catalonia, Spain by (Font Vivanco, Puig Ventosa, & Gabarrell Durany, 2012) utilized a Network-Based Spatial MFA of MSW management system to characterize waste flow and to understand the system behavior. The study applied a Net Recovery Index (NRI) and a Transport Intensity index (TII) to evaluate the efficiency of municipal bio-waste management performance in Catalonia, Spain with information provision from an MFA diagram. The indicators verification was implemented by comparing differences of MSW management scenarios. The MFA diagram contains all flows of municipal bio-waste which includes both treated bio-waste from composting household and unsorted waste. They are quantified by weight express as ton/ year excluding air and water emission flow. The flow outside of established boundary defines the final sink. The MFA diagram shows a picture of generated municipal bio-waste flows go to treatment and disposal plants. It reveals the signification of generated secondary waste from primary waste treatment where a ton of treated primary waste generates 0.37 tons of secondary waste. The waste prevention action and policy of waste management has to cover the entire lifecycle of MSW management. It considers not only the efficiency of waste management and recovery energy, but also achievement on waste prevention level such as quantity of secondary waste. It should be noted that the NRI index is 0.62

which shows the low performance of converting bio-waste to resources. It is because the large amount of bio-waste go to landfill without prior treatment and biogas recovery. Moreover, the MFA diagram provides the information on the average distance of all flow of municipal bio-waste transportation calculation in the system. The result of TII demonstrates that primary waste plays an important role in energy consumption of waste transportation by comparison of TII values between secondary and tertiary wastes. However, the secondary also plays a significant role in energy consuming. It has TII values close to the primary waste even though its quantity flow is less than half of the primary waste. The bio-waste management system is investigated through the scenario and verified by both of indicators. From this research, not only MSWM technology implementation is recommended to improve efficiency, but it also covers collection system and energy consumption in MSWM system. Because of the network of MFA implies system metabolism and contribute to improving the waste management processes.

In another study of waste in socio-economic MFA, (Eckelman & Chertow, 2009) demonstrated the material flow analysis of waste management in Oahu, Hawaii to solve a waste management problem due to a lack of disposal site. The MFA of material in Hawaii reveals the quantity of import, export, and stocks material through the economic system and mass balance of generated waste. The source of generated waste and waste management are also presented in the MFA diagram. The majority of material import is foreigner goods and most waste treatment performance in Oahu is through burning with energy recovery (electricity in Oahu consumes waste to energy 5-7%) while the refuses goes to landfills. The stock materials such as construction can become waste in future, and it might be a problem for waste management. The MFA can track both quantities of waste daily and the accumulated waste to help designing policy and planning of waste management system in the future. The visualization of MFA diagram shows a mass balance of importation goods and stock material are the quite high quantity and mismatch some of the materials between apparent consumption and waste generation. The opportunity of waste management improvement through MFA is not only focus on the quantity of material and treatment procedure, but also considers the time to emit pollution to the environment. From the case studies of MFA, both of them attempt to improve the efficiency of MSWM by using different procedures based on the individual finding in the diversely socio-economic pattern.

2.5 Geographic Information System (GIS)

GIS is a model using for site-specific data. It is a one of decision-making tool by the linkage between location and information differs from the paper map which presents in many layers of data. Each layer data represent the different information on the same geographic area. It can choose what layers are interpreted by selection the specific data and map. For example of implications are urban planner to follow up the fringe growth; a biologist to understand the species population in a specific area; natural hazard analyst to identify risk areas by the disaster; a geological engineer to identify the geological texture for construction; a forest manager to monitor the data tree and soil.

The procedure of GIS comprises of four that are data capture and preparation; data management, including storage and maintenance; data manipulation and analysis; and data presentation. It is based on a computer system which coordinates the data systems and transformation them for analyzing the georeferenced data. The approach to use GIS for helping decision-making contains three main steps that are a map, evaluation, and action (Environment Systems Research Institute, 2012; Otto Huisman, 2009).

GIS techniques are widely used in MSWM and landfill site planning. Some works combine GIS with LCA to assess the hazard of the site and apply the specific data for planning the sustainable growth. The demolition waste also implements GIS to handle by the characteristic of generation and distribution of geographic information. From the spatial-temporal scale, output contributes to design the options for management the demolition waste by waste recycling facility is better than landfilling (Wu et al., 2016). The incineration sites planning in Santiago Island of Cape Verde are for example of using the combination between GIS and the analytical hierarchy process (AHP). The combination models are to evaluate criteria weights with judgment by spatial data of establishing. The method is effectiveness to decide the options and ranking process (Tavares, Zsigraiova, & Semiao, 2011). GIS can signify in waste management decision support such as waste strategies, site selection, and management plans, and waste facility system flow. The program not only is important, but the analysis outputs also is a key factor. It can make the output powerful and combine with the useful program (Mott MacDonald, 2006).

2.6 Carbon emission intensity (CEI)

Carbon emission intensity (CEI) can be defined as normalizing carbon emission. It defined in term of total carbon dioxide equivalent per functional unit or financial unit, for example, ton of CO_2e per ton of product produced, ton of CO_2e per weight worth of product produced, and ton of CO_2e per one million Yen: M-JPY (Nansai et al., 2012; Reachberger, 2004; Zhao, Deutz, Neighbour, & McGuire, 2012). Looking at using CEI as an indicator of the product, Zhao et al. (2012) demonstrated CEI ratio (CEI/GDP) applied from the normal CEI to evaluate carbon emission from products' life and compared it to the value of other countries. It encourages the product becoming more environment friendly. In addition, numerous studies have performed CEI with energy to find the trend of energy consumption and emission (Nag B. and Parikh J., 2000(Fan, Liu, Wu, Tsai, & Wei, 2007). Indeed, the GHG emission on MSWM assessment is popular in term CO_2 equivalent (CO_2-e) as demonstrated in Cifrian, E. et al. (2012) where the authors quantified it in an MSWM system within a specified boundary in term of carbon footprint (CF). To emphasize the comparative GHG emission of MSWM with others, the CEI can be expressed in term ton of MSW as in this research work.

Regarding the GHG emission attribution in cities metabolism, (Kennedy, Pincetl, & Bunje, 2011) investigated GHG emission attribution from 10 cities metabolism. It contributes to a climate change action national plan which the methodology on GHG accounting is based on Intergovernmental Panel on Climate Change (IPCC) guideline. Even though this study did not apply CEI to imply cities' GHG emission, it accommodated to quantify GHG emission in different urban metabolism systems including waste management system. For CEI computation, IPCC guideline has provided the methodology of estimating GHG emission (Intergovernmental Panel on Climate Change, 2006a). Looking at CEI of MSWM in Bangkok, IPCC 2006 has prepared methodology guidance on estimation CO_2, CH_4, and N_2O of individual stages of MSWM and includes activity data, emission factor, and other relative parameters. The CEI of MSW metabolism in Bangkok will show more explicit GHG emission and can help identifying which management stages emit the most GHG.

2.7 Energy Intensity (EI)

An energy intensity is an energy consumed to produce products/service per unit of nation economy (energy unit/ GDP) (Ayres, 2010). Numerous studies on energy intensity in term of energy consumption/GDP investigated EI within geological boundaries for improvement on energy efficiency and reducing GHG emission. These studies include (Barnali NagU, 2000; Bhattacharyya & Ussanarassamee, 2004; Chandler, 2011; Ernst Worrell, 2000). On a comparison with EI in other unit forms, Hasanbeigi et al. (2011) examined energy intensity expressed as energy consumption per physical output of 13 textile plants. This kind of EI is used for improving energy efficiency reflection with separate calculation between electricity and fuel intensities. They performed a separate analysis of current practice in each plant, in a similar group of textile plants inside and outside the countries, and the best plant of EI management with all of them. In addition, the comparison was carried out for the same sub-sector for effective analysis of influences of EI in each textile sub-sector and stages of manufacturing. To productively quantify energy consumption in Bangkok's MSW metabolism, energy consumption per ton of MSW in the system will be implemented in each district area and management stage. The difference of EI in each district area and management stage will show the opportunity for energy saving or management including reducing GHG emission as illustrated in the conclusion sections of Hasanbeigi et al. (2011) study.

2.8 Scenarios Analysis

Future scenarios can be studied and organized through scenarios planning based on present information to make future systematic with several analysis methods to achieve the highest predictability. In addition, it can be applied in various fields such as a business, government, and in the private sector for encouraging decision making

(Höjer et al., 2008; R. Radfar, 2008). The scenarios assist in preparing the future information. It can also be adapted in environmental works. Appropriate scenarios can be selected using several tools to specify the scenarios phenomenon and a suitable representative in system analysis to prepare information for adaptation for future events. The result of scenarios explores the probability, possibility, and preference. Most of the scenarios generate from different starting points such as method and objectives. Table 1 presents the type of scenarios. The important starting point of scenario development is the appropriate type of scenario selection to specify and represent future situation (Höjer et al., 2008).

It is favorite using scenarios strategy in a waste study such as comparative the impact of waste treatment technologies, site selection, and assessment the effect from policies. (K. S. Woon & Lo, 2013) investigated the waste disposal option in Hong Kong by proposed four scenarios choices and using carbon intensity as indicator decision. The aim of scenarios is to explore the options which one is at least emission of waste disposal to implement in Hong Kong. The four scenarios were an assumption based on the current policy framework and current situation of waste in Hong Kong. The Business As Usual (BAU) is a current situation case for comparative with the three options of advanced incineration facility (AHP) and landfill extension (LFE). Finally, AIF releases less GHG emission than LFE, however; the energy offset and carbon storage are also less.

Cuberos Balda, Furubayashi, & Nakata, (2016) exhibited the integration waste-to-energy (WTE) technologies into the electrical system to follow the low-carbon path in Venezuela and simultaneously examined the emission reduction of waste management. It used five case studies under two scenarios that are the current waste collection service (88% of waste generation) and assumption of improvement waste collection service (94%). The cases are current fuel subsidy, no fuel subsidy, subsidy WTE technologies, carbon tax policy, and carbon-reduction policy. However, carbon tax and policy are the highest emission reduction. The research recommended to implement carbon tax is the best for support financial on waste management to be more effective.

Table 2-2 Categories and key aspects of scenarios (Höjer et al., 2008)

Scenario category/ type	Quantitative/ qualitative	Time frame	System structure	Focus on internal or external factors
***Predictive*- what will happen?**				
Forecasts	Typically quantitative, sometimes qualitative	Often short	Typically one	Typically external
What-if	Typically quantitative,	Often short	One to several	External and possibly internal

Scenario category/ type	Quantitative/ qualitative	Time frame	System structure	Focus on internal or external factors
	sometimes qualitative			
Explorative- what can happen?				
External	Typically qualitative, quantitative possible	Often long	Often several	External
Strategic	Qualitative and quantitative	Often long	Often several	Internal under influence of the external
Normative- how can a certain target be reached?				
Preserving	Typically quantitative	Often long	One	Both external and internal
Transforming	Typically qualitative with quantitative elements	Often very long	Changing, can be several	Not applicable

CHAPTER III
METHODOLOGY

Figure 3-1 shows a proposed comprehensive analysis utilized in this study to investigate low carbon Bangkok's MSW management system. Firstly the current Bangkok's MSW metabolism and sub-process evaluation were investigated and demonstrated by MFA and GIS to find out the options directions for enhancing the waste management system. Parameters used in performance assessment included mass MSW flow in term of waste utilization, emission, and energy consumption. These are indicators that often used in the waste sector. Secondly scenarios development carried out for exploration the potential options to become the low carbon MSWM scheme. They were analyzed in term of individual and combination actions. Thirdly the potential options were assessed by the same parameters at earlier step and advantage and disadvantage analysis. After options analysis applied; the low carbon MSWM scheme is the output. Finally, a tool to promote low carbon MSWM policies and implementation in local areas were developed. The methods utilized in an individual section can be illustrated as shown in the following sections.

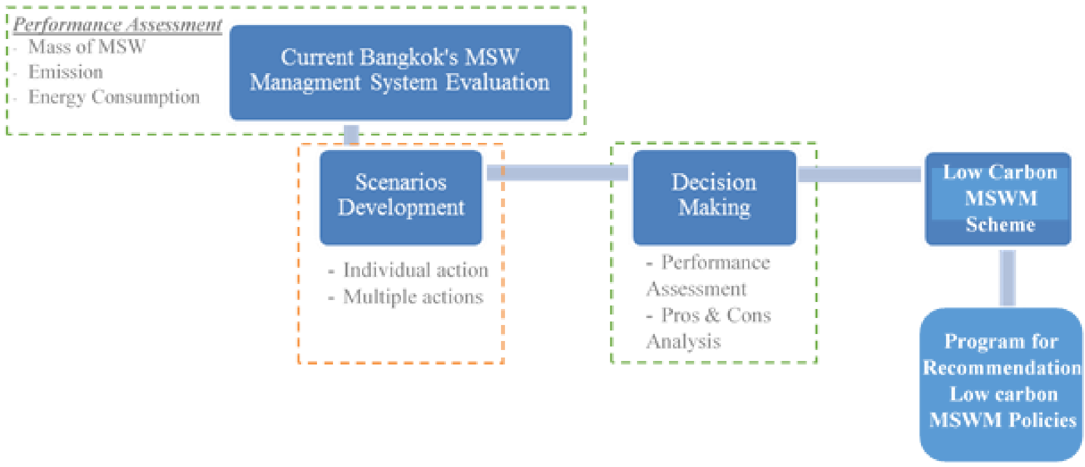


Figure 3-1 Comprehensive analysis of this research

3.1 Data Collection

The data collection of the research was from various source; however, the most data used in the study from BMA recording by online system and real time. The source data in the research were BMA's recorded data, interview the officers from government organizations, governance reports, sites visiting, and information from Journal/reports/online data. The details source data and data are as following.

3.1.1 BMA's Recorded Data

The main data of the study is mass of Bangkok's MSW which is in term of MSW_c. The MSW_c is collection MSW represents as MSW generation because of the mass MSW recording is measurement in the collection system step by local government authorities which is before entering transfer stations. In addition, the vehicle for waste collection is GPS installation, then it can also track the mass MSW_c per vehicle. The percentage MSW collection is 93 of MSW generation (Department of Environment Bangkok Metropolitan Administration, 2009). Therefore, MSW_c can represent as MSW generation and the most reliable for analysis in the research. The mass MSW_c or waste through the research is wet weight. Mass MSW_c remaining at transfer station and sending to landfilling is recording by BMA (Appendix). The mass bio-waste of local project data (community solid waste based management, CBM) is from local authorities recording (50 districts). Not only mass MSW_c was got from BMA or local authorities, the data of energy consumption and quantity vehicles for waste in collection system of each district was from BMA and local authorities' document. This information used in calculation energy consumption and emission of Bangkok's MSWM. However, the energy consumption in transportation to landfilling (WTL) calculated from distance between transfer station and landfilling sites which the mass MSW_c transportation is the document real-time by BMA.

3.1.2 Interview

The second source of data in the research was from interview. Interviewers were officers of Department Environment; local officers of Prawet, Bangkapi, Lardkrabung, Sapansoong, and Suanluang districts; and composting plant owner. The interview contributes to fulfill the incomplete data and recheck the data got from BMA's recorded data.

3.1.3 Governance Reports

A few data in the study got from governance reports, for example, Bangkok State of Environment in 2010-2011, Executive Summary of Climate Change Roadmap of Bangkok, and Development Plan 12 years of Bangkok (2013-2016). If the data cannot find in BMA's recorded and interview, governance reports are a good choice and reliable data source to apply in the study. The criteria governance reports selection for utilization is publication and reliable government organizations. The data from the governance reports were the population, size district areas, land use of Bangkok, budget/expenditure of Bangkok's MSWM of each district, and MSWM roadmap/plan.

3.1.4 Sites Visiting

The site visiting assisted to more understand the overview data of Bangkok's MSW metabolism. Visited sites were Nong Khaem, Sai Mai, On Nuch transfer stations; composting plant; infectious waste plant. The information/data from the site visiting were repetition and according with BMA's recorded, interview, and in government reports. It helps to confirm and recheck the data that are trustworthy.

3.1.5 Journals, Reports, and Online Data

The data was aside from mentioned above were from journals, reports, and online data and not much used in the research. The data from journals were information for benchmarking of emission and energy consumption of MSWM and scenarios development; from the organization reports were constant in emission estimation such as the IPCCC 2006 guideline and Clean Development Mechanism methodology; and from online data was investment cost in advantage and disadvantage analysis. The data from this source was at least in the research.

3.2 Material Flow Analysis (MFA)

The current Bangkok’s MSW metabolism and sub-process evaluation were the first step of analysis in the research. The tools demonstrate the current Bangkok’s MSW metabolism were MFA. The details of MFA design are as following.

3.2.1 MFA Design

MFA of MSW in Bangkok diagram was designed with various scales including district area (local area) and MSWM stages (3 transfer stations region and whole flows of Bangkok’s MSW as big picture). All flows of MSW began with generation from municipalities to end-of-life at disposal sites. The quantities of input, stock, and output materials were calculated following conservation law (Eckelman & Chertow, 2009). The other materials such as water and air emission was excluded from this study. The main source of Bangkok’s MSW information used in MFA design was from BMA’s recorded data. Beside, a few information from district government officers (local government), and governance reports with relative Bangkok’s MSW, national reports, and interviewing. The procedure of MFA design can be described as following.

3.2.1.1 Define Objective and System Boundary

The objective of MFA of Bangkok’s MSW is to quantify MSW flows to assess the current situation of MSWM. With respect to the terminology of material used in

MFA, MSW is represented as goods expressed in weight per unit time. The MSW stream started from municipalities to disposal sites. The MSW went through 3 transfer stations with only one composting plant available at On-Nuch transfer station. The collection system and transportation were also included in the study. The red frame of Figure 3-2 indicates the boundary of this study. Even though the location of landfill sites are out of Bangkok area, for effectively assessment and potential sustainable MSWM scheme, landfill sites were included in this study as a part of Bangkok's MSWM system. MFA of Bangkok's MSW comprised of MSW streams in 50 districts area, three transfer stations, and intermediate treatment of a composting plant. All streams in Bangkok required 4 MFA diagrams to completely identify opportunities for improvements and to understand Bangkok's MSW metabolism.

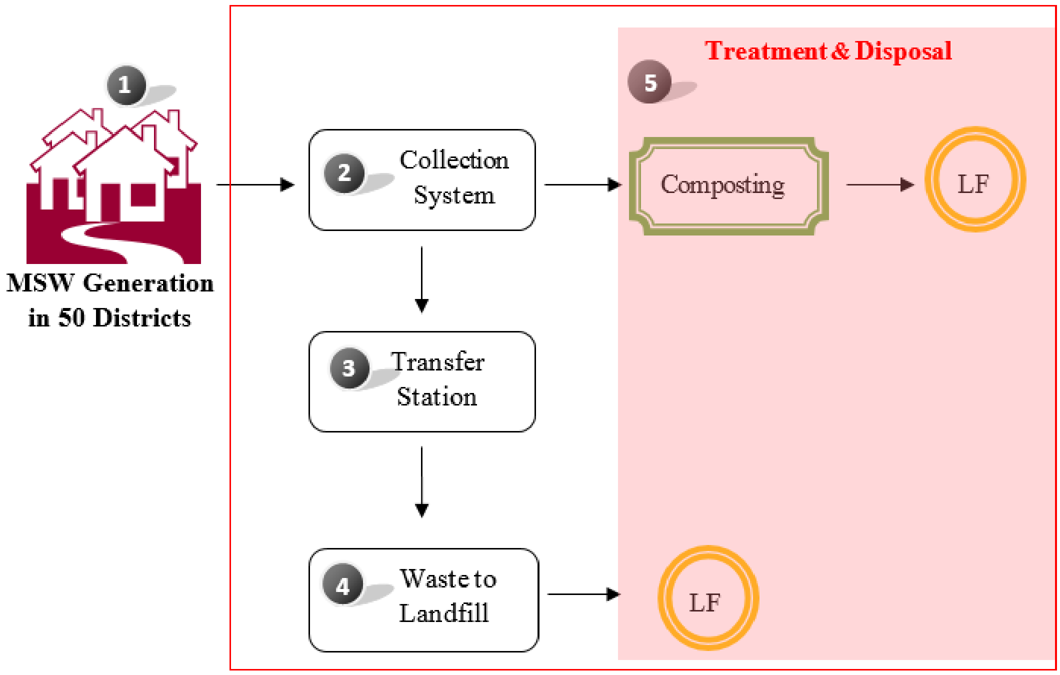
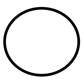


Figure 3-2 Bangkok's MSW management system and boundary of MFA.

3.2.1.2 Identification of Relevant Flows and Processes

The main processes in the MSW MFA (Figure 3-2) are comprised of collection system from households to transfer stations (2), and transportation from transfer stations to disposal sites (4), at transfer stations (3), and landfill sites (5). The marking of Figure 3-2 represents as following:  is representative the main process of MSWM steps,  is representative the treatment process of MSW, and  is representative the disposal step.

SANKEY diagram is used to illustrate various schemes (Herva, Neto, & Roca, 2014). Arrows in MFA diagrams indicate direction of MSW according to its metabolism. Sizes of arrows also represent mass of MSW. Arrows in MFA diagrams represent emission and energy consumption obtained from Emission flow analysis (EFA) and Energy flow analysis (ENFA). For EFA, direct and indirect emissions were represented separately by different colors in the scheme. Similarly ENFA separated diesel and electricity consumption using different colors. In addition, electricity production in the disposal stage was also represented in term of quantity.

3.2.1.3 Determination of Mass Flow and Stock of MSW

The data were obtained from BMA's online database of weights of waste activities. The MSW input from district areas into the system were obtained from local governments and used in the calculation of mass balance in each process until it reaches disposal sites. Mass in a MFA analysis is, typically, cut off at the level less than 5% of total mass (Brunner P.H. and Rechberger H., 2004). This study utilizes a lower cut off at 1.5% of total mass of MSW. The stock of MSW was shown in each step of MSWM. The mass stock contributes to an understanding of the limitation and time required for landfills to be filled which can be used to support decision making process on sustainable MSWM scenarios.

3.2.1.4 Balancing Total Material Flow in the System

Material accounting in MFA was applied using mass balance equation. This helps improving an understanding of the system and identifying flows, stocks, and concentrations parameters. The mass balance equation utilized in this study can be expressed as:

$$\text{Mass}_{\text{Input}} = \text{Mass}_{\text{Stock}} + \text{Mass}_{\text{Output}}$$

3.2.1.5 MFA Diagram

From the MFA studies comprised of 3 scales (local areas, transfer station region, and the whole of Bangkok's MSW stream), the MFA results can be illustrated in form of diagram of MSW flows in the unit of weight per unit time within the defined boundary systems. The MFA diagram comprises of all processes, stock, MSW flows, and input/output was visually presented for all MSW flows and metabolism in Bangkok to help identifying the Bangkok's MSW problems and opportunities for improvements. The processes for EFA and ENFA are similar to that of MSW MFA. The current situation of MSWM was assessed for its efficiency through evaluation methods such as percentage of MSW utilization, CEI, and EI.

3.3 Geographic Information System (GIS)

GIS is a second tool to demonstrate the current Bangkok's MSW metabolism and sub-process evaluation which is the first step analysis in the research as shown in Figure 3-1. It contributes to decision supporting on MSW management by providing data interpretation based on geographic area and localize performance. The hotspot areas of each indicator disclose. ArcGIS ® software version 9 by ESRI implemented through the study. The data preparation for interpretation with program GIS was as following: mass MSW (ton/day), Mass MSW per capita (kg/capita/day), density of MSW (ton/km^2/day), Bangkok's MSWM emission (tCO_2e/year), Bangkok's MSWM carbon emission intensity (tCO_2e/ton/year), Emission of CS in Bangkok's MSWM (tCO_2e), Bangkok's MSWM energy consumption (MJ/year), and Bangkok's MSWM energy consumption intensity (MJ/ton/year). All parameters divided in fifth levels that are very high, high, medium, low, and very low exception the energy parameter of both net and intensity units were sixth levels which the last level was offset energy (less than 0). The range of levels of each parameter was different. They calculated from average value of each parameter from 2008-2013. The same parameter had the same rage level in 2008-2013. Only mass MSW was original data got from BMA's recorded; while others were from calculation. The detail of calculation of parameters of performance assessment is in the next section.

3.4 Performance Assessment

After the current Bangkok's MSW metabolism was analyzed and demonstrated by MFA and GIS, the sub process of MSWM evaluation proceeded by emission and energy consumption in term of net and intensity units. The performance assessment contributes to define which sub-process should be enhanced firstly.

3.4.1 GHG Emission and Carbon Emission Intensity (CEI)

GHG emission (tCO_2e) is analyzed and used as an indicator reflecting waste management performance and level of environmental burden (K. S. Woon & Lo, 2013). An assessment framework is based on the four main stages of Bangkok's MSW management. Boundary of GHG emissions for individual stages is shown in Figure 3. Emission calculation was based on IPCCC 2006 guideline and Clean Development Mechanism methodology (United Nations Frameworks Convention on Climate Change, 2013). Additionally, to benchmark Bangkok's MSW metabolism, emissions of MSW among different stages and different cities were compared.

Carbon emission intensity indicator (CEI) is calculated from GHG emission (tCO_2e) divided by a ton of MSW_c of the individual stage (Zhao et al., 2012). Calculations of total GHG emission in Bangkok's MSW metabolism can be expressed as shown in Eq.1.

$$GHG_{Total} = GHG_{CS} + GHG_{TS} + GHG_{WTL} + GHG_{LF} \qquad \text{Eq. 1}$$

Where GHG_{Total} is total GHG emission which is a summation of GHG from individual stage of waste management (collection system, transfer station, transportation, waste to landfill, and landfill), GHG_{CS} is GHG emission in collection system (CS), GHG_{TS} is GHG emission at transfer station, GHG_{WTL} is GHG emission of waste to landfill, GHG_{LF} is GHG emission at landfills. The detail of individual stage calculations can be described as following:

3.4.1.1 Collection System

The main emission from a collection system is from the transportation from waste generation to transfer stations (M1 in Figure 3-3). The distance traveled for collection system was based on diesel consumption records in 2013 which was, then, converted using a ratio of 2 km/l (BMA's assumption). GHG emission calculation can be expressed as shown in Eq.2.

GHG[1] = Fuel consumption x EF　　Eq. 2

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[1] IPCC, 2006 IPCC guidelines for national greenhouse gas inventories, Volume 2 energy, 2006.

[2] UNFCCC, AM0025 version 14.0.0 Sectoral scopes: 01 and 13 EB 68, 2012.

[3] UNFCCC, ACM0001 version 15.0.0 Sectoral scope: 13, 2013.

Where Fuel consumption is obtained from converting recording distances of the collection system and EF is emission factor which is 2.7446[4] kgCO_2e/l for this study.

3.4.1.2 Transfer Station

At three transfer stations, only the On Nuch transfer station divides MSW into two parts which consist of (i) 1,200 ton/day MSW that passed through a pre-treatment process via composting and (ii) 3,300 ton/day MSW, which is directly sent to landfill (similar to the other two transfer stations). The GHG emission calculation included that of the composting process. For the transfer stations without a prior treatment (M1 in Figure 3-3), it is estimated based on fuel consumption of backhoes. The assumption was based on site visiting data of three transfer stations which comprised of four backhoes of each transfer station for grouping the MSW. The backhoes operation 19.8 hour per day and the property of diesel consumption is 11 liter per hour. The emission factor is 2.7446 kgCO_2e/liter of diesel. Then, the GHG emission was approximately 966.10 tCO_2e/year for each transfer station.

[4] Thailand Greenhouse Gas Management Organization (Public Organization), 2015.

Emissions from composting (M2 in Figure 3-3) are calculated using AM0025 version 14.0.0 (UNFCCC, 2012) and ACM0001 version 15.0.0 (UNFCCC, 2013) as shown in Eq.3. The data for calculation is most from interview and site visiting.

$$GHGCP = PEElectricity\ consumption,y + PEFuel\ consumption + PECH4,\ y + PEN2O,y + PELF \qquad \text{Eq. 3}$$

Where GHG_{CP} is total emission at composting, $PE_{Electricity\ consumption,y}$ is a summation emission of energy consumption in composting processes which calculations of each term are shown in Eq.4 and Eq.5, PE_{Fuel} consumption is an emission from fuel consumption in composting processes which can be calculated as shown in Eq.6, PE_{CH4}, y is Methane emission per year from the composting processes which can be calculated as shown in Eq.7, $PE_{N2O,y}$ is Nitrous oxide emission per year from the composting processes which can be calculated as shown in Eq.8, and PE_{LF} is emission from landfill of residue from composting processes (M3) as shown in Eq.9.

$$EC_{Pj,comp,y} = Q_y \,.\, SEC_{comp,default} \qquad \text{Eq.4}$$

$$PE_{Electricity\ consumption,y,\ y} = EC_{PJ,y} \,.\, EF_{grid,y} \,.\, (1+ TDL_y) \qquad \text{Eq.5}$$

$$PE_{FC,y} = Q_y \,.\, EF_{FCdefault} \qquad \text{Eq.6}$$

$$PE_{CH4,y} = Q_y \,.\, EF_{CH4,y} \,.\, GWP_{CH4} \qquad \text{Eq.7}$$

$$PE_{N2O,y} = Q_y \,.\, EF_{N2O,y} \,.\, GWP_{N2O} \qquad \text{Eq.8}$$

$$BE_{CH4SWDS,y} = \varnothing.(1-f).GWP_{CH4}.(1-OX).16/12.F.DOC_f.MCF.\sum_{X=1}^{Y}\sum W_{j,x}.DOC_J.e^{-Kj(y-x)}.(1-e^{-kj}) \qquad \text{Eq.9}$$

3.4.1.3 Waste to landfill

Distance of waste to landfill was classified as the distance between transfer stations and landfill sites. The distance was obtained from records of trips of daily transportation. The emission calculation follows the same model (M1) as that of the collection system (as shown in Eq.2).

3.4.1.4 Landfill Operation and Decomposition of Organic Matter

In an early CDM project, method for calculating landfill emission (M4 in Figure 3-3) was used as shown in Eq.9. While operating a CDM projects (Landfill gas recovery), the emission was calculated according to Clean Development Mechanism Project Design Document Form (United Nations Frameworks Convention on Climate Change, 2010, 2012) as shown in Eq.10-15. The local data was mostly applied in this scenario. Typically, CH_4 is not immediately created after bury the wastes. The decomposition period used in this study is 1 year (Intergovernmental Panel on Climate Change, 2006b). The percentage of LFG recovery rate is 94 and 64 for Kamphaeng San and Panomsarkham landfills, respectively (Jaroensompong Co., 2012; Progress Energy Co., 2010).

$$GHG_{LF} = BE_{CH4,\,y} + BE_{EC,\,y} \quad \text{Eq. 10}$$

$$BE_{CDM\ Project} = (MD_{project} - MD_{BL,y}).GWP_{CH4} + EL_{LFG,y}.CEF_{grid} \quad \text{Eq.11}$$

$$MD_{project,y}=MD_{flared,y} + MD_{electricity,y} \qquad \text{Eq.12}$$

$$MD_{BL,y} = MD_{project,y}.AF \qquad \text{Eq.13}$$

$$MD_{flare,y} = (LFG_{flare,y} .W_{CH4,y}\cdot D_{CH4,y})-(PE_{flare,y}/GWP_{CH4}) \qquad \text{Eq.14}$$

$$PE_{flare,y} = \sum^{8760}_{n=1} TM_{RG,h} . (1-\eta_{flare,h}).GWP_{CH4}/1000 \qquad \text{Eq.15}$$

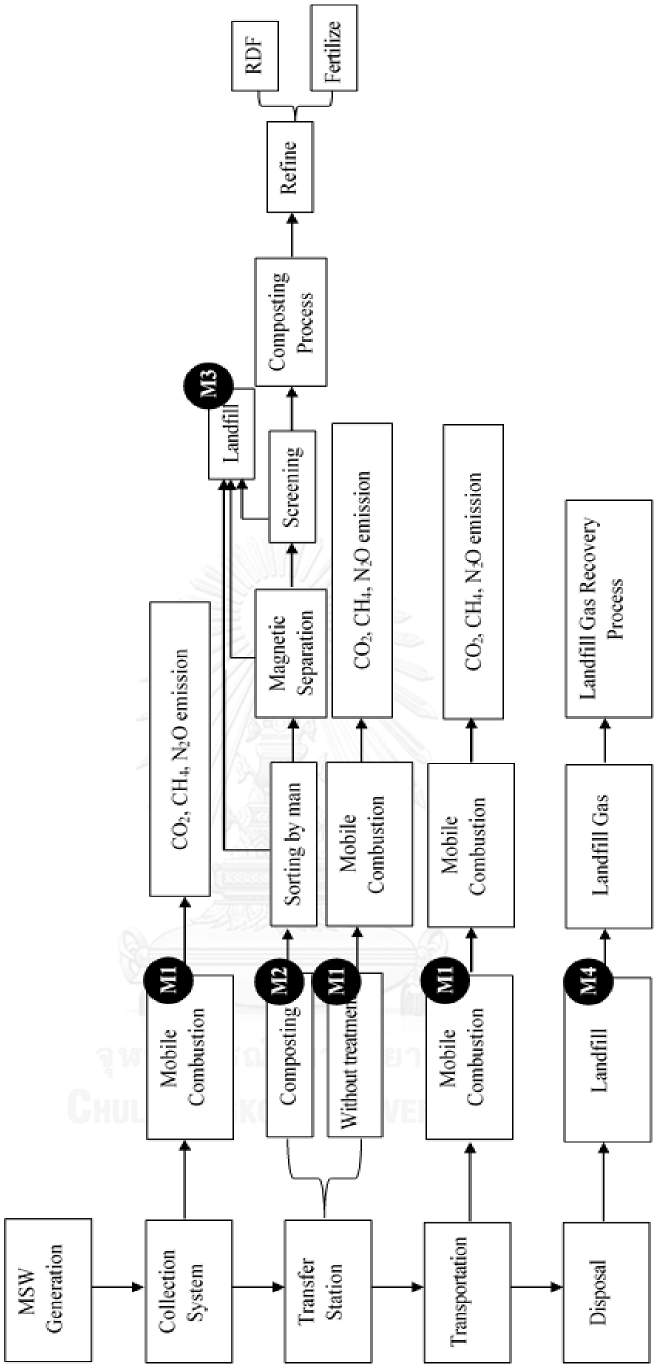


Figure 3-3 Diagram of GHG emission individual MSWM stages Note: M1 is GHG emission from mobile combustion process; M2 is GHG emission from composting process; M3 is GHG emission from landfill without recovery LFG process; M4 is GHG emission from landfill with recovery LFG process.

3.4.2 Energy Consumption (EC) and Energy Intensity (EI)

The other indicator for assessment Bangkok's MSWM is Energy Consumption (EC) which indicates energy uses in Bangkok's MSW metabolism in individual stages. The data of energy consumption was based on BMA recorded (Department of Environment Bangkok Metropolitan Administration, 2010, 2011, 2012b, 2013) and organization reports such as CDM report projects. Electricity and fuel consumption were calculated separately. These factors were converted to the unit of Joule as a summation of energy consumption. For analysis of EC hot spot in each stage of MSW metabolism, the individual EC was calculated in term of EI. The formula can be expressed as

EI (MWh or GJ/ ton of MSWc) * Total MSWc = EC (MWh or GJ)

The electricity consumption of transfer station and fuel consumption of composting plant were excluded from this analysis due to the lack of data. Moreover, they represent only a small fraction of the entire processes.

3.4.3 Scenarios Development

The future circumstance can be studied and organized through scenarios planning. By using present information to make future prediction using several analysis methods to achieve the highest predictability. In addition, it can help to assess the performance in various fields such as a business, government, and in private sector to encourage decision making (Höjer et al., 2008; R. Radfar, 2008). The scenarios assist to prepare the future information can also be adapted in an environmental study with much of perspectives and multidiscipline remain the same. Appropriate scenarios can be selected using several tools to specify the scenario phenomenon and suitable representative in system analysis to prepare information for adaptation on coming event. The result of scenarios explores the future in term probable, possible, and preferable, which generates from different starting point of scenarios such as method and objectives.

It should be noted that most of GHG emission is from energy consumption (Nakata, Silva, & Rodionov, 2011). To propose a framework for low carbon Bangkok's MSW management, options were created based on the current Bangkok's MSW management system (Figure 3-2) with focuses on reducing energy consumption simultaneously. The framework of scenarios also are developed which coincided with Bangkok's MSWM policies that comprise of zero waste management concept in 20 years plan of Bangkok (2013-2032), 3Rs in upper rate 20% per year of waste generation source in 12 plan of Bangkok (2013-2016); reducing GHG emission of waste management sector as in Bangkok master plan on climate change (2013-2023), and more utilization MSW according to the Municipal solid waste management plan of Bangkok (2015-2019) (Jungrungreung, 2015). Not only low emission of waste management system was focused, but also reduction of environmental load was included based on declining wastes to landfill (Inazumi et al., 2011). To reduce energy consumption, the waste transportations (collection and WTL stages) were focus in scenarios development. It can be done by reducing round of waste transports, distance of transport, and increase efficiency of fuel consumption. Energy consumption of transfer stations and landfill gas were not of interests because transfer stations are only the place for wastes to wait for transporting to landfill and energy offset is higher than consumption at the landfills. The scenarios were, then, in order to achieve low carbon waste management, it is important to aim to reduce both quantity of MSW for transport and distance. It should be noted that this study excluded fuel consumption efficiency in vehicles. This is because the BMA have always checked the vehicles to ensure that they are comply with the principle of automobile fuel economy standards (Soren Anderson, 2010). Nevertheless, Bangkok's vehicles for waste transportation consisted of more than 90% diesel vehicles. Further emission reduction can be achieved by switching from diesel to natural gas vehicles (Jose M Lopez, 2009).

To reduce landfill waste, emission, and energy consumption at the same time, four main scenarios of this study were presented and eight hybrid scenarios were analyzed to investigate which multiple actions are the most effective option for Bangkok's waste management. In total, there were 12 scenarios included in this study as summarized in Table 3-1. Only scenario 1 and 2 were not hybrid scenarios. This is because they are based on the same function of reducing distance between transfer stations and at sources of waste generation.

Table 3-1 Description of design low carbon Bangkok's MSW management system scenarios

Name	Scenarios	Description
1	Decentralized composting plants in individual local areas (50 districts). Decentralized composting plants in pattern clusters (13 clusters) of high activities areas.	It serves for representative scattering waste management as decentralized composting of food waste in two patterns that were individual local areas and clusters of high activities areas. The system designs 10% food waste of Bangkok's MSW generation is separated and individually collected to treatment by vessel composting under aerobic condition and without residue (Lundie & Peters, 2005). It contributes to reduce waste for transport and food waste to landfill which is simultaneous waste utilization (Font Vivanco et al., 2012). This scenario is accordance with the first strategy of the Municipal solid waste management plan of Bangkok (2015-2019) and in the third scope of Bangkok master plan on climate change (2013-2023) to promote organic waste utilization.
2	Establish 14 transfer stations in high waste generation activities areas.	It contributes to reduce energy consumption and GHG emission in waste transportation. There are more transfer stations in in high activities areas which have energy consumption intensity of collection system higher than 7.5 l/ton. Even though this scenario is new installation Bangkok's

Name	Scenarios	Description
		MSWM policy/plan, it is quite according to the second strategy of the Municipal solid waste management plan of Bangkok (2015-2019) to reduce energy consumption and GHG emission in collection system by changing the route.
3	Change types of fuels in vehicles for waste collection system and WTL.	It aims to reduce emission of transportation, then all waste vehicles change from diesel to natural gas consumption. It can reduce GHG emission from emission factor decreasing. Even though this scenario is new installation Bangkok's MSWM policy/plan, it is quite according to the third scope of Bangkok master plan on climate change (2013-2023) to enhance efficiency of fuel consumption in collection system and waste transportation.
4	Campaign of reducing waste generation rate by 25%	The campaign of reducing 25% waste generation rate by government sector is mainly approach 3Rs principle. It may not seem enough to achieve the target, due to recycling waste in Bangkok is 15% at present. Then, Waste bank campaign supposes to support 25% of waste generation reduction. It reduces waste for transport and waste to landfill. This scenario is according to the twelve years plan of Bangkok (2013-2016) for reducing waste at generation source upper rate 20% by 3Rs.
H1	Combination scenarios 1+3	Decentralized composting and changing type fuel
H2	Combination scenarios 1+4	Decentralized composting and campaign

Name	Scenarios	Description
H3	Combination scenarios 1+3+4	Decentralized composting, changing type fuel, and campaign
H4	Combination scenarios 2+3	More transfer stations and changing type fuel
H5	Combination scenarios 2+4	More transfer stations and campaign
H6	Combination scenarios 3+4	Changing type fuel and campaign
H7	Combination scenarios 2+3+4	More transfer stations, changing type fuel, and campaign

In addition, the *scenario 4*, the project to reduce waste generation by 25% using a waste bank program, shows an efficiency of reducing waste in Thailand by 9.68%. However, it is the scale of communities which is smaller than the city as Bangkok. Then, the operators of a waste bank projects as the case study reference will be the communities of local areas (Challcharoenwattana & Pharino, 2015). BMA has been operating waste bank in Dindang flat and On Nuch municipalities, but the quantity is less than 5% of MSW_c. Additionally, emission, energy consumption, and cost analysis of waste bank program are excluded in the calculation due to its existing plan to achieve the target.

3.4.4 Analysis of Advantages and Disadvantages of Management Scenarios

Advantage and disadvantage of waste management in different aspects have been addressed in various researches (Cheng, Chan, & Huang, 2003). The criteria of four subjects were from reviewing and SWOT analysis result of the Bangkok issues on MSWM (Department of Environment Bangkok Metropolitan Administration, 2016). Table 2 shows a detail of analysis of each subject. Subject's criteria were divided into three levels which consist of an explicit condition by references and practices. There are different weights, which displayed in parentheses, for classification of the subjects of scenarios.

The basis of weighting factors of each subject was as following: The first subject is *technology* was divided in three levels by degree of expertise, then; the weighting technology of four scenarios were decided based on the degree of expertise operation and new/existing installation. For the scenario one is composting which is moderate technologies (Barlaz, 2013). There are similar level to the technologies use in scenarios two and three (Semin, 2009; Stantec Consulting Ltd., 2014). The only technology in third scenario is the lowest expertise need because of it requires manual to reduce waste generation at source according to the waste hierarchy principle (3Rs) and promoting the project by media (Peek, 2012). Moreover, all technologies of scenarios have been operating at present exception scenarios two.

The second subject is *investment cost*. This issue relates with the budget which BMA set up in every year. Due to framework BMA's budget for MSWM has to establish before earlier two years according to the redtapism, then the activities plan and budget always different and cannot operate an effective MSWM plan. In addition, the high budget of MSWM has to get permit and authorize by government stakeholder such as congress which takes a time. The low budget plan/activities can affect an effective MSWM in Bangkok. In this case, the investment cost represents a part of budget because of it quite has completely information than operation and maintenance cost. It was divided in three level by range of investment cost which set up in accordance with the yearly expenditure/budget of BMA. The data for analysis investment cost and weighting were based on the reference. The investment cost of composting in scenario one was assumption from operating 38 ton per day (10% of food waste in MSW). The cost was grading (31,400 USD/ha), paving (123,000 USD/ha), land acquisition (2,500 USD/ha), and building (75 USD/m^2) (Levis & Barlaz, 2011). The conversion between US dollar and Thai Baht was 30 THB/USD. The investment cost of scenario two was based on the transfer station construction budget in Thailand which the service assumption is 200 ton per day (Tamadue Municipality Government, 2015). Investment cost of scenarios three was based the company's catalogue of converting diesel to CNG engine which the company registered with Department of Land Transport (Paknamrodprakob Company Ltd., 2012). Converting engine of 8 piston truck is 35,000 THB and 6 piston truck is 29,000 THB. The 8 piston truck is for vehicle for waste in WTL which is 50 by interviewed data and 6 piston truck is for CS, which is around 1800 by BMA's recorded data. The investment cost for promoting campaign of scenarios four was main from media. The assumption is main using advertisement on newspaper (size 10 inch of advertisement) and T.V. (5 minute of advertisement) which the cost is 3,000 THB/inch of newspaper and 70,000 THB/minute of T.V. advertisement (Bangkok Business, 2014; Thairath, 2014).

The third subject is *social* which divided in three levels by desirable communities nearby the facilities or projects. The waste management system considers the social aspect has high chance of successful (WSP Group SRL, 2009). There are positive level means agreement the projects and support; neutral level means after explanation the project, some opposite people of communities is agreement; and negative level means nearby communities are opposite the facilities/projects, even though the project has explanation. The weighting of social aspect on waste management scenarios was based on desirable communities, also. Waste management projects, construction/facilities such as composting plant (scenario one) and transfer station (scenario two), are mostly opposite by the communities because of health and environmental risk and loss property value. In opposite, the friendly environmental waste management projects are positive by the communities.

The forth subject is *policy implementation*. The decision of this subject is the readiness of policies to implement which divided in three levels. There are ready level means the MSWM policies are operating but they need some support/enforcement to achieve the goal; rearrangement policy level means incomplete policies and they have to improve; and new setting policy level means no policy in the Bangkok's MSWM plan and need to set up. The weighting of scenarios were based on MSWM policies plan in the Municipal solid waste management plan of Bangkok (2015-2019).

For weighting combination scenarios was based on average the single scenarios. In advantage and disadvantage analysis, weighting is decision making on the best scenarios to implement/ design low carbon scheme and policy recommendation which the highest weight is the best option.

Table 3-2 Criteria for pros and cons analysis.

Subjects	Score	Criteria	Source
Technology	Simple (3)	Technologies need moderate degree expertise and are operating, which is most developing countries implement such as sanitary landfill without recovery energy and waste vehicles in the collection system. It is operating at present.	(Department of Environment Food and Natural Affairs, 2011; Sharholy, Ahmad, Vaishya, & Gupta, 2007)
	Medium (2)	Technologies need some know-how and are working in both of developed and developing	

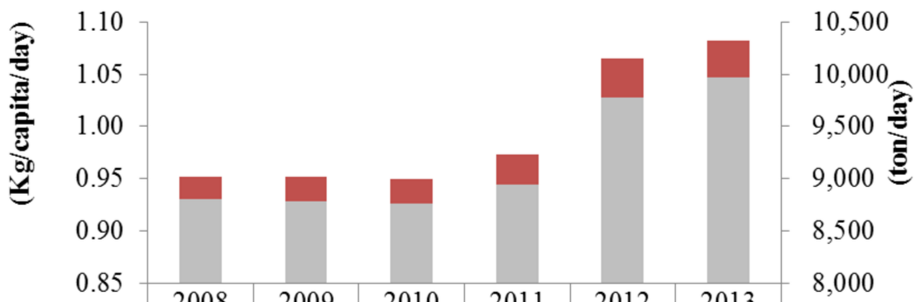
Subjects	Score	Criteria	Source
		countries such as composting, mechanical biological treatment (MBT), and incineration. It is operating at present.	
	Advance (1)	Technologies need high degree expertise and are most operation in developed countries such as advanced thermal technology and vacuum waste collection system. A new setting need.	
Investment Cost	Low (3)	Lower 50 million THB	(Bangkok Metropolitan Administration, 2014)
	Medium (2)	50 - 100 million THB	
	High (1)	Upper 101 million THB	
Social Aspect	Positive (3)	The agreement is supporting by Bangkok's population.	(Gerrar, 1993; Pollution control Department, 2004)
	Neutral (2)	Agreements after government clarify.	
	Negative (1)	Protesting/disagreement by population nearby the sites of waste facilities as Not In My Backyard (NIMBY) principle.	
Policy implementation	Ready (3)	The systems have already existed and can implement immediately.	(Department of Environment Bangkok Metropolitan Administration, 2016)
	Rearrangement policy/system (2)	Improvement the existed system.	
	New setting (1)	Set new regime/policy.	

CHAPTER IV
CURRENT SITUATION OF MSW METABOLISM IN BANGKOK

This chapter presents the current situation of the Bangkok's MSW metabolism. The urban metabolism concept can be obtained based on analysis of MSW mass and energy flows. It is to characterize the MSW system and present the metabolism. The trend of MSW_c in 2008-2013, MSW_c's MFA of three scales (city, transfer station geographics, and local areas), and MSW_c for entire Bangkok city geographic are analyzed and present in term of MSW_c in annual, MSW_c per capita, and density of MSW_c. The analysis of the trend of Bangkok's MSW_c helps to understand the variation of the quantity of waste in the past six years by the BMA recorded. The study of three scales MSW_c's MFA and MSW_c on Bangkok geographic are used to conceive the MSWM stages and relation between areas and mass MSW_c, respectively.

4.1 Trend of Bangkok's MSW_c in 2008-2013

Bangkok's MSW generation over a 6-years period (2008-2013) was analyzed and presented as shown in Figure 4-1. Average daily MSW_c in Bangkok during the study period gradually increases approximately 11% in term of ton/day and 13% in term of kg/capita/day. Although the total population in Bangkok since 2008 has been quite stable; in 2012, MSW_c significantly increased by 9.3% from that of 2011. The sudden increase of wastes in 2012 can be attributed mainly to the 2011 flood disaster in Bangkok. As expected, the disaster like massive flooding can significantly cause an increase of total amounts of waste generation from debris and reconstruction activities (Brown & Milke, 2016). Beside, the registered population in Bangkok is quite stable since 2008; the non-registered population trend increases approximately 8.2% in 2010 from 2000. For in the research fixed non-registered population at 36.9% of registered population, then it may be cause of stable population in Bangkok (Public Relation Group, 2014). Economic consideration by Gross Provincial Product (GPP of Bangkok) has increased trend 35% in 2013 from 2011 (Research and Evaluation Group, 2015). The urbanization of Bangkok which indicated by household income index increase 500% in 2011 as comparison with 1999. Therefore, non-registered population such as foreigner tourist, economic, and urbanization can be cause of increasing trend MSW_c in 2013. Likewise, Chen and Wu (2011) study that economy and urbanization are important factors on waste generation (Liu & Wu, 2011). However, among many factors that caused increasing average MSW metabolism in the 6-years, one major factor can be a consequence of flooding.



	2008	2009	2010	2011	2012	2013
MSWc (kg/capita/day)	0.95	0.95	0.95	0.97	1.06	1.08
MSWc (ton/day)	8,804	8,788	8,769	8,943	9,774	9,963

Year

Figure 4-1 Trend of MSWc in Bangkok from 2008 – 2013

Currently, Bangkok MSW management system can handle approximately 9,700 ton of wastes per day based on the designed criteria of 1 kg/capita/day since the year 2000. Meanwhile, recent MSW per capita since 2012 and 2013 were 1.06 and 1.08 kg/capita/day, respectively. Beside, the Nation MSW generation rate in 2012 was 73,335 ton/day (Pollution control Department, 2014). Bangkok's MSW_c is 13.32% of total national MSW generation. The trend of MSW exceeds the current capacity of the waste management system by approximately 6-8%. Due to Bangkok's MSWM treatment and disposal has been fixed quantity of MSW by the contracts with private corporation, then the exceeding MSW_c remains in the municipalities. The MSWM should be enhanced or the waste generation should be reduced at source.

Most urban areas of low to middle-income countries have waste generation rate less than 1 kg/capita/day. For instance, Jakarta, Indonesia, has waste generation rate of 0.88 while the rate in Beijing, China, is at 0.90 kg/capita/day (Bhada-Tata, 2012).

However, waste generation rate in Manila, Philippines is 3.00 kg/capita/day. On the other hand, urban areas of high-income countries tend to have higher waste generation. For example, Santiago, Chile, has wasted generation rate of 1.63; Sao Paulo, Brazil, is at 2.00; Macao and Hong Kong's waste generation rates are 1.51 and 2.47 kg/capita/day, respectively (Hoornweg D. and Tata P.B., 2012). Even though rates of waste generation in urban areas of high-income countries are higher than 1 kg/capita/day, the systems are typically well designed with sufficient capacity and efficiency to handle the generated waste through application of sorting and recycling (A. Pires et al., 2011). Bangkok's MSW_c rate over six-year trend is less than that of urban areas in high-income countries. However, an unexpected situation such as flood disaster can overload the existing waste management system (Department of Environment Bangkok Metropolitan Administration, 2012a). It is, therefore, essential to improve MSW management system of Bangkok to have a higher capacity with better efficiency to handle future waste generation and events like disasters.

4.2 Material Flow Analysis (MFA)

To better understand the current Bangkok's MSW metabolism, MFA was analyzed in 3 scales (city, transfer station geographics, and local areas) to explore waste utilization and flows.

4.2.1 City Scale (Bangkok)

Metabolism of MSW management in Bangkok was calculated using material flow analysis diagram. Figure 4-2 presents MFA of MSW (ton/day) in 2013. The processes of Bangkok's MSW metabolism are shown using arrows on the top of the figure which tracked MSW_c metabolism by its flow. An average amount of generated MSW that was collected by local government was approximately 10,879 ton/day. The highest composition of MSW comes from food waste (41-48%). At the household level, a small percentage of recyclable MSW was separated by Informal Recycling (IR) such as by scavengers at the rate of approximately 185 ton/day (1.7%). BMA's waste utilization projects can help treating approximately 730 ton/day (6.71%) of MSW_c. The projects contain the programs such as local composting, community-based management (CBM), and Bangkok's school waste banks. The majority of MSW has been collected and sent to transfer stations (TS) at the rate of approximately 9,405 ton/day (92%). The final treatment and disposal of wastes were mainly done using landfills. There is a small percentage of MSW, which was pre-treated through composting (1,200 ton/day capacity) at the On Nuch TS. It should be noted that almost all countries in Southeast Asia mostly use landfills for final disposal. Singapore is an exception where MSW are mostly recycled (Ngoc & Schnitzer, 2009).

Consideration MSW_c stocks at transfer station, the quantity was from mass balance MSW_c input and output in daily by BMA's recording data of weighting machine at transfer stations. The MSW_c stock at transfer station will be transported to the landfill sites in the next day, however; the mass MSW_c stock at transfer station from daily collection system remains which is similarity quantity. The number of stock is not much because of the contracts between transfer station companies and BMA limit and control performance of MSWM. By the time, BMA can track the performance of transfer station companies in real time.

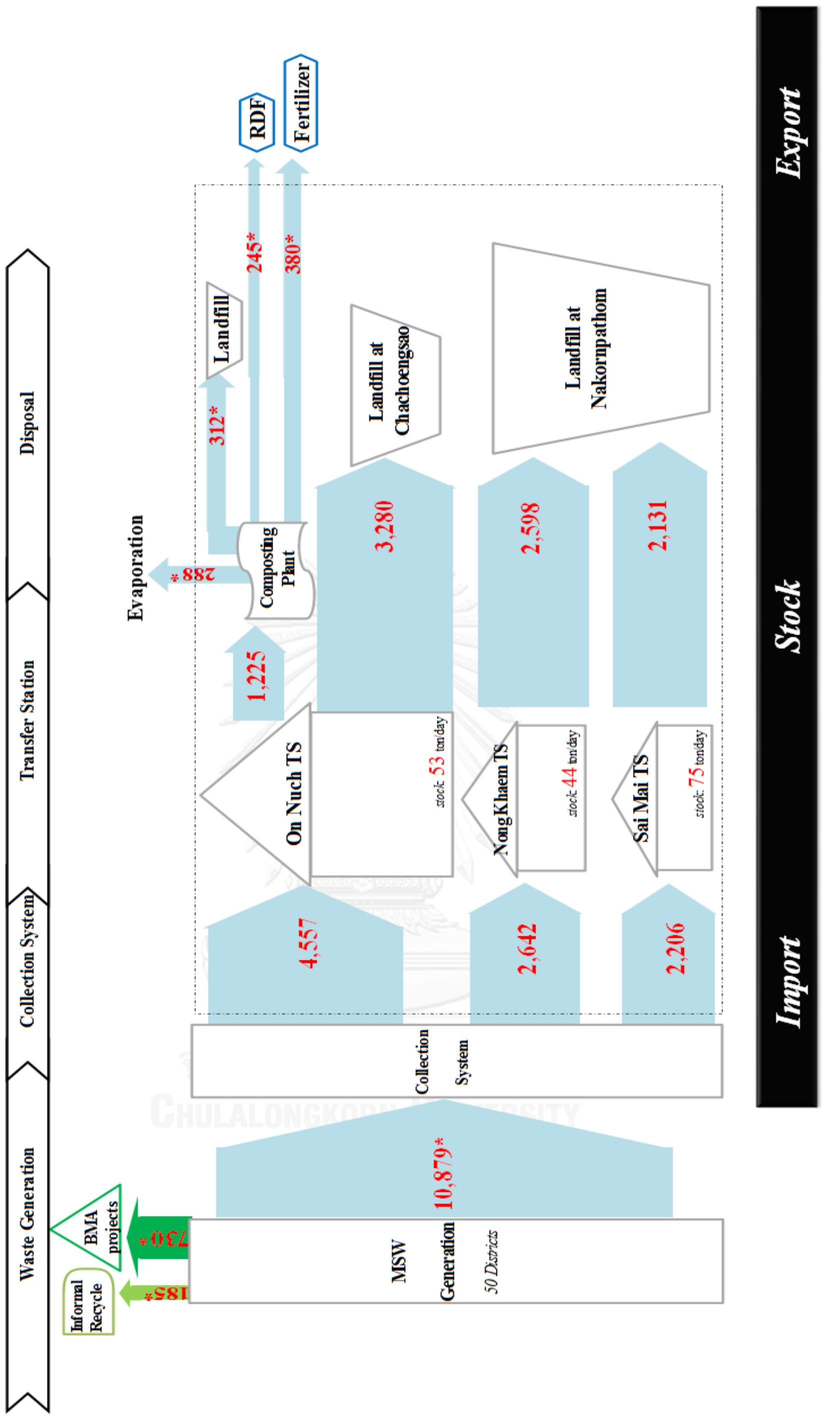


*Figure 4-2 MFA of Bangkok's MSWc (ton/day) Note: * means the number from calculation. The number in diagram from BMA's raw data (BMA's recording).*

4.2.2 Transfer Station Geographic Area Scale

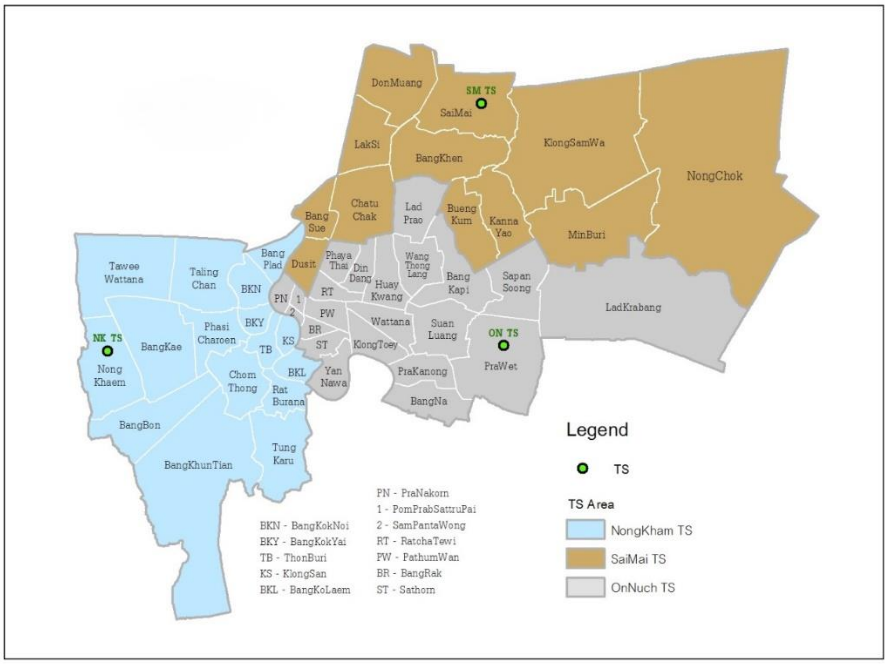


Figure 4-3 Boundary of transfer station regions.

Figure 4-3 shows three zones of MSWM based on transfer station (TS) geographic; the blue color section is Nongkham TS, the gray color is On Nuch TS, and the brown color is Sai Mai TS regions. Based on the mass flow of MSW in each transfer station region, Figure 4-4 to 4-7 present all flows of MSW_c (ton/day) in 2012. Figure 4-4 are mass flow MSW_c of On Nuch TS region which is the highest amount MSW_c and the plastic wrap is used for MSW_c without prior treatment for landfilling. Only On Nuch TS region has intermediate treatment by composting which the composting MSW_c flows diagram is exhibited in Figure 4-5. It shows the ratio of waste utilization as RDF and fertilizer, nevertheless; it still has high amount to landfilling. Only mass MSW_c flow in the composting process was based on estimation by composting technique which got from interview the owner composting plant. From MSW_c is wet weight, then in the composting process has mass loss by evaporation. Figure 4-6 shows the mass MSW_c at Sai Mai TS region which is the lowest MSW_c when compares with others two transfer stations. It is 100% direct to disposal by landfilling without prior-treatment is likewise Nongkhaem TS region in the Figure 4-7.

MFA diagram of TS regions scale is consistent with MFA's diagram city scale. The local areas (districts) have their own collecting system of MSW and sends MSW to their transfer station geographic which displays different thickness lines in the MFA diagram. The amount of MSW_c at TS service are limited quantity by BMA. MSW_c flows in three of transfer station regions are mostly to landfilling similar to Bangkok's MSW metabolism. The stock at transfer station of TS region scale is also in accordance with the city scale. Even though the only On Nuch TS has intermediate treatment by composting; landfilling is still the highest of TS geographic.

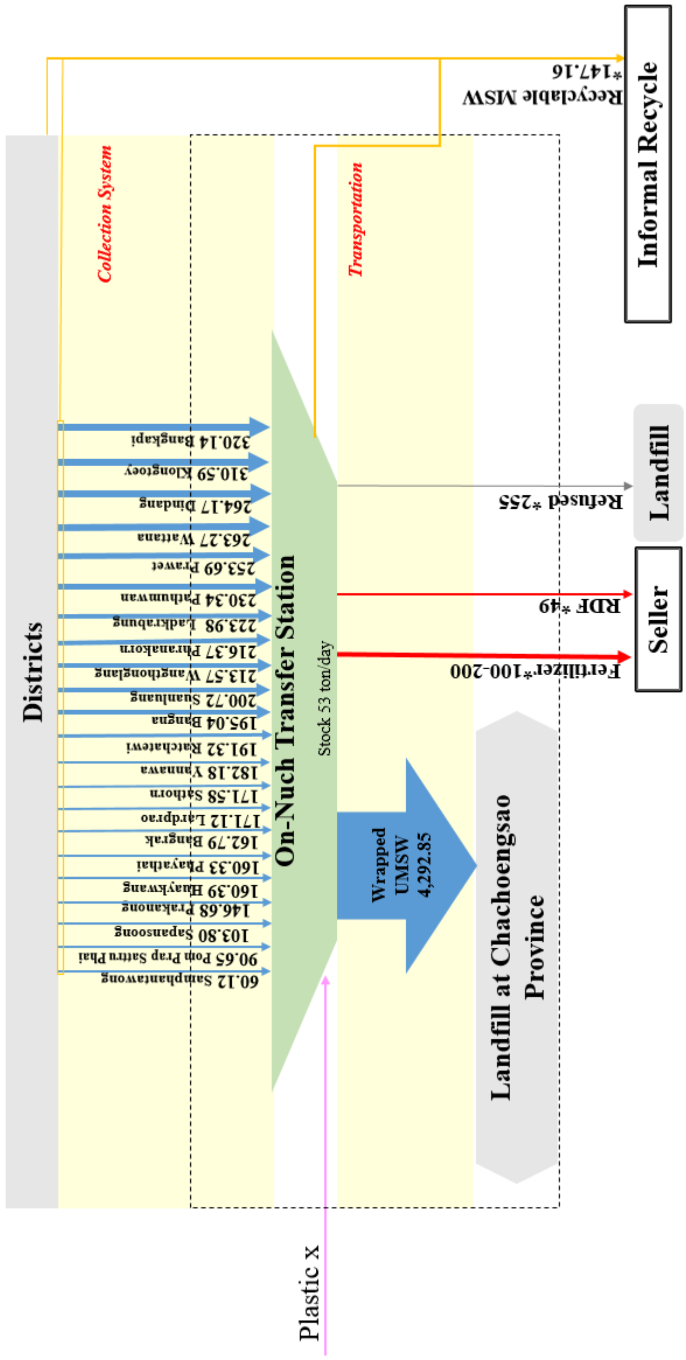


*Figure 4-4 Mass flow diagram of MSW at On Nuch TS region (ton/day) Note: * means the number from calculation. The number in diagram from BMA's raw data (BMA's recording).*

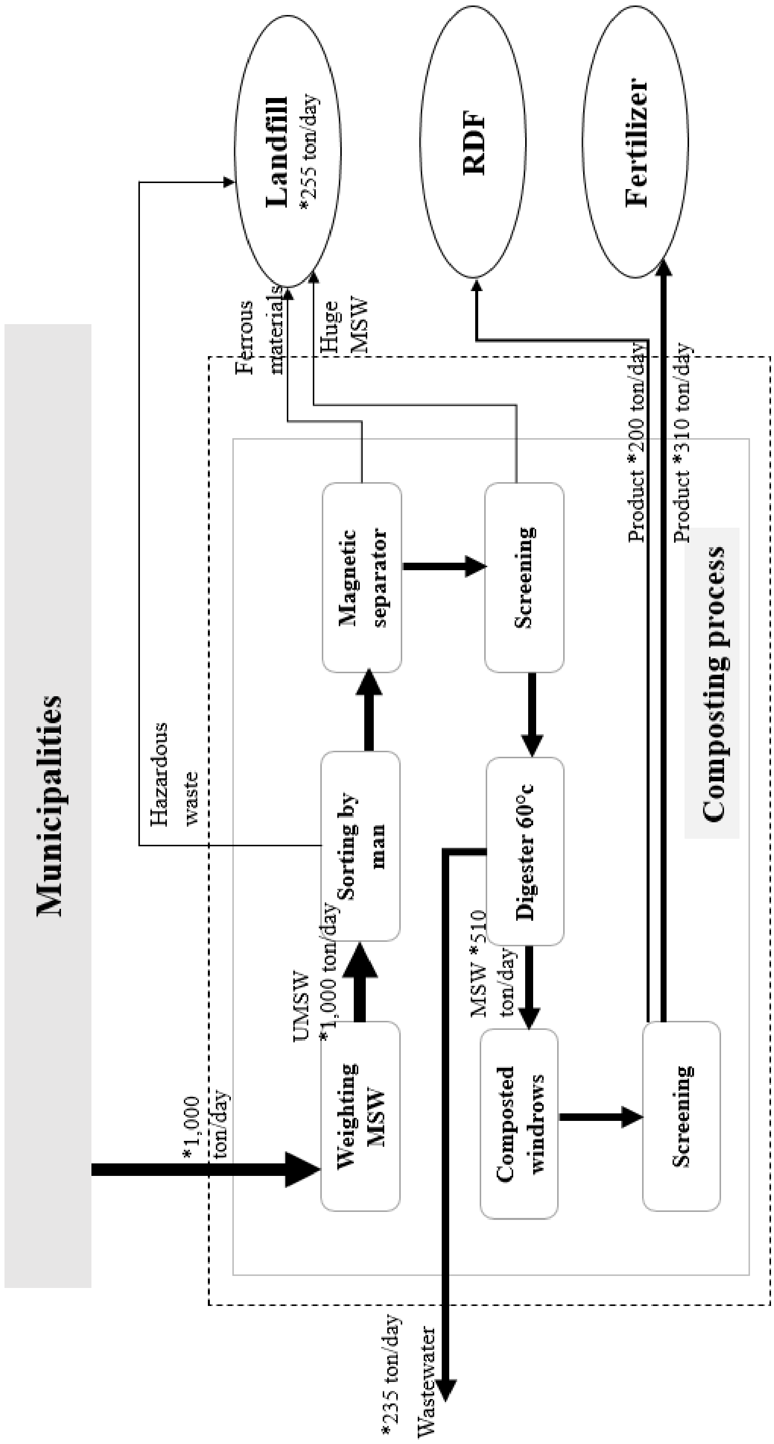


*Figure 4-5 MSW flows at intermediate treatment (composting plant).Note: * means the number from calculation.*

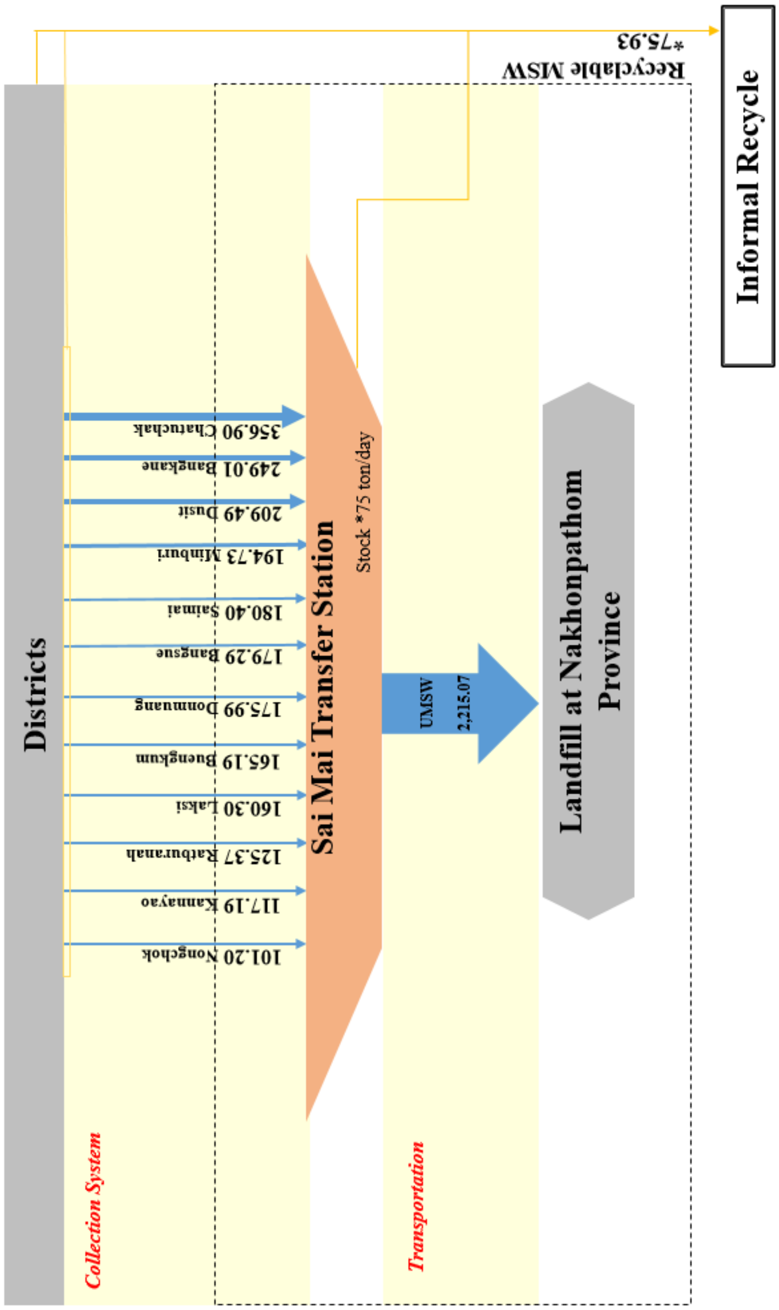


*Figure 4-6 Mass flow diagram of MSW at Sai Mai TS region (ton/day) Note: * means the number from calculation. The number in diagram from BMA's raw data (BMA's recording).*

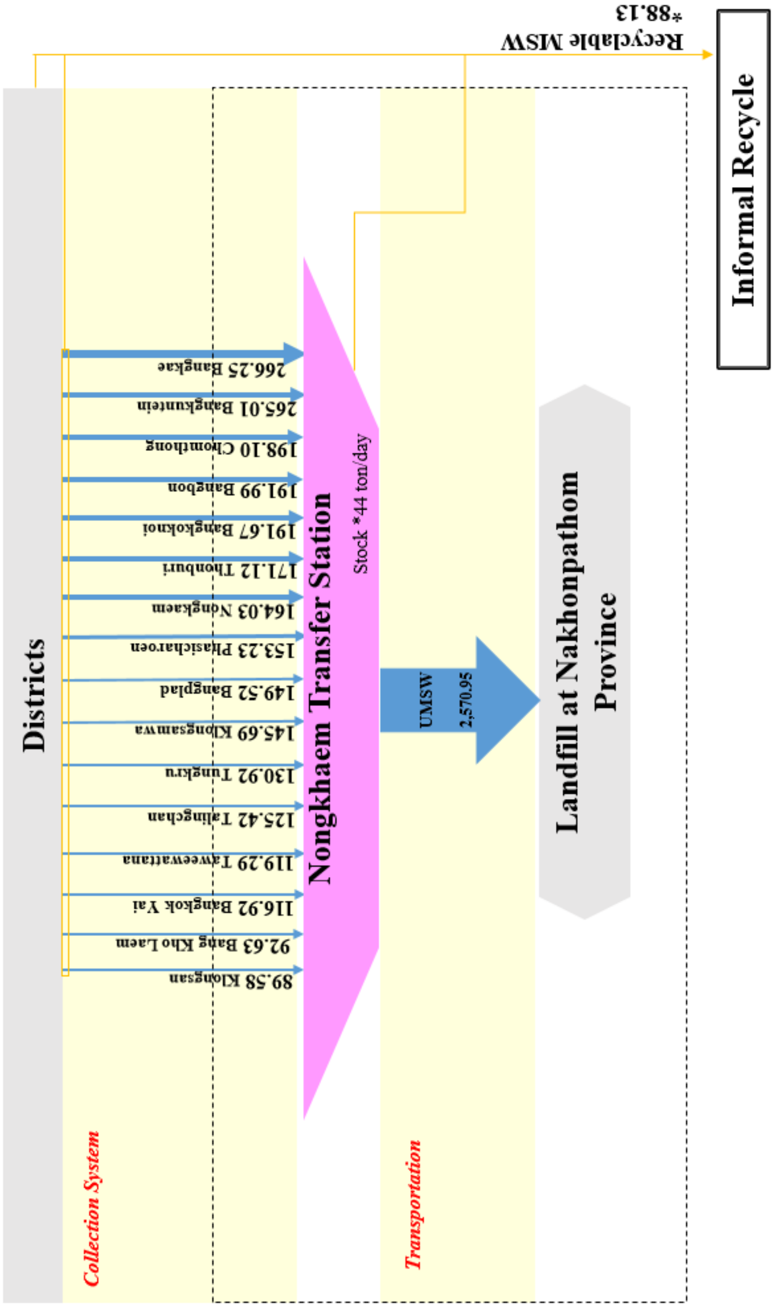


Figure 4-7 Mass flow diagram of MSW at Nongkhaem TS region (ton/day)

*Note: * means the number from calculation. The number in diagram from BMA's raw data (BMA's recording).*

4.2.3 Local Areas Scale

MFA in local scale is used to demonstrate more detail of the flows of MSW_c in Bangkok. The all data was from BMA's recording. The flows of MSW_c in local scales represent Sai Mai, On Nuch, and Nongkhaem TS geographic were Chatuchak, Prawet, and Bangkae districts in 2012. They representative because of massive MSW_c are in top five ranking and high amount of CBM project which is bio-waste from market and restaurant joined in the local government composting project. Figure 4-8 is MFA of mass MSW_c at Chatuchak district which was the highest MSW_c in the local areas. However, amount bio-waste in CBM project is not much as MSW_c quantity when compares with other district. Figure 4-9 is MFA of MSW_c at Prawet district. It has different flows from Chatuchak and Bangkae because it has a part of MSW_c composting before landfill. However, it has high quantity of landfilling. Figure 4-10 is MFA of MSW_c at Bangkae district shows the flow similar to Chatuchak which is direct to landfilling without prior. The amount of bio-waste in CBM project is the highest among comparison districts, while the MSW_c is not much as Chatuchak. The local authority is influence on local waste utilization. Even though they locate in different TS regions; their main MSWM flows in local areas are similar that are to transfer stations (blue line); bio-waste for local composting (orange line); recycling MSW (RMSW) at municipalities; collection system; and transfer station stages (yellow lines) for informal recycle; and landfill gas recovery. The stock in landfill sites is from landfilling of local areas in 2011.

The MFA diagrams of the local scale present most of the waste flow (96% of MSW_c) to landfilling. The bio-waste is for composting in local areas as CBM project which are variety percentage depending on local government authority fixing the quantity of bio-waste utilization. The bio-waste does not general come from households but rather it is generated from gardening and yard wastes in a public area and restaurants/markets. This CBM project is according to the BMA policy to encourage utilization of wastes in local areas. The quantity of landfilling in each local area depends on the quantity of MSW_c. The stock at TS is similar in the MFA city scale, however; this number stock is from a local area' MSW_c in the day before. It is transported to landfilling in the next day. The stock in landfilling is buried in every year until the expired contract with BMA. The landfilled MSW_c will be ownership by the landfill owner.

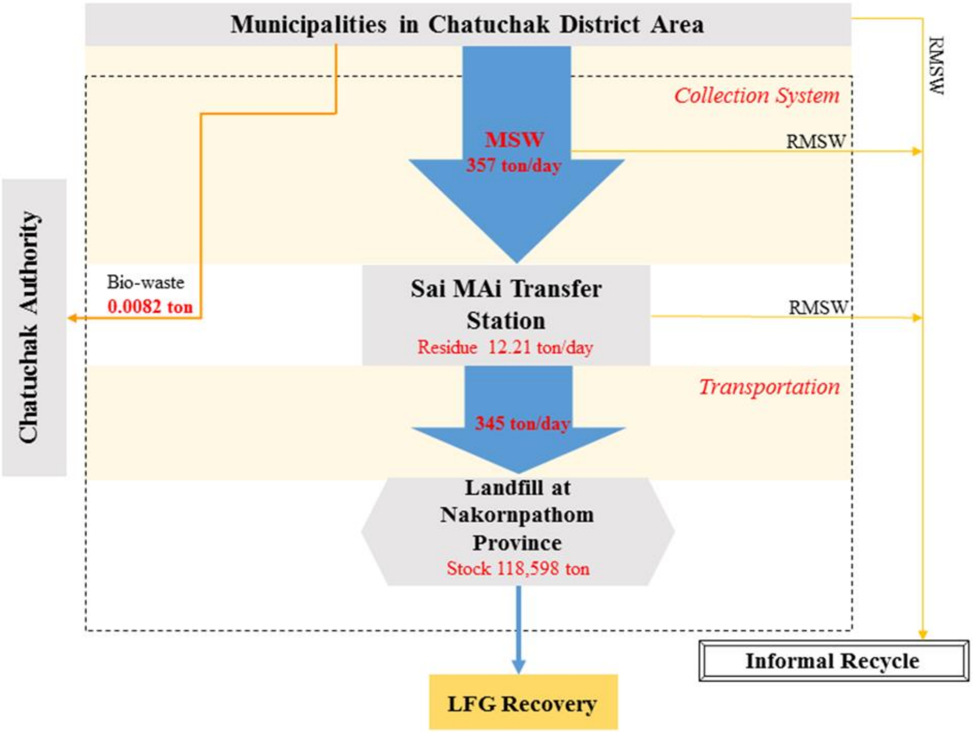


Figure 4-8 Diagram of MSW flows (ton/day) in Chatuchak district area

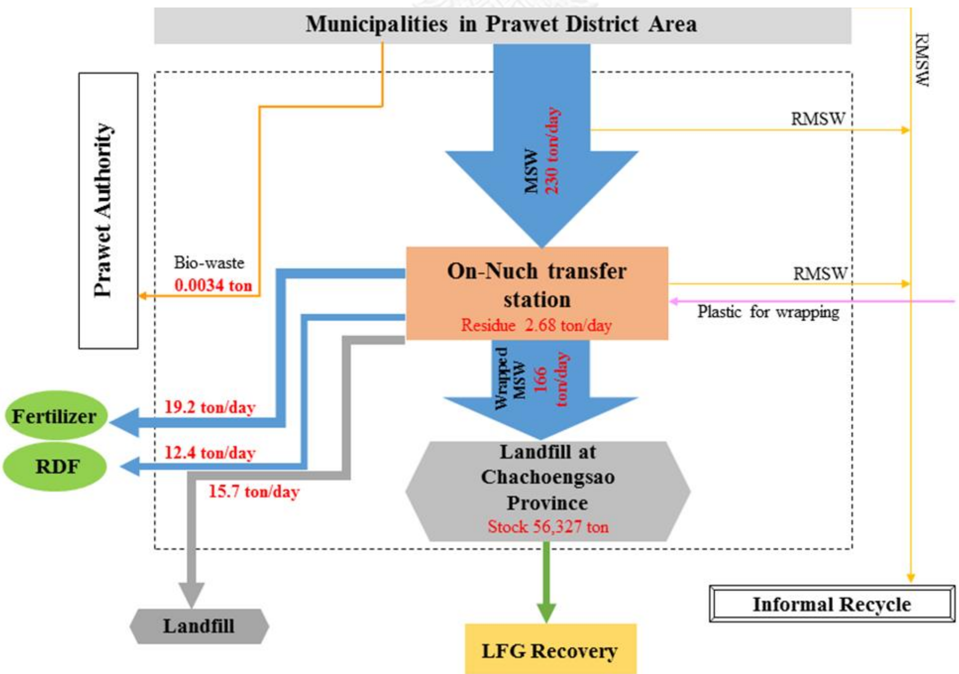


Figure 4-9 Diagram of MSW flows (ton/day) in Prawet district area

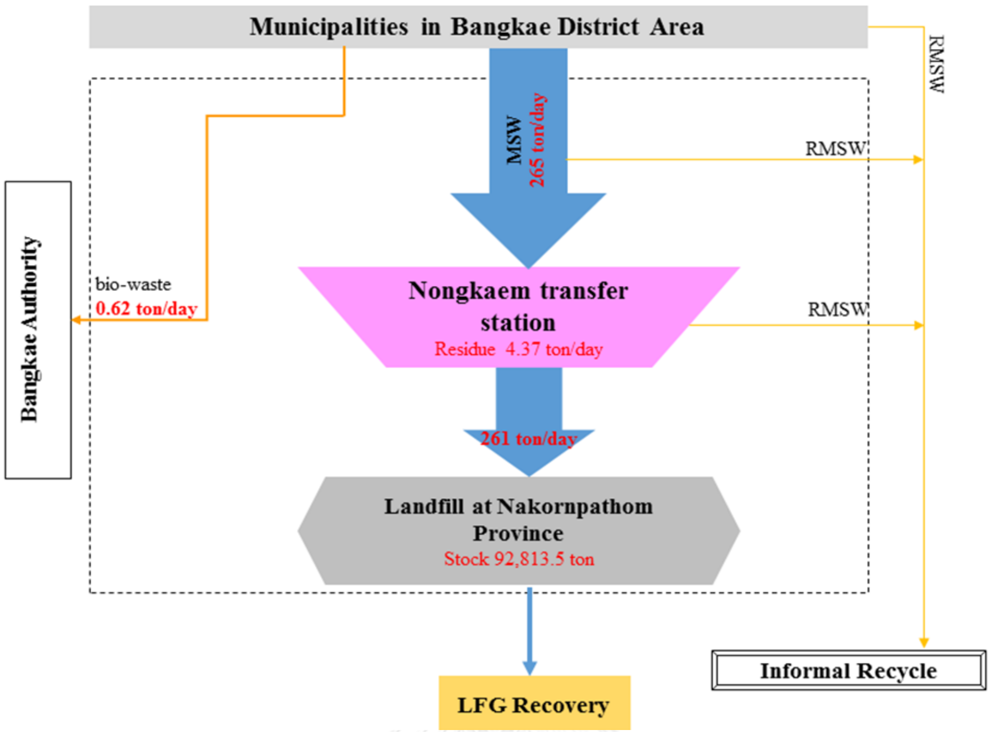


Figure 4-10 Diagram of MSW flows (ton/day) in Bangkok district area

The three of MFA diagram scales display in similar pattern. However, the local areas scale demonstrates more detail of the other scales. It appears as small fraction of bio-waste utilization at the local authority. The three scales of MFA highlight interesting areas which can be opportunities to improve Bangkok's MSW metabolism including the majority of landfilling flows, high quantity stock, various flows bio-waste utilization in local areas, huge landfilling from intermediate treatment by composting, and mostly RMSW is informal recycle.

The majority of Bangkok's MSW_c (86%) stored at landfills where major compositions of MSW_c consist of food wastes. While, food wastes without prior treatment in the European Union are banned in landfills. Enforcement of used up landfill spaces is also in effect (European Environment Agency, 2009; A. Pires, G. Martinho, & N.-B. Chang, 2011). Landfill usages can be reduced through sorting and prior treatment for used in generating renewable energy and composting before the final disposal (Arena & Di Gregorio, 2014; Cifrian, Galan, Andres, & Viguri, 2012; Font Vivanco et al., 2012). With the significant portion of the landfill containing food wastes, Bangkok's MSW should focus on improving prior treatment of food wastes before landfilling.

4.3 Current Bangkok's MSW Metabolism by Data Interpretation Based on Geographic Area

To demonstrate the distinct Bangkok's MSW metabolism on district territories, the quantity of MSW_c are displayed on geographic areas of Bangkok in term of an average (ton/day), per capita (kg/capita/day), and density (ton/km^2/day). The different terms of indicators are used to display the apparent MSW_c on geographic areas which contributes more understanding and efficient policies/ recommendation of current Bangkok's MSWM.

4.3.1 Term of Annual MSW_c

Figure 4-11 to Figure 4-16 illustrate maps of the quantity of MSW_c in Bangkok since 2008 to 2013. The category colors shown in five levels depending on the amount of MSW collected per day of 50 local areas can be described as follow: The red category is very high level (upper 232.3 ton/day). The orange category is high level (192.6-232.3 ton/day). The yellow category is medium level (152.8-192.6 ton/day). The green category is low level (113.1-152.8 ton/day). The hard green category is very low level (less 113.1 ton/day).

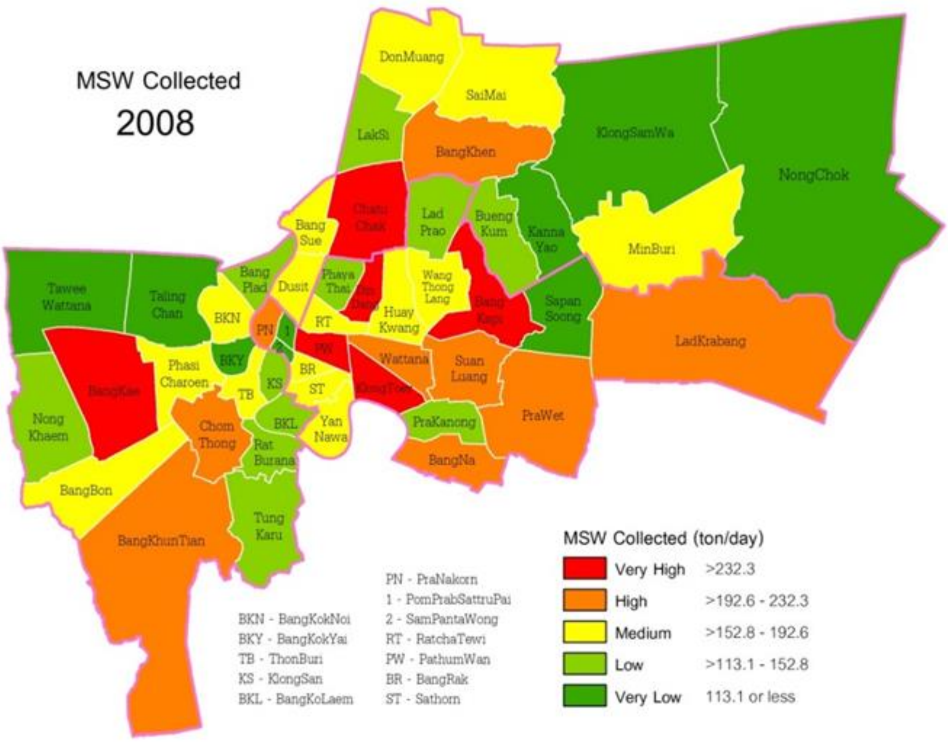


Figure 4-11 MSW_c (ton/day) in 2008

Some local areas have major changes in the quantity of MSW_c in some years. This is indicated by the change of categorys color of local areas based on different levels such as that of Bangkuntien, Bangkok Noi, and Bangkhen. In 2008 to 2010, the hot spot areas of high quantity MSW_c (ton/day) were six districts which are less than that of during 2011 and 2013 (7-11 districts). The districts at very high level (red category) after flooding crisis were Pathumwan, Wattana, and Ladkrabung districts which were not flooding areas. Their percentages of increasing MSW_c in flooding crisis year (2012) were 10-20 from 2010. However, Donmuang and Sai Mai districts were the hard flooding areas with increasing percentage of MSW_c of 34 and 17 percent, respectively, from that of 2010. These represent increases from medium level (yellow category) to a high level in 2012. In the later year, the percentage of MSW decreases by 25 and 5 percent, respectively. The four hot spot areas increasing in 2013 is in accordance with increasing trend of mass MSW_c (13%) as compared with 2010. The different category areas in 2012 and others year before shows flooding effect increasing MSW_c. In addition, income by tourist increased 46% in 2013. Income BMA by tax index from estate construction along with BTS and MRT lines was 5.98% compared with 2012 (Office Depot Bangkok, 2014). It can be conclusion that the reasons of increasing hot spot areas in 2013 are not only flooding disaster effect in the last three months of 2011, but economic growth, urbanization, and non-population were also. Interestingly, the flooding areas are not the only sites of MSW increases, but some areas without flooding also have to increase MSW.

The hot spot areas since 2008 include Bangkae, Klongtoey, and Bangkapi districts. Bangkapi had the highest MSW_c. The districts that have stable level of MSWc since 2008 include: at medium level areas (yellow category) were Sathorn, Yannawa, Dusit, and Minburi districts; at low level areas (soft green category) were Ratburana, Bangkolaem, Klongsan, and Bangplad districts; at very low level (hard green category) were Tawee Wattana, Bangkok Yai, Pomprab Sattrupai, Sampantawong, and Nongchok districts. It should be noted that the districts with high level (orange category) vary from year to year since 2008. The results of MSW_c territory show that 32% of local areas (16 districts) had been stable, and 58% (34 districts) had varied quantitative level for six years.

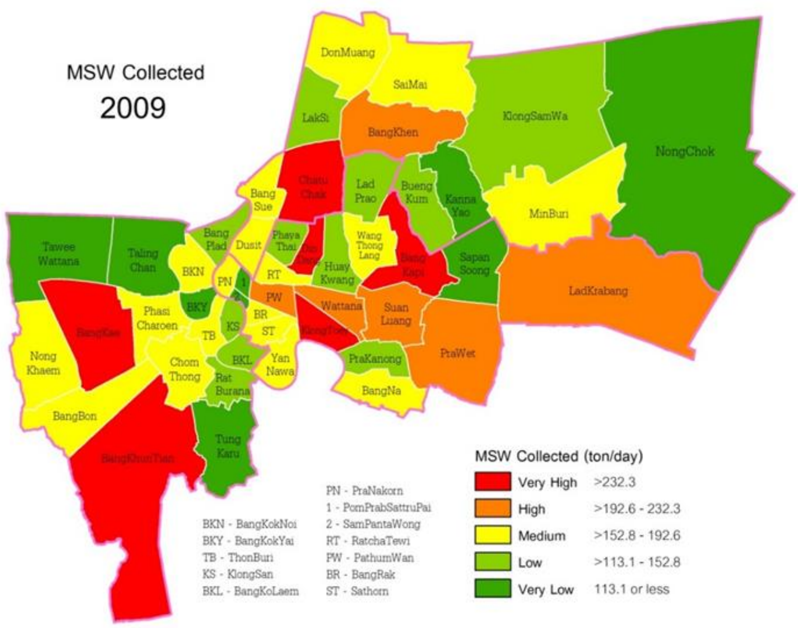


Figure 4-12 MSWc (ton/day) in 2009

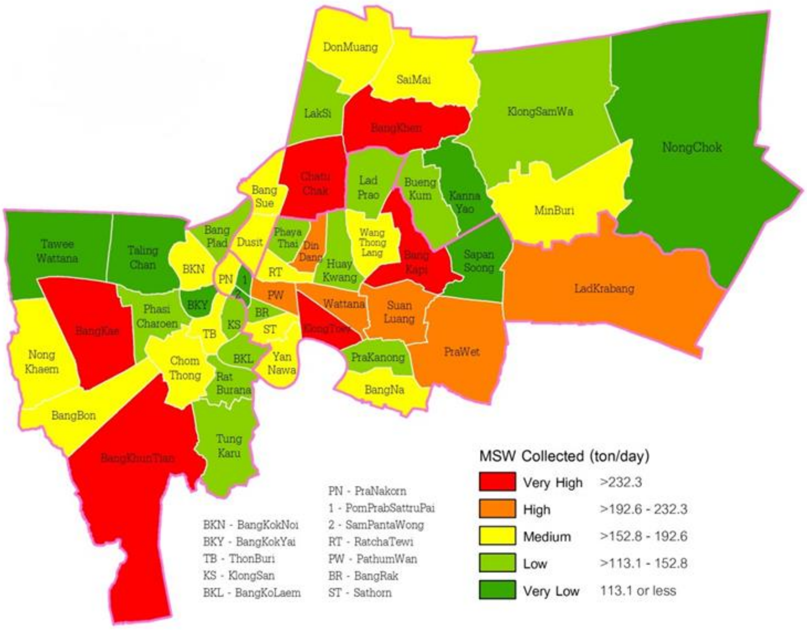


Figure 4-13 MSW$_c$ (ton/day) in 2010.

Considering population trend and MSW$_c$ in 2013, MSW$_c$ was increasing quite significantly in some districts, while the registered population was stable. Wattana, Lardkrabung, and Prawet districts, for instance, had the percentage MSW increased by 8, 8, and 12 percent from that of 2012, respectively. Klongsamwa district was an exception where increasing population trends with increasing MSW at 31% with MSW$_c$ quantity increases by 13%. The trend of MSW$_c$ quantity in 2013 increased quite significantly in some districts, mostly urban fringe which are mostly residential areas. This could be caused by the increases in non-registered population and improvement of public transportation to the suburbs of Bangkok. In addition, the numbers of household and condominium in Bangkok increased by 3% and 62% in 2013, respectively. The increase of MSW generation of districts followed the same trend of the rises of a condominium in those areas. The category of MSW_c at the high level is mostly in commercial and government institute zones. Interestingly, while Pomprab Sattrupai, Bangrak, and Sampantawong districts were commercial areas, they, however, had a low level of MSW_C. In contrast, Bangkae, Lardkrabung, and Bangkuntien, which were mostly rural or agriculture areas with low-density residential, had a very high MSW_c level. Mazzanti M. et al., (2008) reported that commercial areas has a high volume waste. It contrasts with Bangkok's MSW_c quantity on geological that is not all commercial areas are high MSW_c quantity.

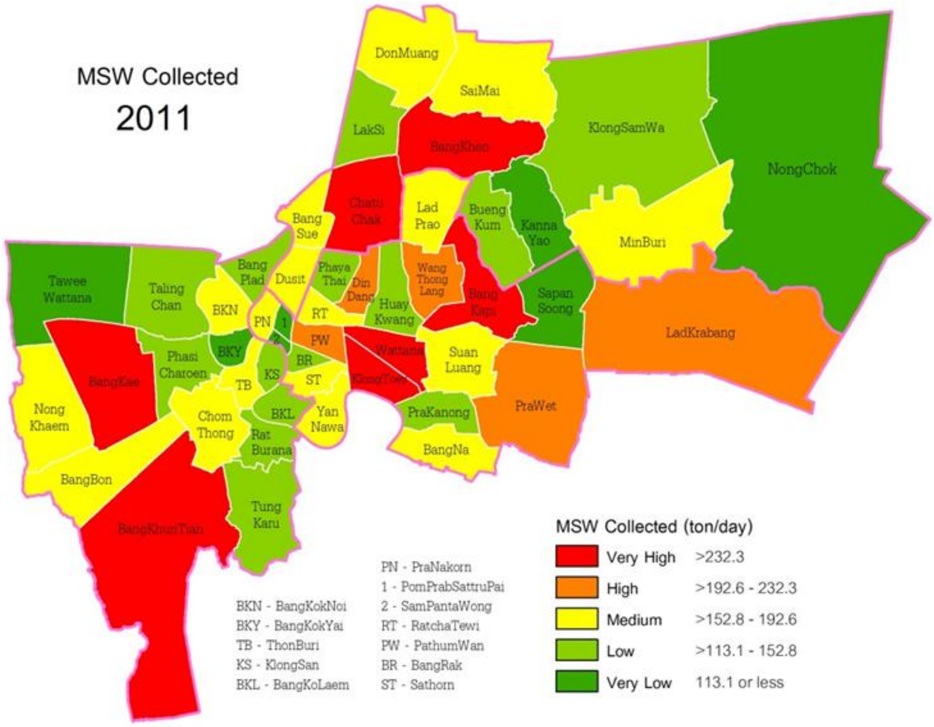


Figure 4-14 MSW_c (ton/day) in 2011.

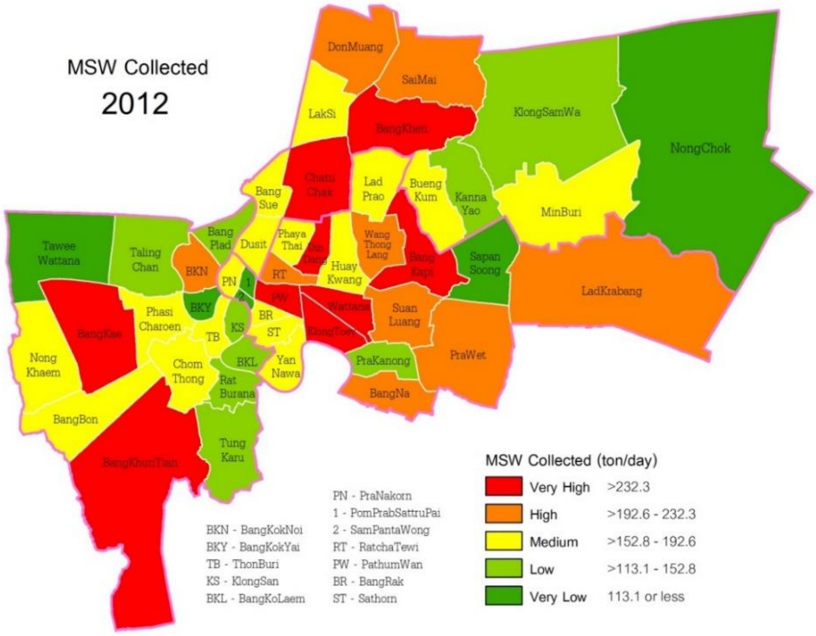


Figure 4-15 *MSW_c (ton/day) in 2012.*

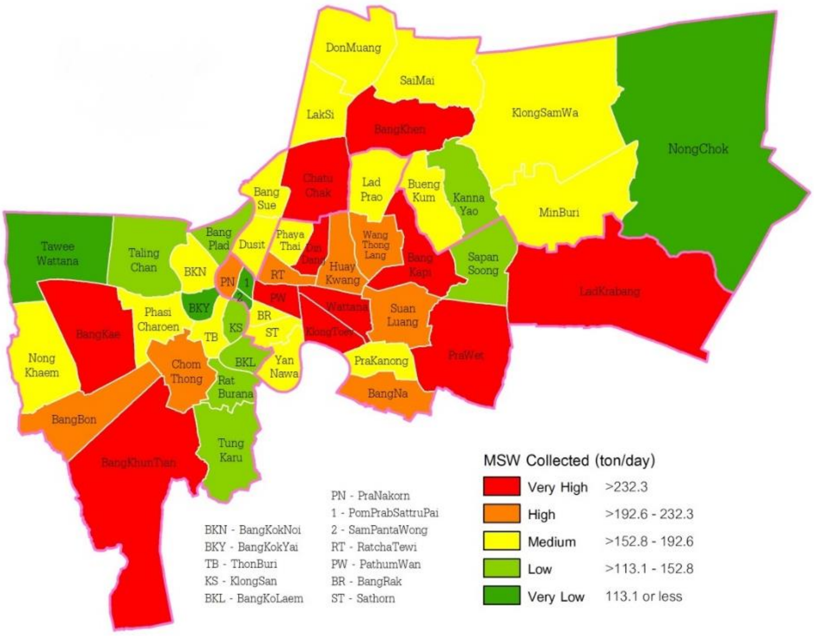


Figure 4-16 *MSW_c (ton/day) in 2013.*

4.3.2 Term of MSW_c per Capita

Figure 4-17 to Figure 4-22 present maps of the quantity of MSW_c per capita (kg/capita/day) in Bangkok since 2008 to 2013. The category colors displayed in 5 levels depending on quantity of MSW collected per capita per day of 50 local areas include: red category indicating very high level (upper 1.45 kg/capita/day), orange category indicating high level (1.16-1.45 kg/capita/day), yellow category indicating medium level (0.87-1.16 kg/capita/day), green category indicating low level (0.58-0.87 kg/capita/day), and hard green category indicating very low level (less 0.58 kg/capita/day).

The MSW_c per capita category is quite different from MSW_c. The hot spot areas are mostly located in the center of Bangkok, which is mostly commercial, government institutes, and Thai art cultural conservation zones. The districts that were hot spots since 2008 included Phranakorn, Bangrak, Pathumwan, Klongtoey, and Wattana. The location of them are in the center of Bangkok which the hotels rating 1-5 are in here. It can be used as the index of non-registered population such as tourist which is increasing trend. The tourist can affect the quantity MSW_c; 1% increasing tourist can increase waste generation 0.282% (Mateu-Sbert, Ricci-Cabello, Villalonga-Olives, & Cabeza-Irigoyen, 2013). The accuracy number population may impact the reliable result of hot spot areas, due to uncertainly non-registered population. However, the hot spot areas since 2008 is the same type land use and activities impact to MSW_c quantity.

After flooding late in 2011, the hot spot areas increased from previously a medium level included the Ratchatewi district, which, however, it was not flooding areas. It increased by 24% (0.3 kg/capita/day) from 2010, which, should be noted that, was not a maximum increasing area. A maximum increasing area was Donmuang (37%). It is similar to the MSW_c trend, and category that districts at very high level (red category) were not only flooding areas but also; non-flooding areas were also increasing MSW_c. Both indicators of mass MSW_c indicated that Donmuang had the highest increase of the 50 districts after flooding disaster. Considering the quantity in the North of Bangkok areas category after flooding, it shows that mostly they are in high level. This is quite different from MSW_c per year category that up to at very high level.

The areas with stable level of MSW_c per capita since 2008 were as following: at high level were Sampantawong, Yannawa, Phayathai, and Chatuchak; at medium level were Bangkuntian, Klongsan, Pompabsattrupai, and Prakanong; at low level were Taweewattana, Nongkhaem, Bangkae, Talingchan, Phasicharoen, Chomthong, Bangkok Yai, Thonburi, Ratburana, Tungkru, Bangsue, Bangkhen, Ladpao, Buengkum, Sapansoong, and Minburi; at very low level was Nongchok. This shows that most districts (60%) had a stable level of MSW_c per capita since 2008. Consideration land use/ activities, it shows most of them locate in fringe of Bangkok.

Considering the year 2013, most of the hot spot areas (at very high level) were not residential areas. They were commercial, government institutes, and Thai art cultural conservation areas. The results are similar with categorys of MSWc and MSWc per capita territory indicators that residential or high density population living was not the only factor of high MSW generation. The individual activities of local areas also may have impacts on MSW generation, for instance, Pathumwan, Huaykwang, Klongtoey, Wattana, and Bangrak which were not a high density of residential areas.

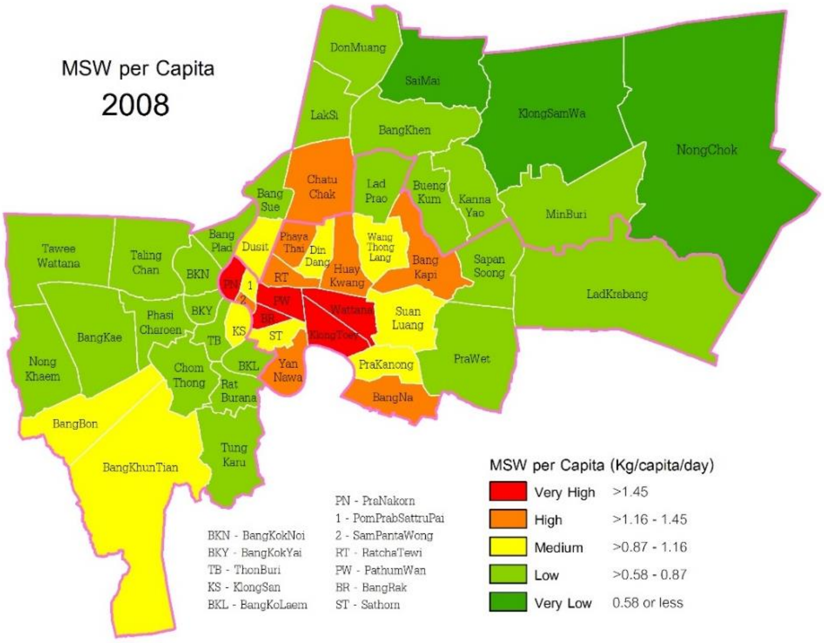


Figure 4-17 MSW_c per Capita (Kg/capita/day) in 2008

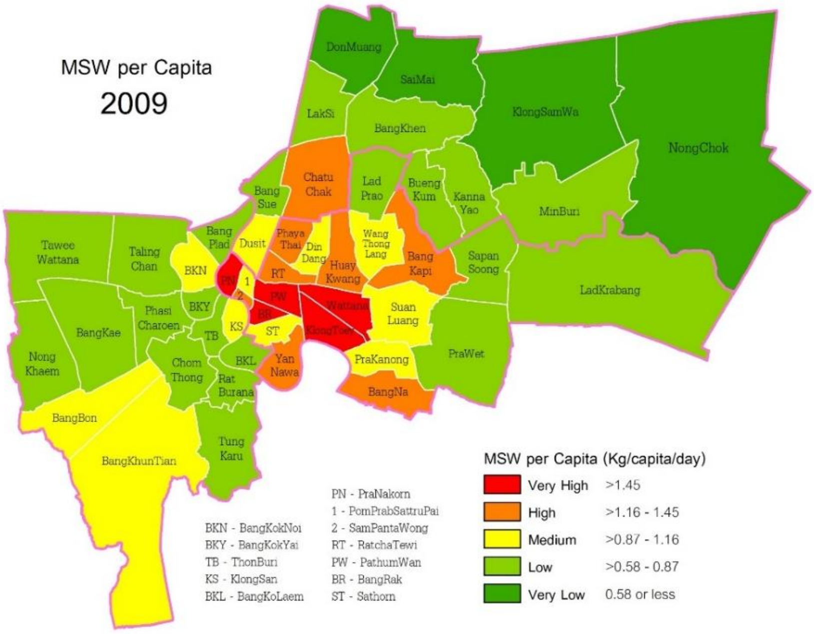


Figure 4-18 MSW_c per Capita (Kg/capita/day) in 2009

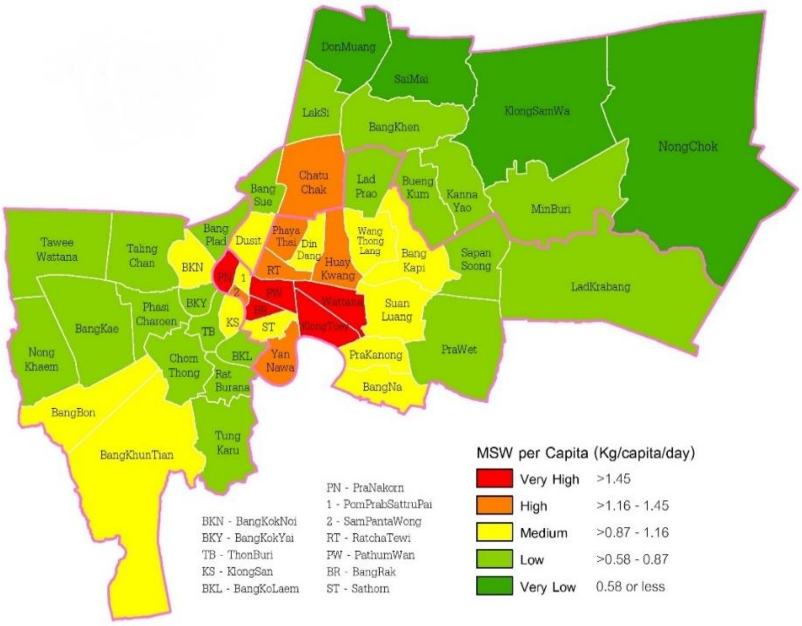


Figure 4-19 MSW_c per Capita (Kg/capita/day) in 2010

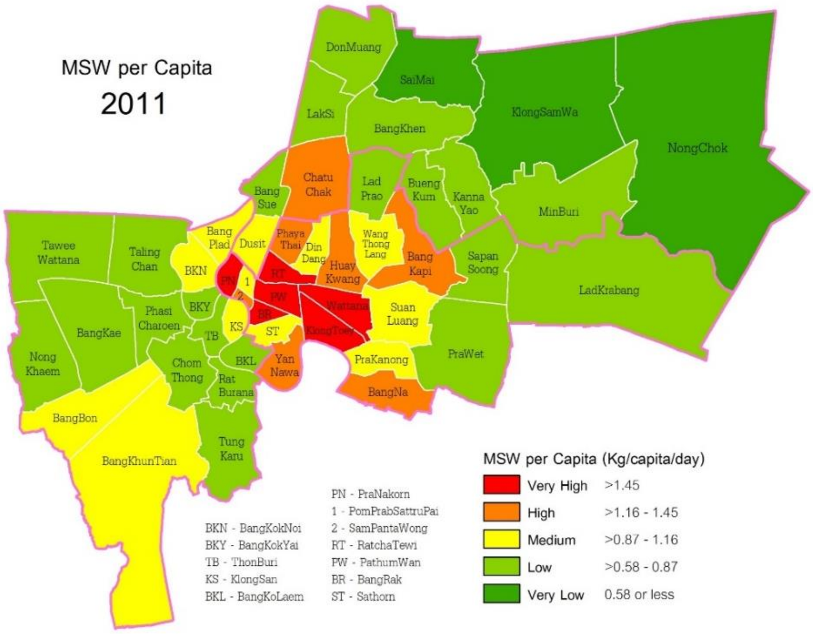


Figure 4-20   *MSW$_c$ per Capita (Kg/capita/day) in 2011*

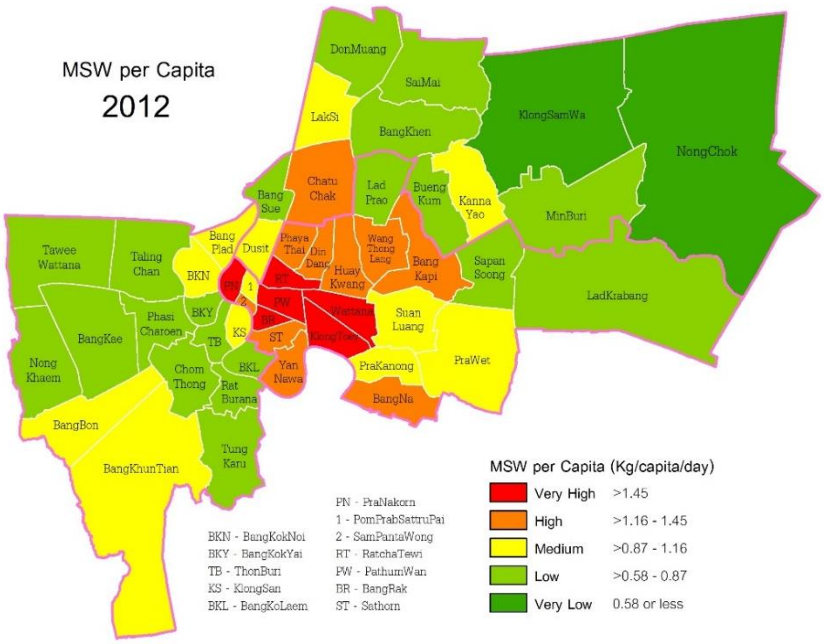


Figure 4-21   *MSW$_c$ per capita (Kg/capita/day) in 2012*

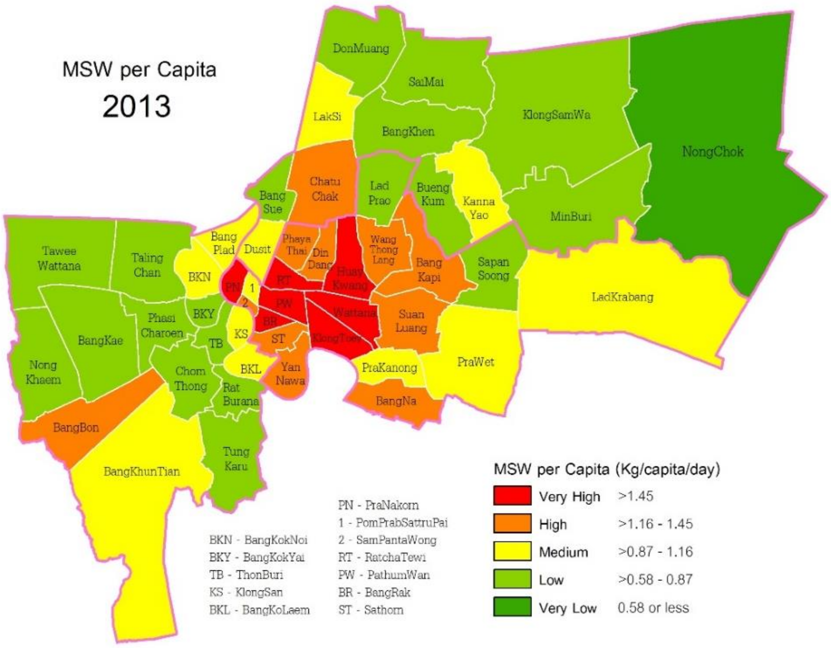


Figure 4-22 *MSW_c per capita (Kg/capita/day) in 2013*

4.3.3 Term of Density (MSW_c per Area)

The indicator MSW_c density on geographic areas (as shown in Figure 4-23 to 4-28) is similar to MSW_c per capita which disperse from the very high level in the center of urban to lower level in the suburb areas. The level of MSW_c density category was quite stable since 2008. It may be because of constant areas size and small areas size with a high density of MSW_c, for instance, Pomprabsattrupai, Sampantawong, and Bangrak. 45 districts (90%) had stable category level since 2008 as shown in Table 4-1. However, flooding crisis had impacts in some districts which were not in the flooding areas similar to that of the other two indicators (MSW_c annual and MSW_c per capita).

Beside, non-registered population and economic can be cause of the hot spot areas from most them in the center zone of Bangkok.

Table 4-1 Level of MSW intensity in all districts since 2008

Level	District
Very high level	Phranakorn, Pomprabsattrupai, Sampantawong, Bangrak, Pathumwan, Ratchatewi, and Dindang
High level	Thonburi, Klongsan, Satorn, Wattana, and Dusit
Medium level	Bangplad, Bangkok Yai, Bangkolaem, Yannawa, Prakanong, Bangna, Bangsue, Chatuchak, Huaykwang, Wangthonglang, and Bangkapi
Low level	Nongkhaem, Bangbon, Bangkae, Talingchan, Phasicharoen, Chomthong, Ratburana, Tungkru, Laksi, Donmuang, Sai Mai, Bangkhen, Ladprao, Buengkum, Kannayao, Sapansoong, Prawet, and Minburi
Very low level	Klongtoey, Phayathai, and Suanluang

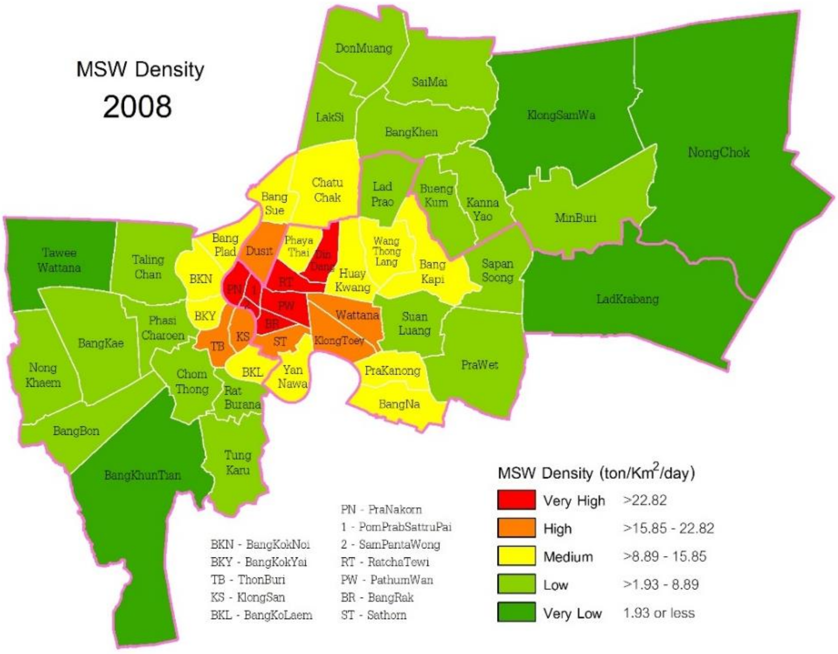


Figure 4-23 Density MSW_c (ton/Km^2/day) in 2008

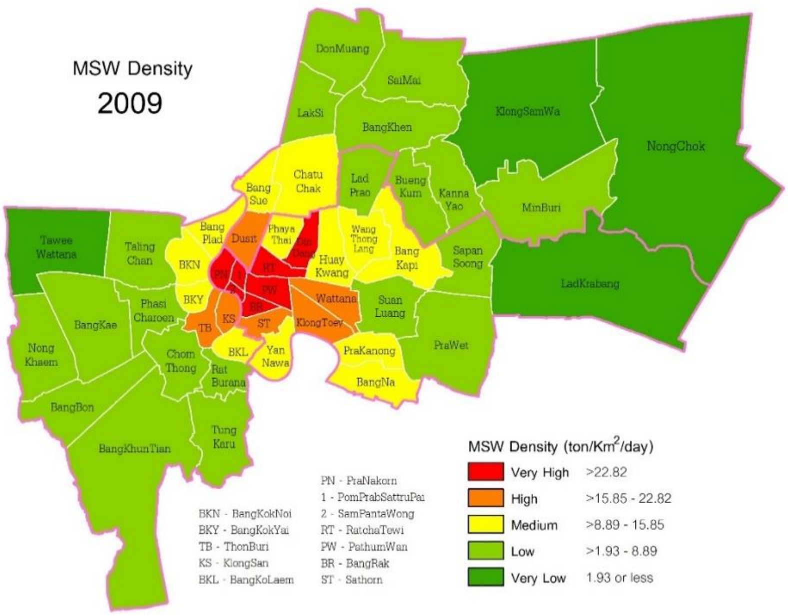


Figure 4-24 Density MSW_c (ton/Km^2/day) in 2009

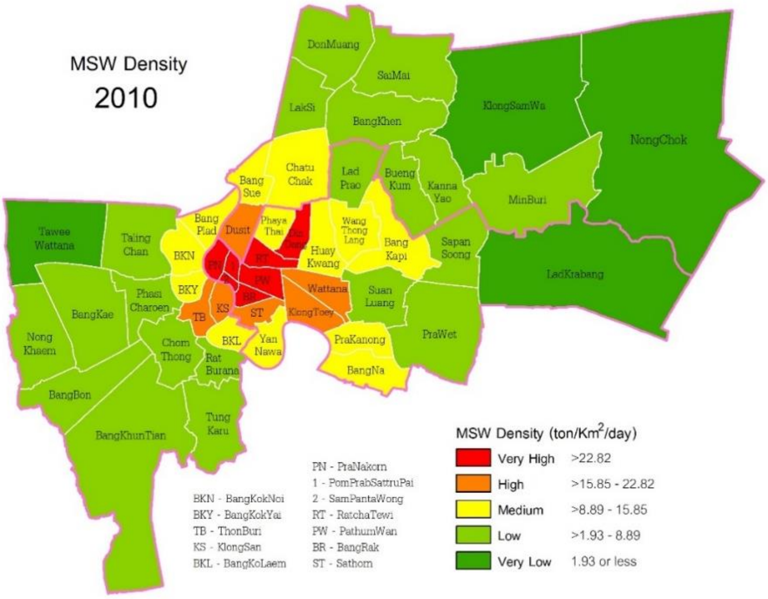


Figure 4-25 Density MSW_c (ton/Km^2/day) in 2010

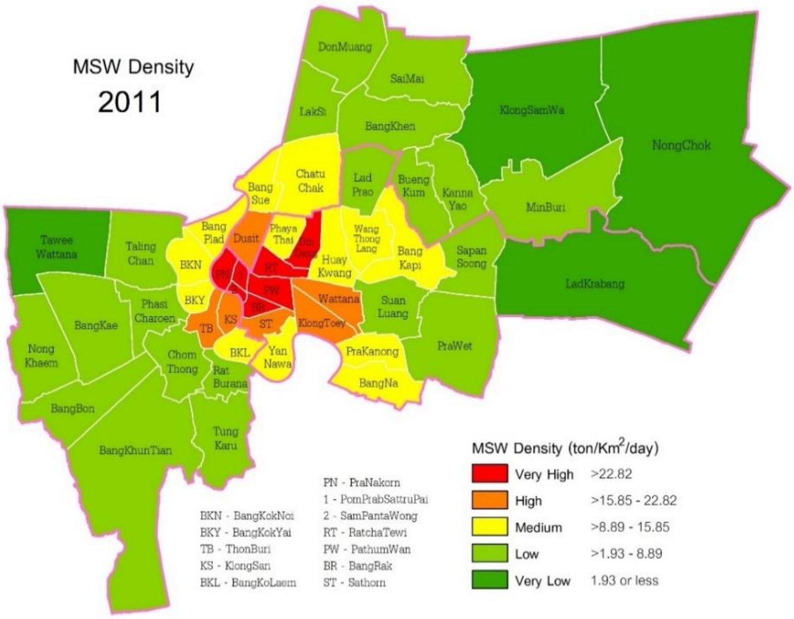


Figure 4-26 Density MSW_c (ton/Km^2/day) in 2011

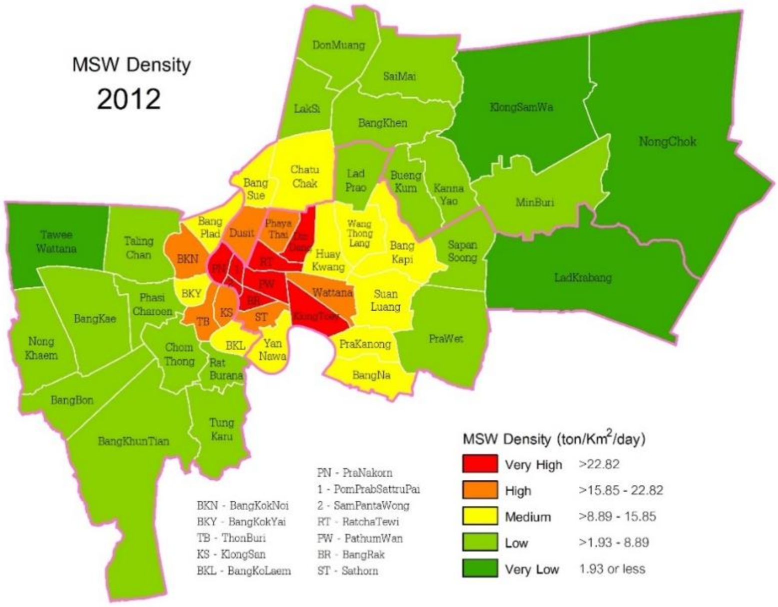


Figure 4-27 Density MSW_c (ton/Km^2/day) in 2012

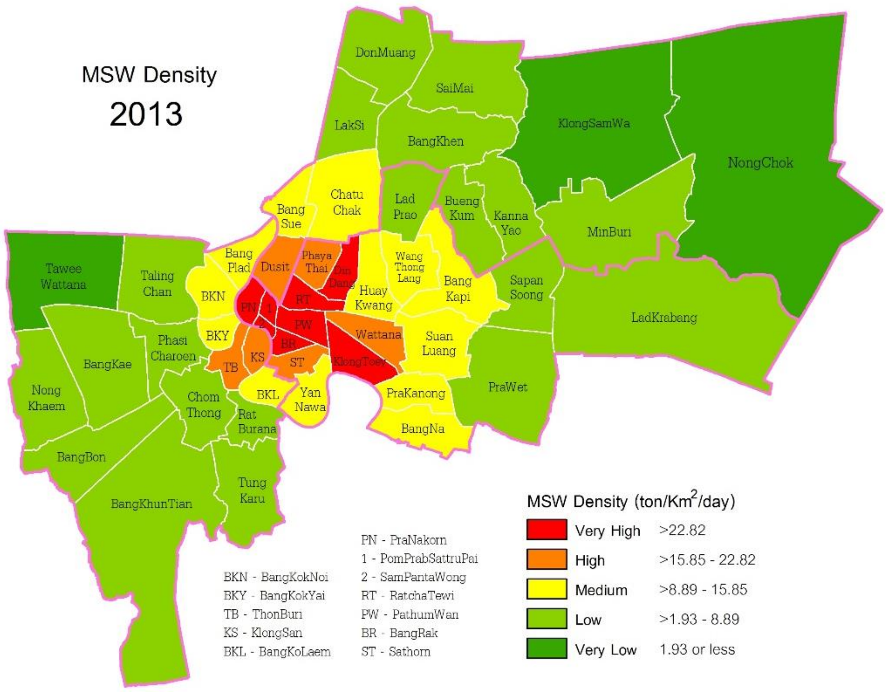


Figure 4-28 Density MSW_c (ton/Km^2/day) in 2013

Out of the 50 districts, the Pathumwan district is the hot spot area as indicated by all indicators in 2013. The category indicators on geographic areas accentuate the areas that should be attended and contributes to informing the unique characteristic of local areas in different time frame.

In summary, key findings of Bangkok's MSW metabolism analysis include:

- The trend of MSW_c gradually increases for six years, even though; registered-population had been stable. This may be caused by non-registered population, flooding disaster impacted, urbanization, and economic growth to MSW_c quantity. Because of they have increasing trend.
- Even though the local areas implement waste utilization and a transfer station has a composting plant, landfilling is still the highest flows with wastes sent directly to landfill without prior treatment.
- The MFA of local area scale provides a basis to explore the opportunity to decentralize composting by the local authority.

- Different terms of indicators on Bangkok's geographic area displays different dispersion of hot spot areas geographic.
- The MSW_c geographic areas show that the hot spot areas of MSW_c per capita and area (density) indicators are gather at the center zone (commercial and government institute areas) of Bangkok. It also demonstrated that activities of individual local areas also may have an impact on MSW generation. On the other hand, the hot spot areas of MSW_c per year are scattered and located mostly in urban fringe which is typically residential areas. Improvement in public transportation and rises of condominium construction contributes to the hot spots of MSW_c.
- Many districts have a stable level of indicators of MSW_c since 2008. Pathumwan is the only area that is the hot spot based on all indicators.
- Not only the 2011 flooding areas had increases of MSW_c, but some non-flooding areas also had increases of MSW_c. It can claim that the

urbanization and non-registered population are the factor of Bangkok's MSW_c.

The result of Bangkok's MSW metabolism study can help improve our understanding of MSWM system and identifying hot spots of mass MSW_c in various MSWM stages and areas. The results can be used to develop a suitable direction for improvements that supports sustainable urbanization growth.

CHAPTER V
PERFORMANCE ASSESSMENT OF BANGKOK'S MSW METABOLISM

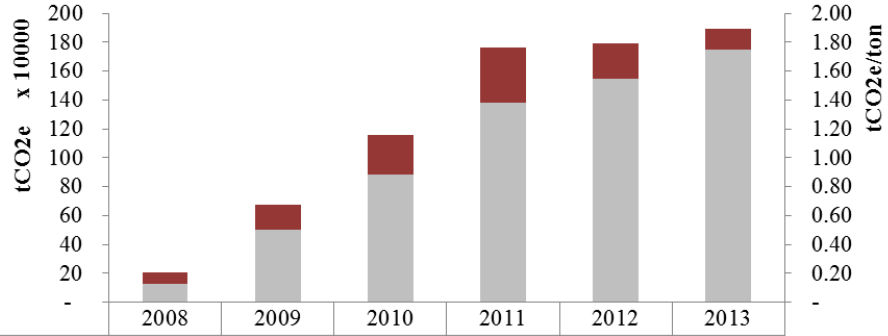
Current Bangkok's MSW metabolism and sub-process evaluation were analyzed using MFA and GIS to gain a better understanding of options for enhancement of the waste management system. The parameters for performance assessment included emission and energy consumption in term of net and intensity units. These are key indicators for the waste sector. The information regarding energy and carbon emission intensity of MSWM helps to assess and identify the level of burden on the environment. Finally, hot spot analysis was implemented to define the problem stages of MSWM and areas in Bangkok's MSW Metabolism.

5.1 Assessment of Bangkok's MSW Metabolism Performance

GHG emission and energy consumption are key parameters to assess the management performance. These parameters are displayed in flow analysis concept. GIS is used to display levels of a burden to the environment in sub-process. In addition, parameters benchmarking was performed to compare the MSWM performance with that of other countries and to identify the level of Bangkok's MSWM performance.

5.1.1 GHG Emission

Figure 5-1 presents the trend of GHG emission from MSW management system in Bangkok. It should be noted that CEI (tCO_2e/ ton) gradually increases between 2008 and 2013. Interestingly, CEI in 2012 only slightly increases in level from that of 2011. This is probably due to increases in the effectiveness of two CDM projects at Chachoengsao and Nakhon Pathom landfill sites. This result confirms that CDM associates with emission reduction (Michael Lazarus, 2013). The total GHG emission and CEI in 2013 is 1,748,115 tCO_2e and 1.89 tCO_2e/ ton, respectively.



	2008	2009	2010	2011	2012	2013
Intensity of Total emission (tCO2e/ton)	0.21	0.68	1.16	1.77	1.79	1.89
Total emission (tCO2e)	128,652	502,576	882,923	1,382,512	1,546,060	1,748,115

Figure 5-1 Trend of GHG Emission from MSW management system in Bangkok.

5.1.1.1 Emission Flow Analysis (EFA)

Figure 5-2 presents EFA of Bangkok's MSW metabolism in 2012. Most of the emission can be classified as indirect and direct emission (99.83% or 1,537,665 tCO_2e) from transportation and landfill sectors. Emission at the disposal stage was expressed as emission reduction because CDM projects were implemented at both of landfill sites (Chachoengsao and Nakornpathom). The emission reduction is equal to 1,538,978 tCO_2e which is derived from the offset of electricity generation and flare of excess landfill gas (LFG) processes (Affairs, 2006). Actual emission exhibits in the EFA (Figure 5-2) that is at disposal stage shows the actual instead of reduction emission from operating CDM projects.

The On Nuch transfer station has the highest daily emission from the waste collection (83 tCO_2e/day), followed by Nongkhaem (53 tCO_2e/day), and Sai Mai (41 tCO_2e/day) transfer stations. However, it should be noted that distance to the service area of On Nuch transfer station region is the shortest. The CEI is interesting because emissions from the collection systems in three regions based on transfer station's geographic areas were different, but their CEI were the same (0.2 tCO_2e/ton). Most of the emission at the transfer stations is direct emission from backhoes except at On Nuch transfer station which some portion can be classified as indirect from composting process (7 tCO_2e/day). For the On Nuch transfer station, direct emission was 98% (298 tCO_2e/day) with the majority came from LFG (51% or 151 tCO_2e/day) of residue composting.

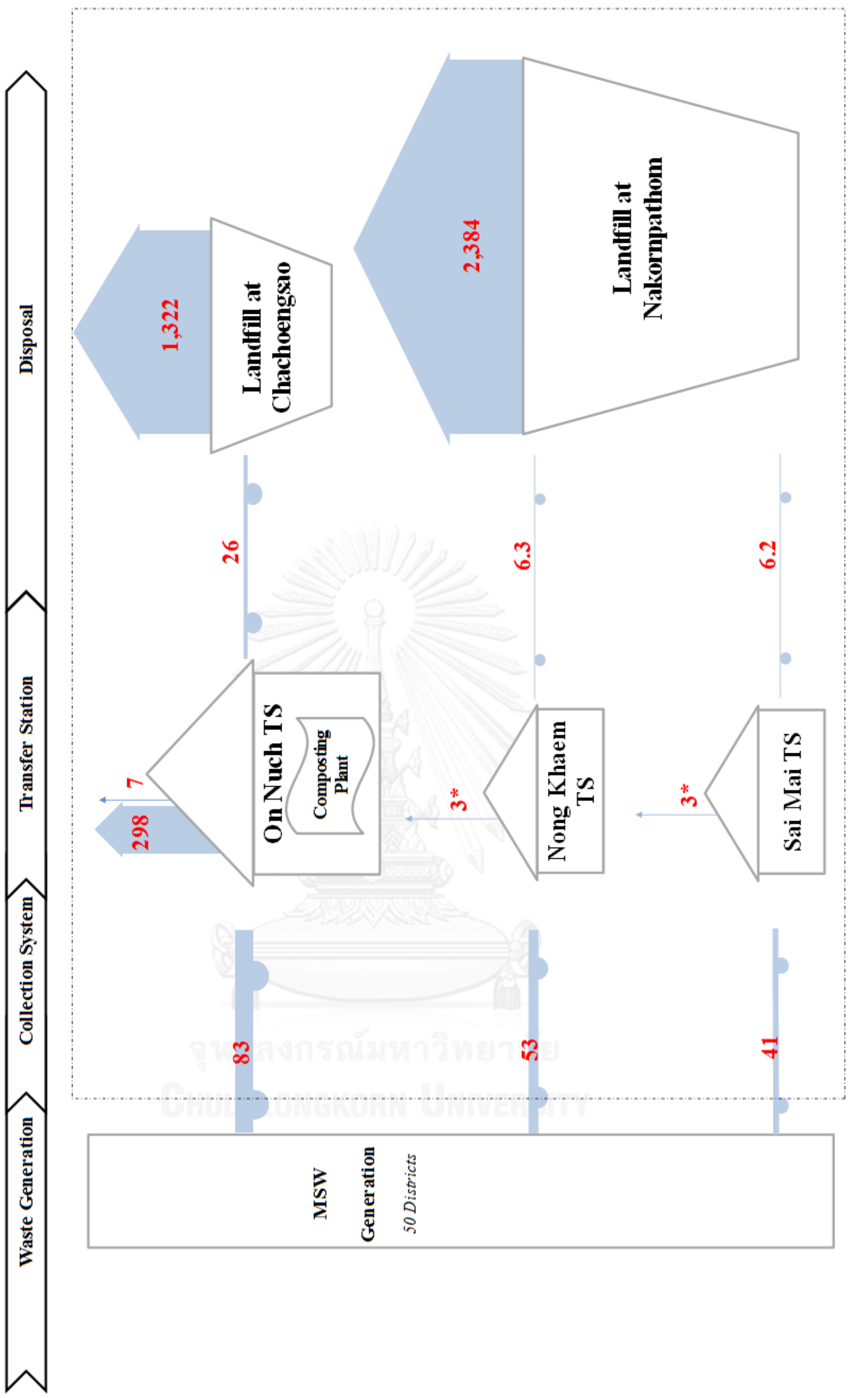


*Figure 5-2 Emission Flow Analysis (EFA) of Bangkok's MSW_c Management (tCO_2e/day) Note: The sign * is estimation value. The representative color flows are direct emission and indirect emission.*

After MSW was collected at the transfer stations, transportation of waste to landfills (WTL) is the next step. Comparing emission of WTL from the three transfer stations, WTL at On Nuch transfer station was the highest (26 tCO_2e/day) because of the longest distance between the transfer station to the disposal site (on average 10,690 km/day round trip). While the average distance of WTL at Nongkhaem and Sai Mai transfer stations to the disposal sites are 2,630 and 2,454 km/day, respectively. However, emission from landfills remains the largest emission stage of Bangkok's MSW management.

5.1.1.2 Localize Performance of MSWM by Emission Indicator

Figure 5-3 to 5-6 shows the GHG emission of Bangkok's MSWM since 2008. They are divided in to five discrete level including; very high level (red contour) (more than 35,415 tCO_2e); high level (orange category) (25,573 - 35,415 tCO_2e); medium level (yellow category) (15,732 - 25,573 tCO_2e); low level (soft green) (5,891 - 15,732 tCO_2e); and very low level (hard green) (less than 5,891 tCO_2e). The trend of net GHG emission during 2008-2013 gradually transforms at very low level (mostly hard green category in all local areas) to a higher level due to landfill gas phenomenon. LFG does not generate in immediately after bury MSW_c in the landfill. As a result, in 2013 most areas are designated in red and orange categorys. Interestingly, areas with a very high level of mass MSW_c also have very high level of net emission.

Consideration of transfer station geographic in 2013, On Nuch region was the highest GHG emission zone according to the EFA result (Figure 5-2). Only five districts of On Nuch TS geographic area fall in high level (Bangrak, Satorn, Ladprao, Phayathai, and Prakanong). Two districts are in medium level (Pomprabsattrupai and Sapansoong) and Sampantawong district at a low level. The highest emission in On Nuch TS regions is caused by the composting plant, collection system, and WTL. While Sai Mai and Nongkhaem regions are mostly high levels (13 districts); with five districts are at a very high level (Bangkhen, Chatuchak, Bangkhuntian, Bangkae, and Bangbon districts). However, just two districts of 50 Bangkok's geographic area are at a low level that is Sampantawong and Bangkok Yai. It is because they are small area than others, and it may emit less in term of the collection system and WTL.

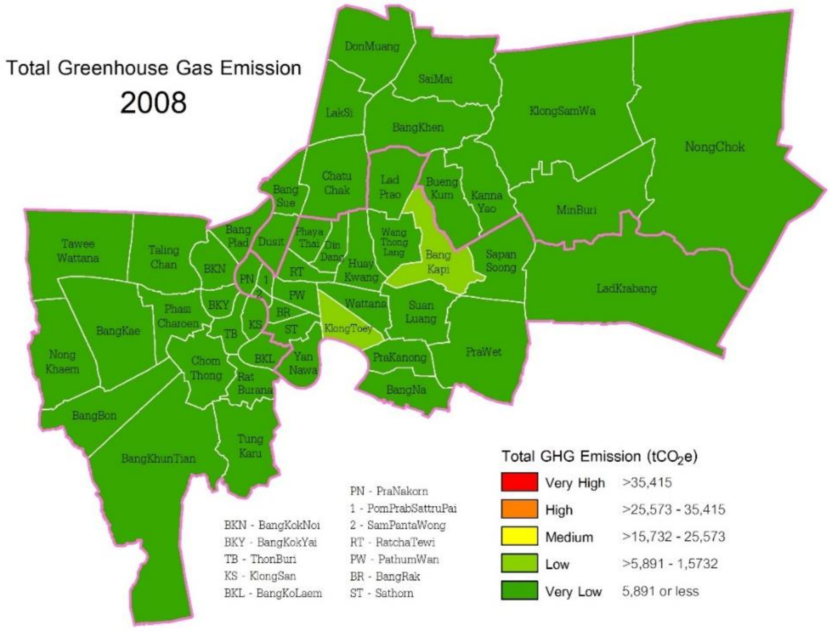


Figure 5-3 Bangkok's MSWM Emission (tCO_2e) in 2008

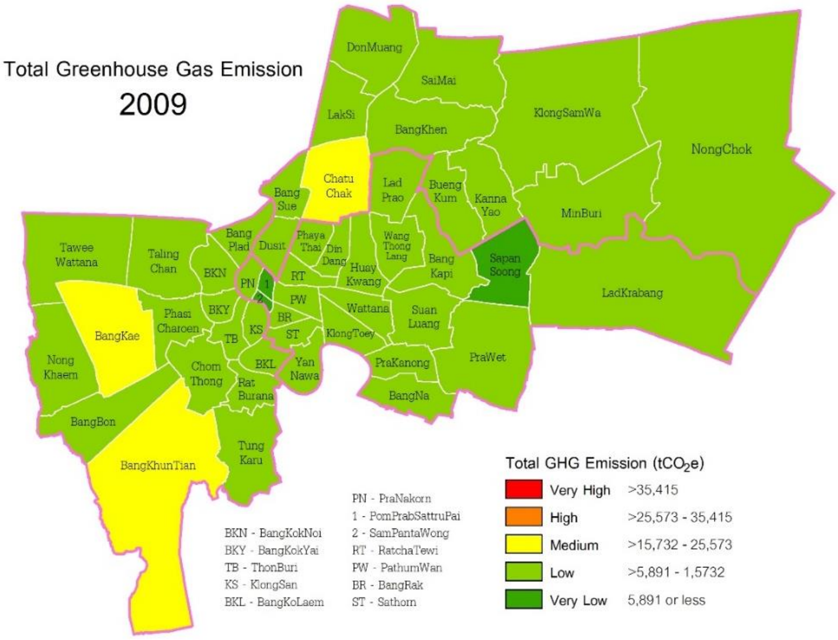


Figure 5-4 Bangkok's MSWM Emission (tCO_2e) in 2009

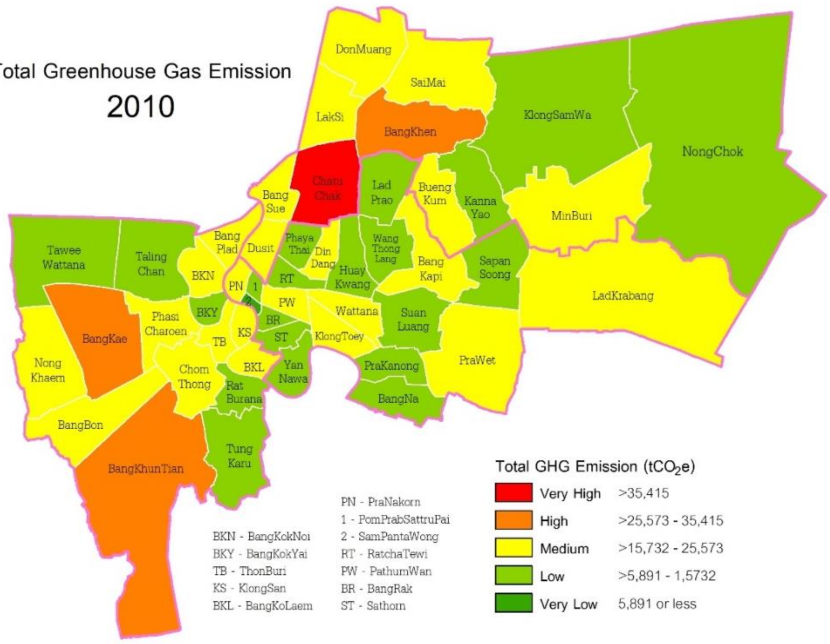


Figure 5-5 Bangkok's MSWM Emission (tCO_2e) in 2010

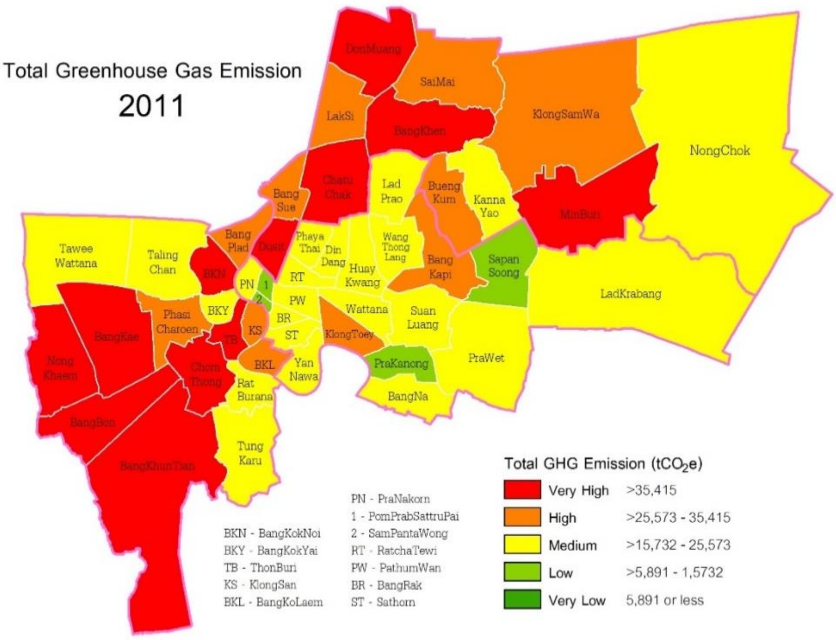


Figure 5-6 Bangkok's MSWM Emission (tCO_2e) in 2011

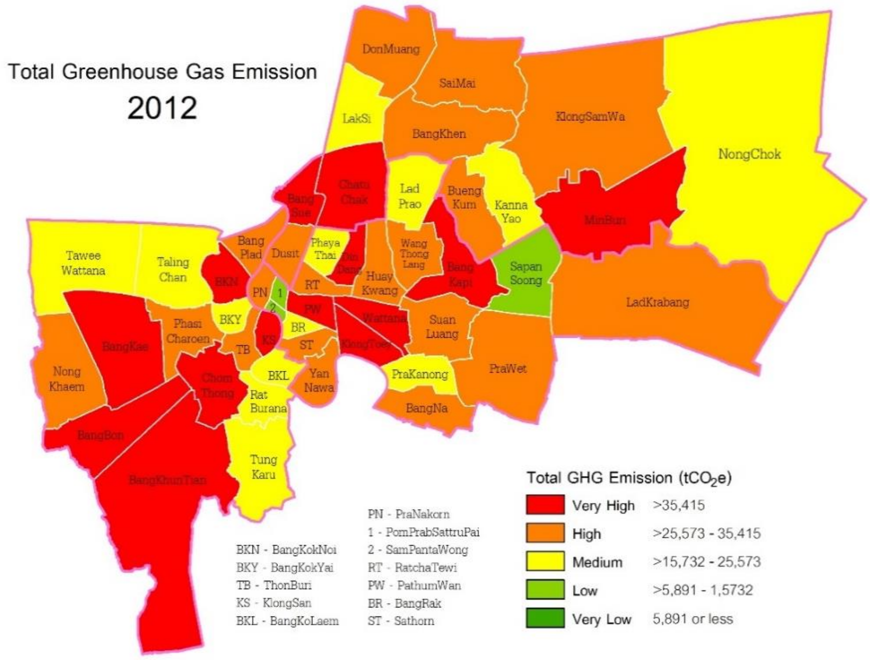


Figure 5-7 Bangkok's MSWM Emission (tCO_2e) in 2012

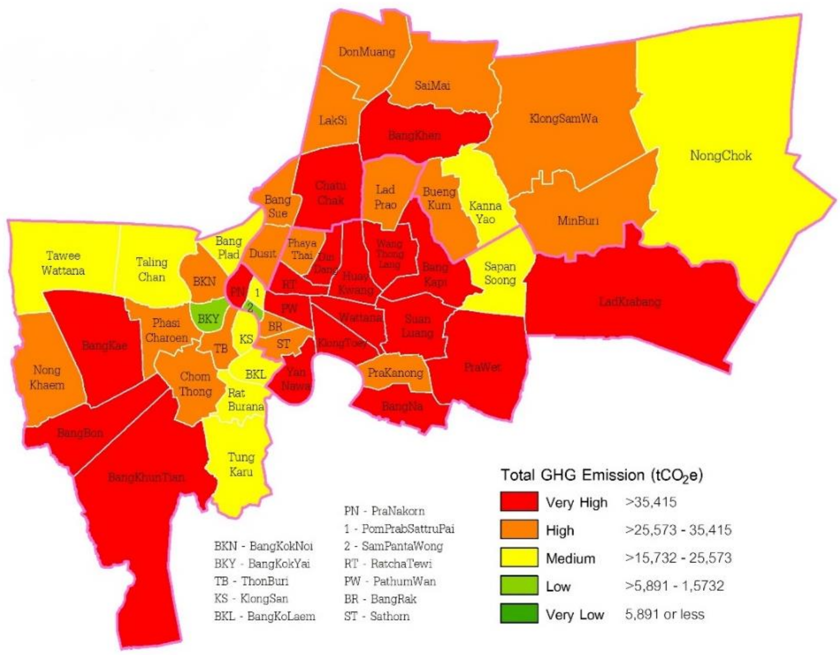


Figure 5-8 Bangkok's MSWM Emission (tCO_2e) in 2013

Figure 5-9 to 5-11 present CEI of Bangkok's MSWM since 2011. They aredivided in to five levels including: very high level (red category) (more than 0.61 tCO_2e/ton); high level (orange category) (0.53-0.61 tCO_2e/ton); medium level (yellow category) (0.45-0.53 tCO_2e/ton); low level (soft green category) (0.38-0.45 tCO_2e/ton); and very low level (hard green category) (less than 0.38 tCO_2e/ton).

The trend CEI of Bangkok's MSWM since 2011 is in contrast with that of the net emission (Figure 5-6 to 5-8) that gradually transforms from very high level to lower level with an exception at the On Nuch TS region. This is probably due to decreasing of net emission and quite a stable level of MSW_c on Nongkhaem and Sai Mai regions. While the net emission decreasing as a result of CDM project, the net emission of On Nuch TS region increases by landfilling from the composting plant without recovery LFG.

Considering CEI in 2013, it is obvious that the CEI of On Nuch TS region is the highest. All districts in On Nuch TS region are at high level, while districts in Nongkhaem and Sai Mai regions are mixes of medium and low levels with an exception of Chatuchak district which is at very low level. This is because the regions have the highest MSW_c but low emission of the collection system and WTL. However, it has high MSW_c than another district; it is quite lower emission in the collection system. Interestingly, the large MSW_c volume can be insignificant with high emission if MSW_c

has a good management such as good management of collection system and WTL, suitable treatment technology.

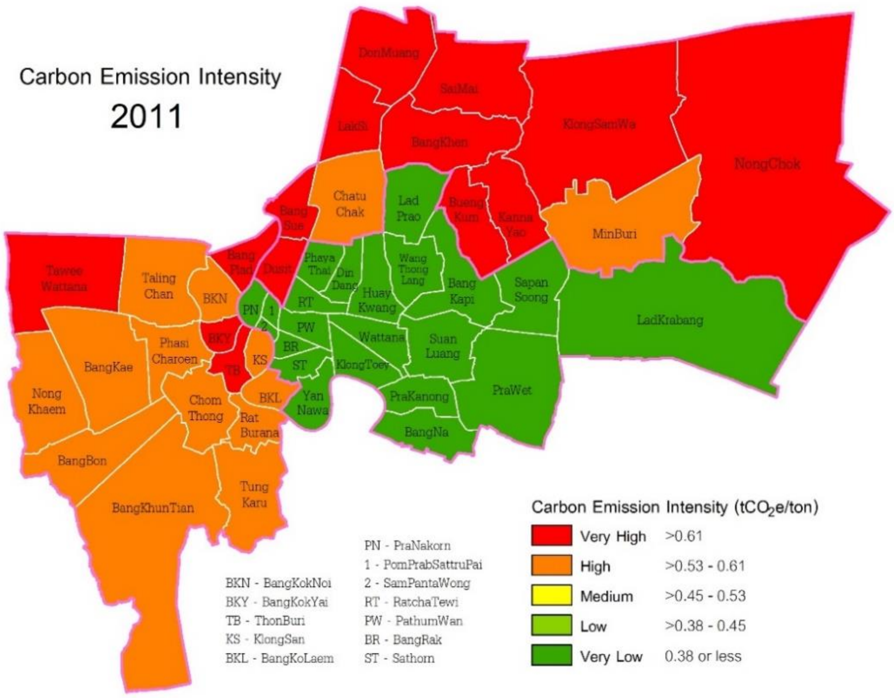


Figure 5-9 Bangkok's MSWM Carbon Emission Intensity (tCO_2e/ton) in 2011

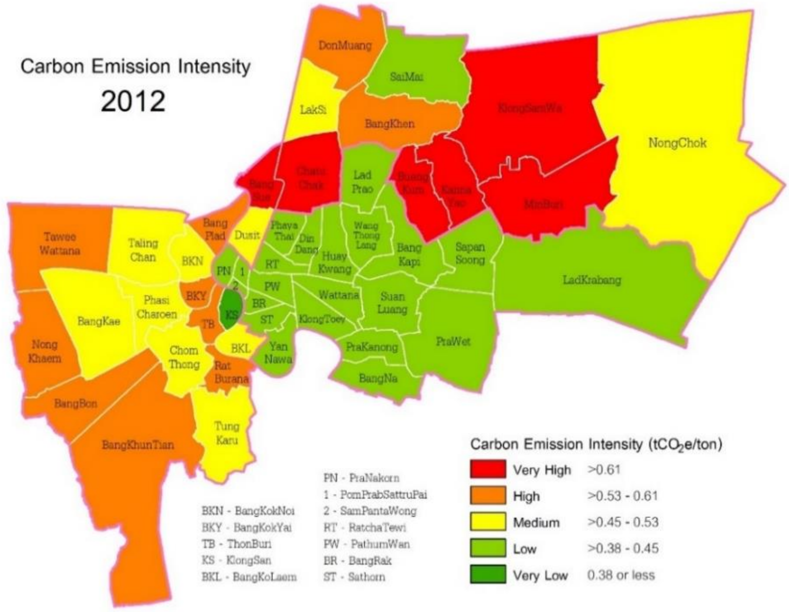


Figure 5-10 Bangkok's MSWM Carbon Emission Intensity (tCO$_2$e/ton) in 2012

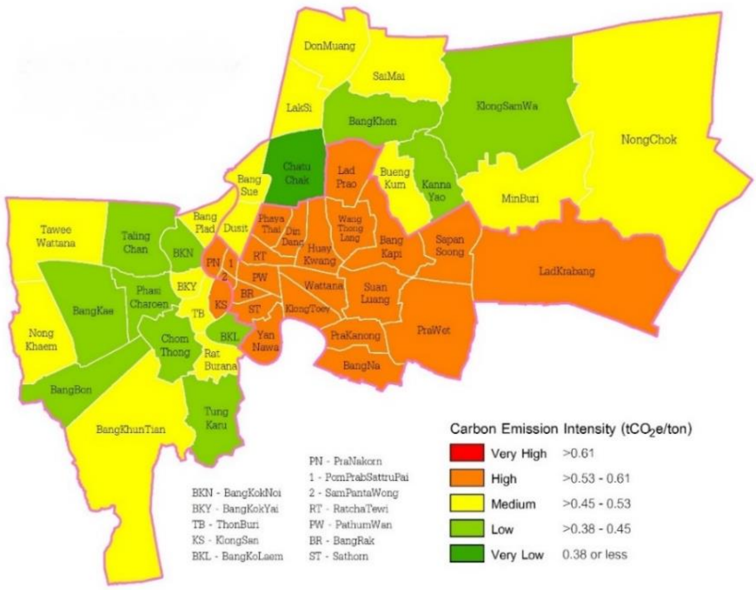


Figure 5-11 Bangkok's MSWM Carbon Emission Intensity (tCO$_2$e/ton) in 2013

Figure 5-12 shows emission from only the collection system in 2013. It can be used to compare between that of the only collection system and net emission. The districts that emit at very high level in a collection system that is quite different from the net emission trend including Bangkuntian, Thonburi, and Donmuang. These districts do not have very high level both of net emission and intensity. They are, however, in term of collection system per MSW_c, are higher than that of other districts. It is interesting that the high emission of collection system is insignificant with size area service and MSW_c quantity because of the biggest area as Ladkrabung and the highest MSW_c quantity as Chatuchak emit less than the smaller size area service and quantity MSW_c.

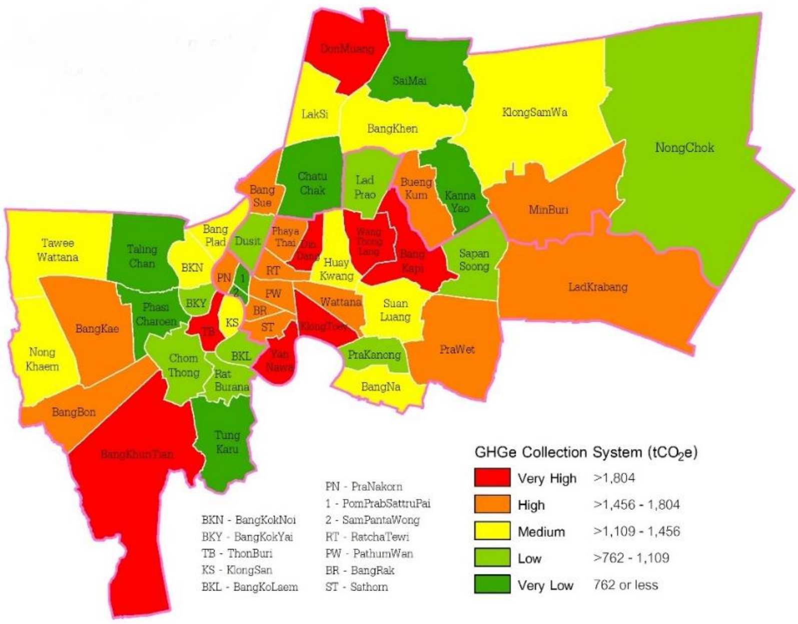


Figure 5-12 Emission of Collection System in Bangkok's MSWM (tCO_2e) in 2013

5.1.1.3 Emission Benchmark

CEI helps to define MSWM performance representing each stage of MSW metabolism. It can represent a gap of waste management and contribute to establishing priority and focus for policy makers (Dapeng & Yan, 2008). Bangkok's MSW emission was compared to that of other areas, as shown in Table 5-1. Based on the size of comparison areas, it is relatively different characteristics due to a lack of data (Wilson et al., 2015). Emission of Hong Kong's MSWM was 296,205 tCO_2e/year with CEI of 0.09 tCO_2e /ton of MSW excluding collection systems. In opposite, CEI of Bangkok's MSWM excluding collection systems is approximately 1.83 tCO_2e /ton. Interestingly, the longer distance of waste to landfill and to compost in Bangkok, the higher difference their emissions become. In addition, Hong Kong has a higher percentage (59%) of recycling than Bangkok (12.44%).

Comparing with other smaller cities, Kawasaki of Japan, CEI of Kawasaki's MSWM is 0.23 tCO_2e/ton less than the CEI of Bangkok. Interestingly, Kawasaki's MSWM utilizes railway in their collection systems to reduce emission (CEI of CS was 0.003 tCO_2e/ton). The railway collection system is suitable because the service area is quite small. In Spain, CEI of Spain's MSWM was 0.75 tCO_2e/ton less than the Bangkok's CEI. The emission reduction of Spain's MSWM comes mainly from recycling systems while that of Bangkok comes from the recovery of renewable energy of LFG. Spain's MSWM was developed to reduce emission from landfills and based on an implementation of a recycling system. Bangkok's MSWM has a high emission (relatively lower performance) as compared to smaller and larger cities.

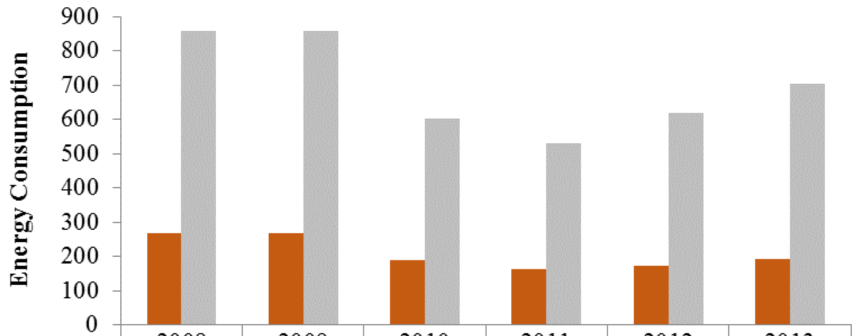
Table 5-1 GHG emission and Carbon emission intensity (CEI) of MSWM in different areas

Location	Area (km^2)	Population (million)	MSW (ton/year)	Treatment process	GHG emission (tCO_2e)	CEI (tCO_2e/ton)	Source
Bangkok, Thailand	568	8.3	3,636,595 (2013)	Composting and LF	1,759,018	1.9	This study
Kawasaki, Japan	143	1.4	490,253 (2006)	Recycling, incineration, and LF	114,441	0.23	Geng Y. et al., 2010
Hong Kong, China	1,104	7.2	3,285,000 (2012)	Recycling and LF	296,205[a,b]	0.09[a,b]	Woon K.S. and Lo I.M.C., 2013
Mediterranean European country (Spain)	504,643	47.3	24,049,826 (2008)	Recycling, MBT, incineration, and LF	18,094,903[a]	0.75[a,b]	Itoiz E.Z. et al., 2013

Note: [a] Collection system excludes emission accounting.
[b] Net emission includes offset from energy recovery.
MBT abbreviates from Mechanical and Biological Treatment.

5.1.2 Energy Consumption

The main categories of energy consumption (EC) in Bangkok's MSWM are electricity, diesel, and renewable energy from landfill gas. The source of data was also identified in the methodology chapter which diesel consumption from BMA's budget and converted by the constant price of fuel. For electricity and renewable energy were from estimation following IPCCC guideline 2006. Figure 5-13 shows net energy consumption of Bangkok's MSWM system decreased between 2009 and 2011. In 2011, EC was the lowest and had gradually increased since then. The trend of EI was similar to that of EC (Figure 5-13). Reduction of energy usage is due to renewable energy from landfill gas. The EC in 2010 was 70 percent of the level in 2009, which mainly because of the offset from renewable energy at the rate of 244.40 TJ (22% of energy usage). The decrease of 18% of renewable energy generation and increasing energy consumption in WTL affected the EI trend increasing in 2013. Not only CDM projects contributed to declines of EI during 2010 to 2013, but also the redesigned policy of reducing diesel consumption in collection systems by BMA was also implemented and produced tangible impacts.



	2008	2009	2010	2011	2012	2013
Energy Intensity (MJ/ton)	267.29	266.90	187.64	162.17	173.51	193.08
Energy consumption (TJ)	858.95	856.10	600.58	529.35	619.02	702.14

Figure 5-13 Trend of Energy Consumption in term of MJ/ton and TJ

5.1.2.1 Energy Flow Analysis (ENFA)

Figure 5-14 presents energy flow analysis (ENFA) of Bangkok's MSW metabolism in 2012 (MJ/day). Most EC in the Bangkok's MSW metabolism was diesel (99.5% or 71,747 litters/day) which consumed by transportations in the collection system and WTL stages. EC per ton of MSW at the On Nuch transfer station region was higher (269 MJ/ton) than that of Sai Mai (99 MJ/ton) and Nong Khaem (126 MJ/ton) while generation of renewable energy at landfilling was lower (-39.07MJ/ton).

5.1.2.2 Energy of MSWM on Bangkok's Geographic Areas

Figure 5-15 to 5-17 show the energy consumption (MJ) of Bangkok's MSWM since 2011 to 2013. It divides in to six levels which differ from emission and mass MSW_c because of offset from renewable energy at landfilling. At very high level (red categoryontourr) the EC is more than 21,701,407 MJ; high level (orange category) is between 15,457,784 and 21,701,407 MJ; medium level (yellow category) is between 9,214,162 and 15,457,784 MJ; low level (soft green category) is between 2,970,539 and 9,214,162 MJ; very low level (hard category) is between 0 and 2,970,539 MJ; and at energy offset (blue category) level is less than 0 which means energy consumption is less than energy production.

Trend EC of Bangkok's MSWM on the geographic area since 2011 is similar to the graph EC (Figure 5-13). It gradually increases EC because of decreasing EC offset districts from seven to only one district in 2013. This is the same as the emission trend that also increases since 2011. It has very high level of EC and also a high level of net emission except Bangsue. Bangsue was different other districts that are at the very high level both of EC and net emission. Considering emission between collection system and total EC of Bangkok's MSWM, Bangsue, Phranakorn, and Wattana were at very high level of total EC; while Bangkuntian, Thonburi, and Donmuang were the only districts that are at very high level of emission in the collection system. Many districts have high both of EC and emission of the collection system. It can be noted that collection system produces quite an effect on the total EC of Bangkok's MSWM.

19 districts have a stable level of EC since 2011. Of the 19 districts, those with very high level of EC include: Phranakorn, Dindang, Wangthoglang, Bangkapi, Wattana, Klongtoey, and Yannawa. Those at a high level include Huaykwang, Bangrak, Satorn, Bangna, Suanluang, and Ladkrabang. Two districts are at the medium level

include Phrakanong and Sapansoong. Those at low level include Sampanthawong, Pomprabsattrupai, and Nongchok. The only district with an offset energy level is Chatuchak. Other 30 districts have increasing EC of Bangkok's MSWM since 2011. However, the EC of Phayathai district declined because of decreasing both of EC in the collection system and WTL. It is interesting that all districts at very high level of EC in 2013 are located in the On Nuch TS region; while Sai Mai and Nongkhaem TS regions have districts which are mixes of high to offset energy levels.

Trend EC of Bangkok's MSWM may be insignificant with MSW_c quantity. Exceptions are Pathumwan, Dindang, Klongtoey, Wattana, Prawet and Bangkapi districts which were high on both volumes of MSW_c and EC. This may be caused by the different in offset renewable energy from landfilling.

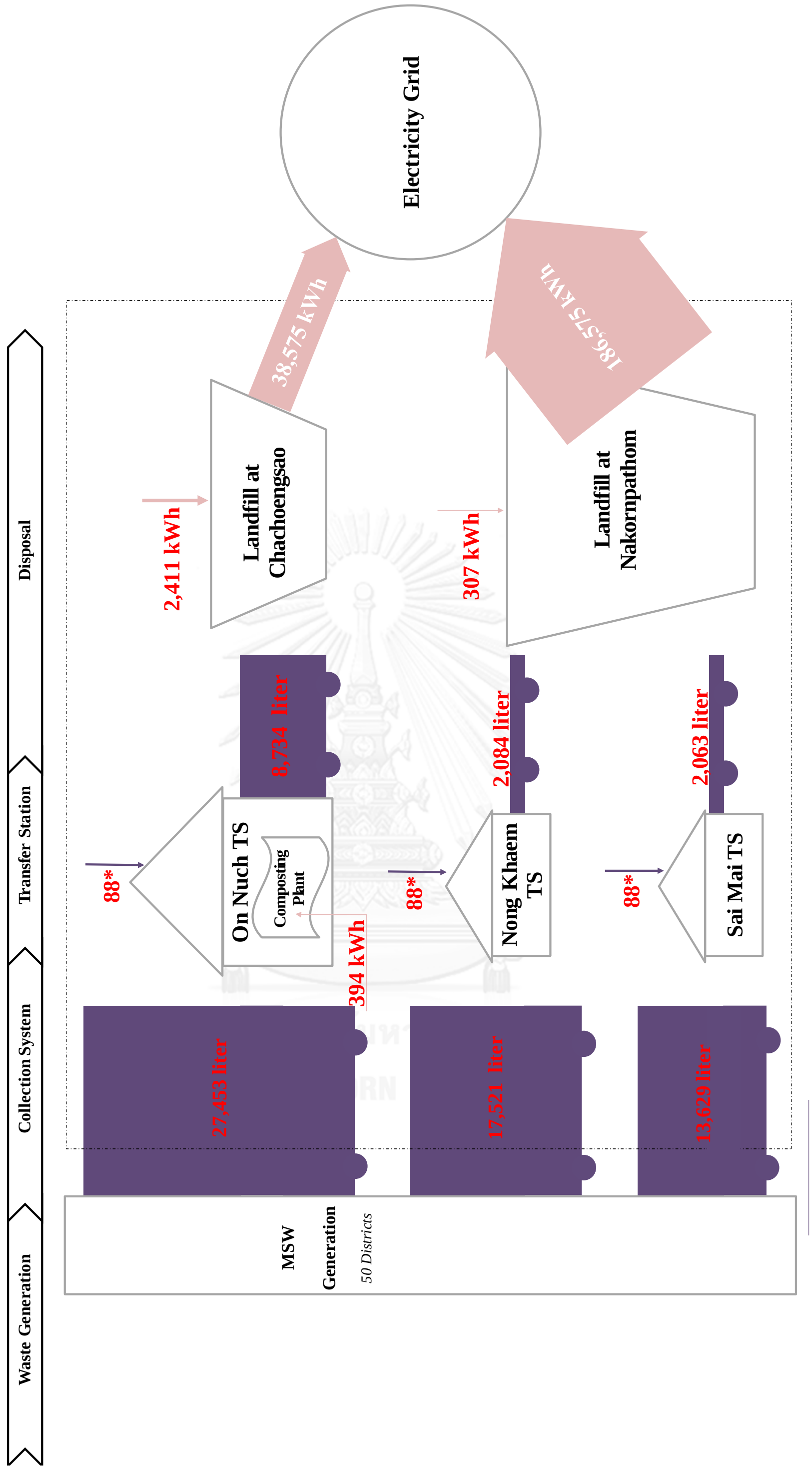


*Figure 5-14 Energy Flow Analysis (ENFA, MJ/day) Note: * means the number from calculation.*

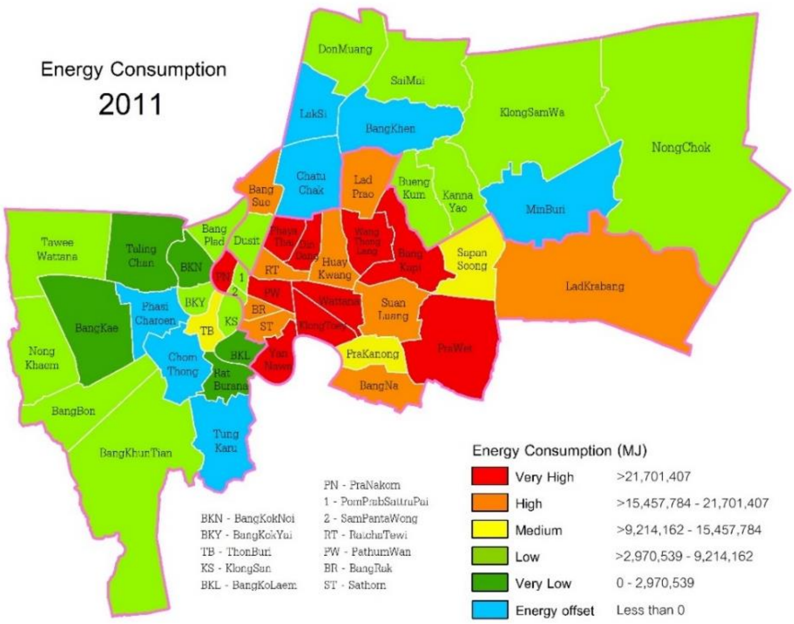


Figure 5-15 Bangkok's MSWM Energy Consumption (MJ) in 2011

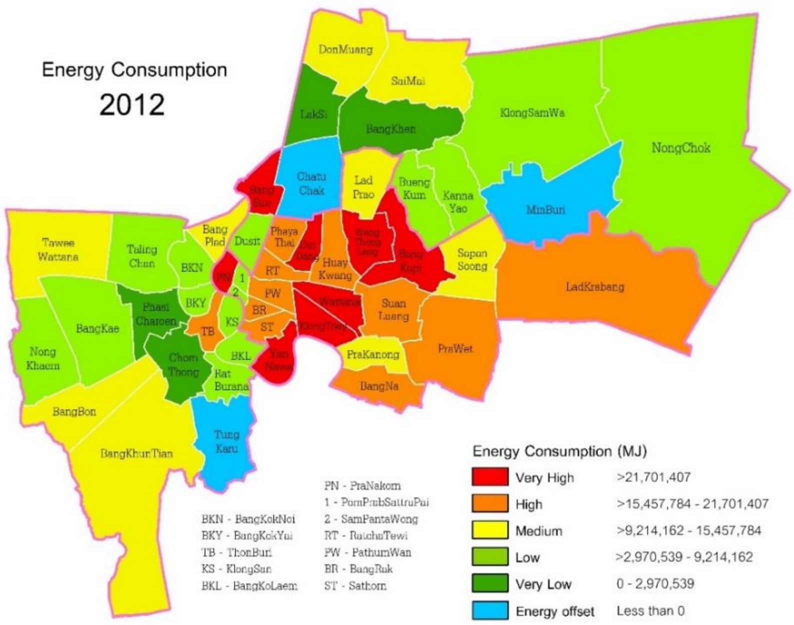


Figure 5-16 Bangkok's MSWM Energy Consumption (MJ) in 2012

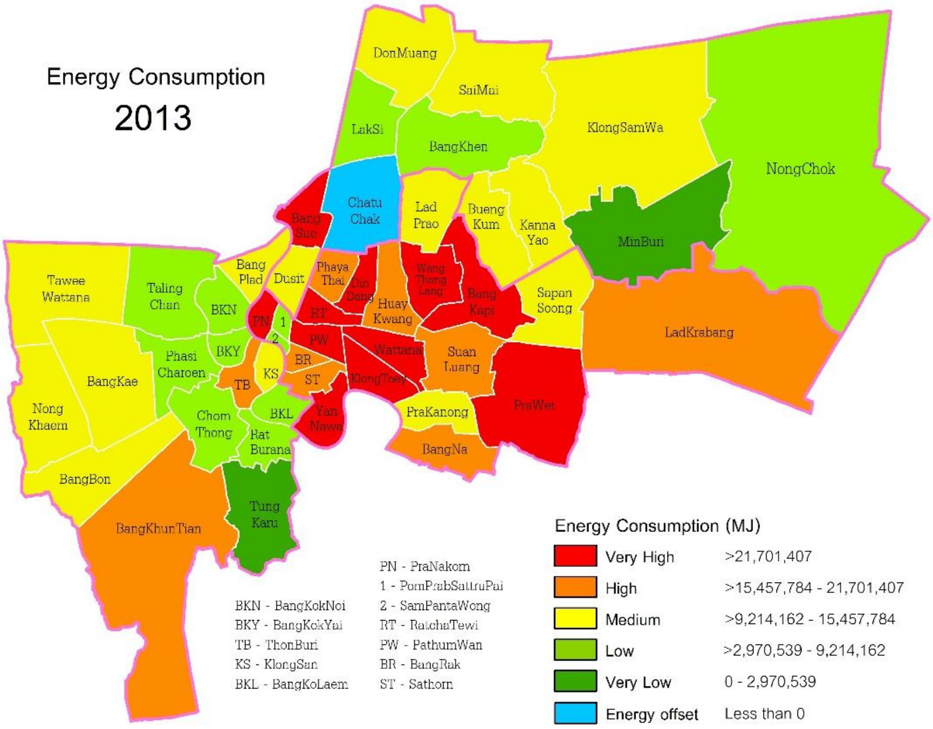


Figure 5-17 Bangkok's MSWM Energy Consumption (MJ) in 2013

Figure 5-18 to 5-20 shows the intensity of energy consumption (EI) on Bangkok's geographic area since 2011. The figures are divided in to six levels including: very high level (red category) (more than 315 MJ/ton); high level (orange category) (between 233 and 315 MJ/ton); medium level (yellow category) (between 151 and 233 MJ/ton); low level (soft green category) (between 69 and 151 MJ/ton); very low level (hard green category) (between 0 and 69 MJ/ton); and energy offset (blue category) (less than 0 MJ/ton).

The trend of EI appears to be very similar to that of EC. It gradually increases since 2011. However, several districts (16 districts) have stable EI level since 2011. Of these districts, the one that have very high level of EI include: Phranakorn, Bangrak, Satorn, Phayathai, and Yannawa. The districts with a high level of EI include: Bangna, Thonburi, Pomprabsattrupai, Wattana, Dindang, Klongtoey, Ladprao, Ladkrabang, Sapansoong, and Prawet. And the only district with energy offset level is Chatuchak. The other 34 districts have increasing level of EI. A few districts are at the very high level both in term of EI and EC including: Yannawa, Phranakorn, and Bangsue. This is in contrast with the majority of districts that do not have the same trend as that of EC. That means high EC districts may not have high EI in the case of high MSW_c. The result of EI on geographic area shows obviously that energy consumption on Bangkok's MSWM is quite insignificant with MSW_c volume.

The trend of EI had not changed since 2008; That of On Nuch transfer station region was higher than other regions because it applied composting to 27% of MSW_c. As a result of CDM projects, this has an effect on the resultant EI, which is display in blue category in some districts. This is due to offset renewable energy and energy consumption of collection system which is varying with time.

In 2012, after the major flooding disaster, the EI increased by 18 MJ/ton of MSW_c compared to that of 2011. The relationship between EI and flooding of local areas were not clear; some EI of flooding areas remained relatively stable, for example, Dongmuang, Bangkae, and Talingchan. Nevertheless, some of the districts had increased EI, for example, Bangkuntien, Laksi, and Nongkhame. Considering EI in 2013, offset from renewable energy was quite stable; while EC in collection system increased according to the trend of MSW_c volume. Consequently, the blue category of local areas decreased. The only district with blue category was Chatuchak district which is a result ofvstable EC in the collection system. It should be noted that its MSW_c quantity increased in the year.

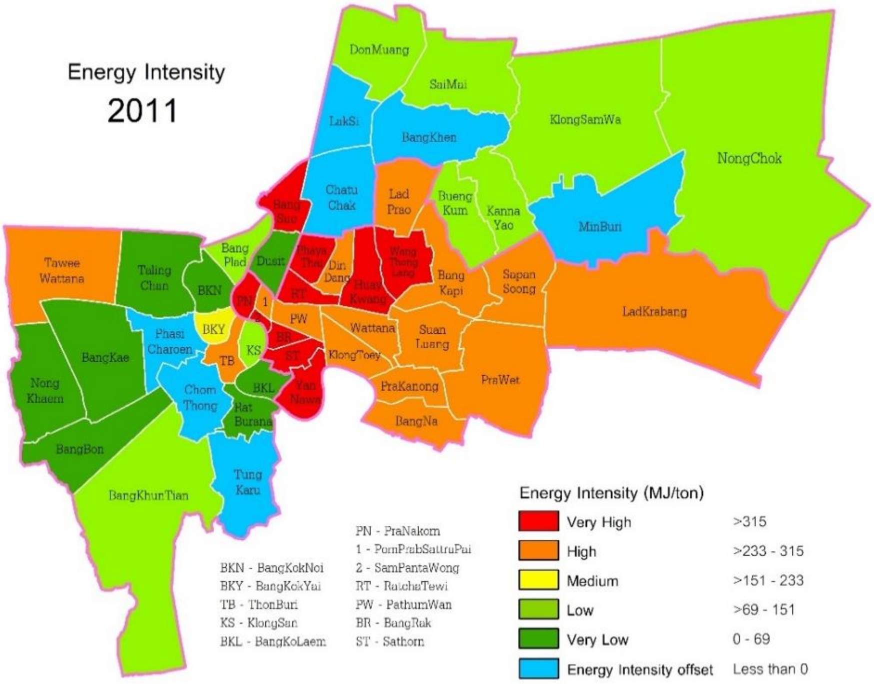


Figure 5-18 Bangkok's MSWM Energy Intensity (MJ/ton) in 2011

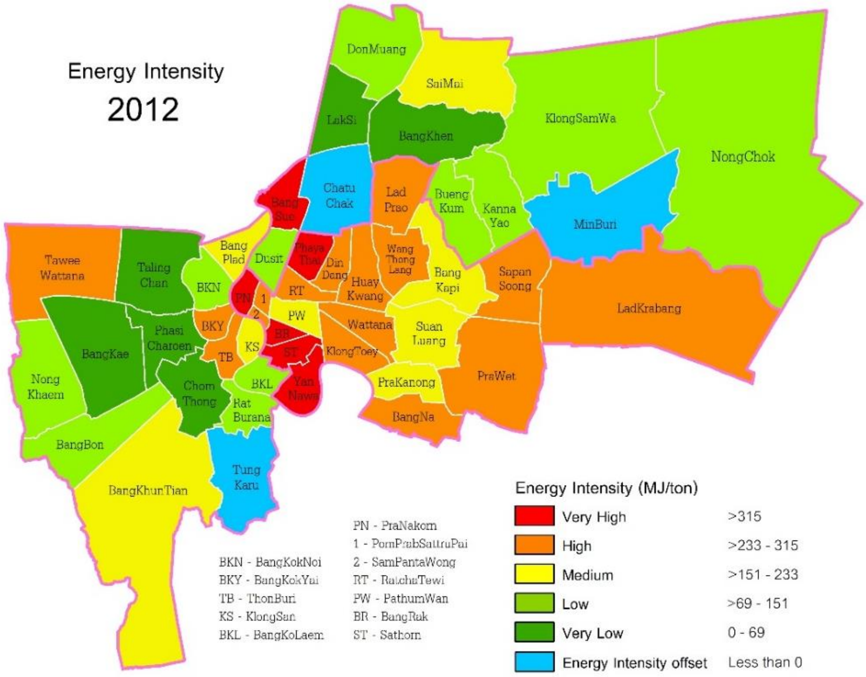


Figure 5-19 Bangkok's MSWM Energy Intensity (MJ/ton) in 2012

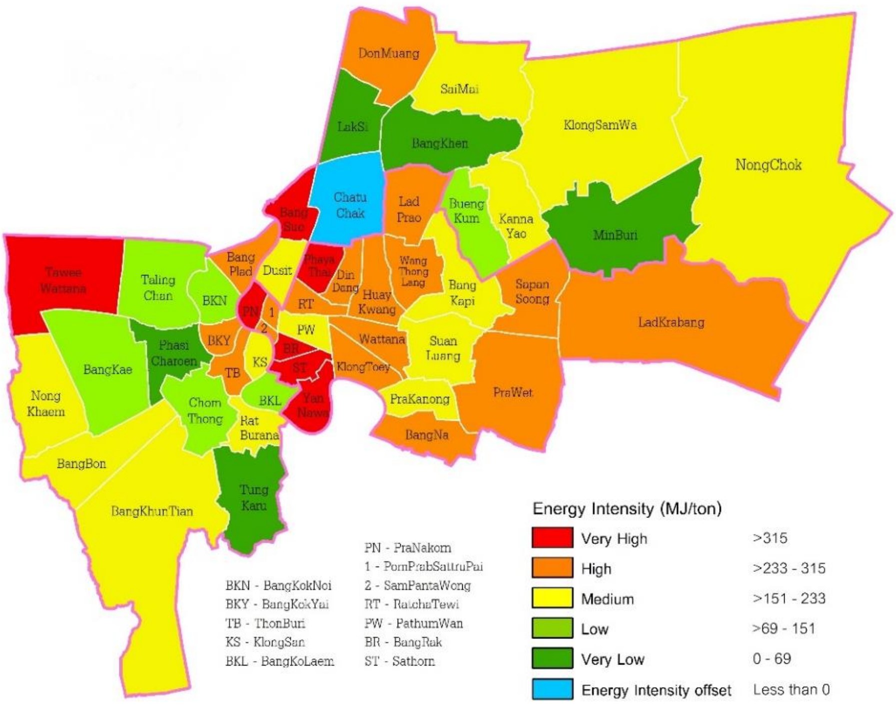


Figure 5-20 Bangkok's MSWM Energy Intensity (MJ/ton) in 2013

5.1.2.3 Energy Consumption Benchmark

To benchmark energy consumption of Bangkok's MSW metabolism, Table 5-2 shows EC and EI of the entire MSWM systems of Porto, Portugal and Hangzhou, China. The lowest EC of MSWM is Porto (-1,111 MJ/ton). The smaller EC could be due to the low quantity of MSW generation and area in comparison. Porto's MSWM has also implemented sorting plants and energy recovery plants to recover energy from wastes. In contrast, energy consumption of Hangzhou's MSWM was the highest (511 MJ/ton), although MSW generation was lower than that of Bangkok. The large portion of EC is from the MSWM system that did not implement energy recovery as that of Bangkok and Porto. There is, therefore, no offset renewable energy from the MSWM. Porto's MSWM system is interesting because the system operation has energy production greater than consumption. At the disposal stage of Bangkok's MSWM, energy production is also greater than consumption (-108 MJ/ton). However, the offset renewable energy was less than the sum of energy consumption of Bangkok's MSW metabolism.

Table 5-2 Energy consumption (EC) and Energy intensity (EI) of MSWM in different areas

Location	Area (km^2)	Population (million)	Treatment	MSW (ton/year)	EC (GJ)	EI (MJ/ton)	Source
Porto, Portugal	41.42	1.0	Sorting, composting, energy recovery and LF	514,832 (2011)	33,299	-1,111	Herva M. et al., 2014
Bangkok, Thailand	568	8.3	Composting and LF	3,636,594.7 (2013)	702,060	193	This study
Hangzhou, China	16,847	2.5	Incineration and LF without recovery LFG	2,500,000 (2010)	1,276,500	511	Dong J. et al., 2014

5.2 Hot Spot of Bangkok's MSW Metabolism Analysis

The parameters that can be used in an assessment of the burden on the environment to help to define the hot spots of Bangkok's MSWM and areas are emission and energy consumption. The hot spots of stage and areas contribute to the design of alternatives and effective recommendation and policy for waste management that can result in immediate improvements. Because improvements to MSWM cannot be all done at the same times; the prioritization strategy of hot spot MSWM can be a good option to implement for effective MSWM improvement.

5.2.1 Hot Spot of the Stage Bangkok's MSWM

Hot spots of Bangkok's MSW metabolism were investigated using GHG emission, Energy consumption (EC), Emission (CEI), and Energy intensity (EI). These indicators can help identifying the level of urban environment because waste metabolism is a part of the urban infrastructure and can be used to describe how sustainable is an urban area. Rapid urban transformation can greatly affect waste management systems (Uyarra & Gee, 2013).

By performing MFA of Bangkok's MSW, we can explore the efficiency of resource utilization. There was a high volume of mass MSW stored in landfills. Resulted GHG emission of Bangkok's MSW metabolism indicates that landfill is a hot spot due to the highest emission (GHG emission of 88% and CEI of 81% as shown in Figure 5-21). However, composting and collection system also produces high emission (CEI of 15% and 3%, respectively). According to energy consumption results (see Figure 5-22), collection system is a hot spot of Bangkok's MSW metabolism because of the highest EC (82 %) followed by WTL (17%). With regard to EC, landfills produced negative EC (-238 TJ). It indicates that landfills generated more energy than they consumed. Unfortunately, the offset energy was only 21 % of total energy consumption. The EC of Bangkok's MSW metabolism is still high. From an integration analysis of emission and energy, it is clear that the hot spots of Bangkok's MSW metabolism are landfills and collection systems.

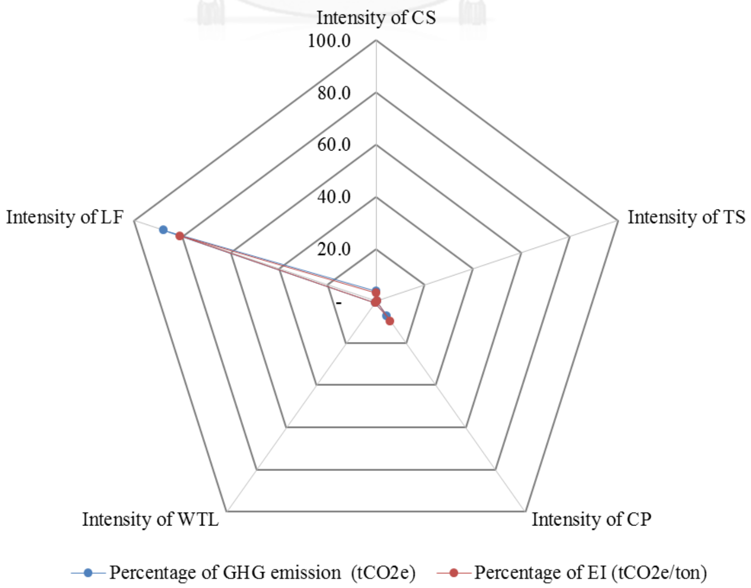


Figure 5-21 Percentage of GHG emission and percentage of CEI in 2013

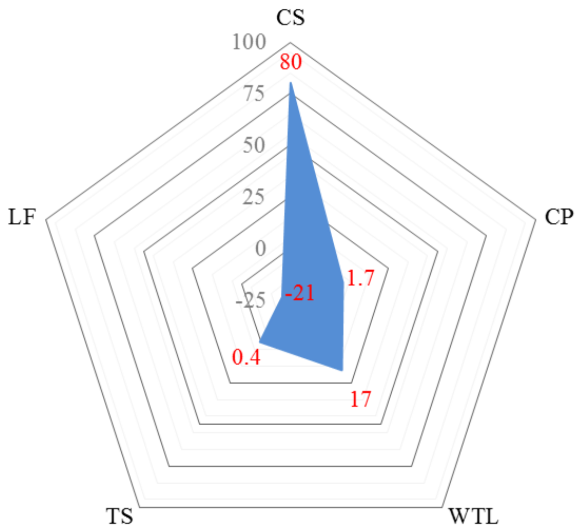


Figure 5-22 Percentage average EC of waste management processes in 2008 to 2013

Reviewing Bangkok's MSW metabolism during 2008 to 2013 help improving our understanding of existing problems and identifying potential areas that can be improved to achieve sustainable waste management system. For instance, redesign of collection systems and implementation of CDM projects. The results from CDM projects show that it can produce both positive impacts on energy consumption and emission.

5.2.2 Hot Spot MSWM Bangkok's Areas

Hot spot areas investigated by using volume MSW_c, MSW_c per capita, GHG emission, Energy consumption (EC), Emission (CEI), and Energy intensity (EI) indicators. They also display on Bangkok's geographic area. Table 5-3 shows the hot spot districts for each indicator, however; only CEI indicator are not shown in the table. At CEI indicator on geographic area is no at very high level then it does not have hot spot area.

Table 5-3 Hot spot districts of each indicator

Indicators	Hot spot districts (at very high level)
MSWc quantity (ton/day)	Bangkae, Bangkuntian, Klongtoey, Chatuchak, Bangkhen, Ladkrabang, Pathumwan, Wattana, Dindang, Bangkapi, and Prawet
MSWc per capita (ton/capita/day)	Rachatewi, Klongtoey, Wattana, Huaykwang, Phranakorn, Bangrak, and Pathumwan
Net GHG emission (tCO_2e)	Bangkae, Bangbon, Bangkuntian, Pranakorn, Rachatewi, Yannawa, Chatuchak, Huaykwang, Bangna, Suanluang, Ladkrabang, Bangkhen, Pathumwan, Wattana, Dindang, Bangkapi, and Prawet
Energy consumption (MJ)	Bangsue, Pranakorn, Rachatewi, Klongtoey, Yannawa, Wangthonglang, Pathumwan, Wattana, Dindang, Bangkapi, and Prawet
Energy Intensity (MJ/ton)	Taweewattana, Satorn, Yannawa, Bangsue, Phayathai, Phranakorn, and Bangrak

Not all indicators have the same hot spot areas; it denotes that the hot spot areas may depend on the indicators used. However, hot spot areas can be grouped with these indicators into two categories. These include net and intensity indicators. Considering the group of net indicators (MSW_c quantity, net GHG emission, and EC), five common hot spot areas are Pathumwan, Wattana, Dindang, Bangkapi, and Prawet. They are all in the On Nuch TS region. It should be noted that this region also has the highest number of hot spots. Using group of intensity indicators (MSW_c per capita and EI), Phranakorn and Bangrak districts are hot spot areas which are also in the On Nuch TS region. The hot spot areas grouping indicator contributes to categorize areas that should be attended with priority for immediate improvement. In the same way, the others hot spot areas of each indicator should attend to improve MSWM after the prioritize areas. The categorization (and prioritization) of hot spot areas contributes to reduce the time and cost to implement effective MSWM strategies and policies.

In summary, key findings from the performance assessment of Bangkok's MSW metabolism are:

- CDM projects and the redesigned policy used in collection systems by BMA are effective on reducing the energy consumption of Bangkok's MSWM.
- When considering energy consumption in the collection system, On Nuch TS region has the highest, however; it has the smallest areas of service. It is worth noting that CEI in the collection system of three TS regions is the same.
- On Nuch TS regions has the highest emission compared to the other two TS because there is a waste to landfill, collection system, and a composting plant.

- The relation between collection system and small size areas can influence on less emission in the districts.
- The results from CEI and emission of collection system in 2013 on geographic area confirm that MSW_c volume is individual with emission if the area has an effective MSWM.
- Benchmarking of emission results shows that Bangkok's MSWM has a high emission (relatively lower performance) as compared to both smaller and larger cities. In addition, to achieve low carbon for BKK's MSWM, a unique MSWM system should be designed and implemented similar to which the comparing cities have done.
- The energy consumption in collection system stage has quite an effect on the total EC of Bangkok's MSWM. Not only quantity MSW_c is main factor on energy consumption of localize performance, but effective MSWM also.
- The result of EI on geographic area shows clearly that energy consumption of Bangkok's MSWM does not depend on with MSW_c volume.

- Results from benchmarking of EC show that Porto, Portugal generates energy from MSWM higher than energy consumption. This has been according to the system designs which is suitable and unique to the city. However, it should be noted that Bangkok's MSWM has higher EC than Porto, while less than that of Hangzhou, China.
- The emission and EC hot spots of Bangkok's MSW metabolism are landfills and collection systems.
- The hot spot district areas identified by net indicators (MSW_c quantity, net GHG emission, and EC) are Pathumwan, Wattana, Dindang, Bangkapi, and Prawet.
- The hot spot district areas identified by intensity indicators (MSW_c per capita and EI) are Phranakorn and Bangrak. However, only Wattana and Pathumwan are a hot spot of MSW_c per capita.
- The other hot spot areas identified by individual indicator except CEI are Bangkae, Bangkuntian, Klongtoey, Chatuchak, Bangkhen, Ladkrabang, Rachatewi, Huaykwang, Bangbon, Rachatewi, Yannawa, Bangna, Suanluang, Bangsue, Wangthonglang, Taweewattana, Satorn.

The result of performance assessment of Bangkok's MSW metabolism contributes to a design of comprehensive analysis of Bangkok's low carbon MSWM scheme. In the next chapter, the scenarios development for investigation effective options of MSWM is presented based on the hot spot of Bangkok's MSW metabolism. The hot spot areas are the defining sites for implementation with priority under the low carbon policies (low carbon MSWM scheme).

CHAPTER VI
BANGKOK LOW CARBON MSWM SCHEME

This chapter presents the Bangkok's low carbon MSWM scheme which was designed by scenarios development including a consideration of implementation of concerning issues in current Bangkok's MSWM system. Various scenarios are developed based on the hot spots of Bangkok's metabolism which are a collection and landfilling stages. The performance of single and multiple actions are evaluated via a set of parameters including GHG emission, energy consumption, the amount of waste to landfill and waste utilization. The results based on an implementation of technological alternatives advantage and disadvantage analysis exhibits the proper actions that can be applied as Bangkok's low carbon MSWM scheme. **Performance Assessment of Management Scenarios**

The performance of various options to improve Bangkok's MSWM in this study are evaluated in term of GHG emission, energy consumption, the amount of waste to landfill and waste utilization. GHG emission is, however, the key parameter to decide for low carbon MSWM. The amount of investment was also performed using scoring methods to weigh out between advantages and disadvantages.

6.1.1 Environmental Indicators

Table 6-1 shows changes in performance of all management options in 4 parameters compared with BAU in 2013. S4 which is a campaign to reduce waste generation rate by 25%, shows the highest GHG reduction (24.49%). Because the amount of MSW_c decrease in the scenario. Energy consumption in waste transportation and waste to landfilling stages in S4 also decreased. On the other hand, decentralized composting plant (S1) increases net GHG emission from the composting process. However, S1 slightly reduces energy consumptions in the collection system and waste to landfill. The GHG emission of a scenario with establishing 14 transfer stations (S2) and changing types of fuels (S3) showed that that the shorter distance between the transfer station and collection service areas and lower emission factor (EF) in the fuel. It can reduce more GHG than the decentralized composting (S1) scenario. The combined actions (H3 scenario) of decentralized composting, changing a type of fuel, and waste reduction campaign show the best performance options to reduce GHG emission up to 30%. Therefore, H3 is a recommended approach for transforming Bangkok toward low carbon MSWM in the future.

The campaign of reducing waste generation (S4) showed the largest reduction in energy consumption. Reducing MSW_c at source has more impact on the reduction of energy consumption than shorter distance in the collection system, decentralize management, and changing emission factor separately. Moreover, the scenario on 10% food waste for decentralized composting does not have a significant effect on energy consumption of Bangkok's MSWM. H3 scenario showed the highest reduction in energy consumption by establishing more transfer stations and implementing a campaign of reducing waste generation in rate 25%.

Within the single action scenarios, only the decentralized composting (S1) and the campaign to reduce waste generation (S4) can reduce waste to landfill up to 0.42% (13,849 per year) and 29.34% (828,447 ton per year), respectively. As a result, 10% of food wastes in MSW of decentralize composting (S1) did not help much in reducing quantity waste go to the landfill; while 25% of reducing waste generation has a high impact to waste to landfill. However, food waste in S1 can be utilized by composting. The multiple actions that has the highest performance in reducing landfill space is decentralized composting and the campaign of reducing waste generation (H2). Increasing waste utilization (composting) and policy of waste prevention/minimization (reducing waste generation) help to reduce the need for more landfill areas.

Table 6-1 Performance of various Bangkok's MSWM options

Code	**Scenarios Development**	**GHG Emission**	**Energy Consumption**	**Waste to Landfill**	**Waste Utilization**
S1	Decentralized composting plants				
	In individual local areas (50 districts).	1.12%	-2.69 %	- 0.49 %	0.42 %

Code	Scenarios Development	GHG Emission	Energy Consumption	Waste to Landfill	Waste Utilization
	In pattern clusters (13clusters) of high activities areas.	1.13%	- 2.22 %	- 0.49 %	0.42 %
S2	Establish 14 transfer stations in high activities areas	-0.65%	-12.38%	-	-
S3	Change types of fuels in vehicles for waste in collection system and WTL	-4.40%	-	-	-
S4	Campaign of reducing waste generation rate by 25%	-24.49%	-24.21%	-29.34%	-
Hybrid Scenarios					
H1	Combination scenarios 1+3	-3.28%	-2.69%	-0.49%	0.42%
H2	Combination scenarios 1+4	-25.60%	-26.43%	-29.83%	0.42%
H3	Combination scenarios 1+3+4	-30.01%	-26.43%	-29.83%	0.42%
H4	Combination scenarios 2+3	-5.06%	-12.38%	-	-
H5	Combination scenarios 2+4	-25.14%	-36.58%	-29.34%	-
H6	Combination scenarios 3+4	-28.89%	-24.21%	-29.34%	-

Code	Scenarios Development	GHG Emission	Energy Consumption	Waste to Landfill	Waste Utilization
H7	Combination scenarios 2+3+4	-29.48%	-36.58%	-29.34%	-

To compare performance assessment of BAU and multiple actions in 2012, Figure 6-1 shows GHG emission (MtonCO$_2$e), energy consumption (TJ), the quantity of waste to landfill and utilization (ton) of Bangkok's waste management system in 2012 (BAU) and multiple actions (H1 to H7). Considering all indicators, H3 is the best combination of three options including decentralized composting, changing the type of fuel, and waste reduction campaign. H3 scenario produces the lowest GHG emission and MSW$_c$ to landfilling and the highest waste utilization based on the comparison of the combined options. However, it is not the lowest energy consumption option. Energy consumption in H3 scenario is greater than that of H5 and H7 by 100 TJ.

	H1	H2	H3	H4	H5	H6	H7	Base year (2012)
Energy Consumption (TJ)	955.41	722.39	722.39	860.35	622.66	744.17	622.66	981.87
Waste go to LF (kton)	2,810.23	1,981.78	1,981.78	0	1,995.63	1,995.63	1,995.63	2,824.08
Waste Utilization (kton)	13.85	13.85	13.85	0	0	0	0	0
Emission (MtonCO2e)	1.50	1.15	1.08	1.47	1.16	1.10	1.09	1.55

Figure 6-1 Performance combined actions (H1-H7) of Bangkok's MSWM comparison with BAU in 2012

This study focuses on designing low carbon MSWM. It is also clear that that the best option for waste management depends on the criteria selection. Nevertheless, investment construction cost is an important factor to consider (Marchettini N. and et al., 2007).

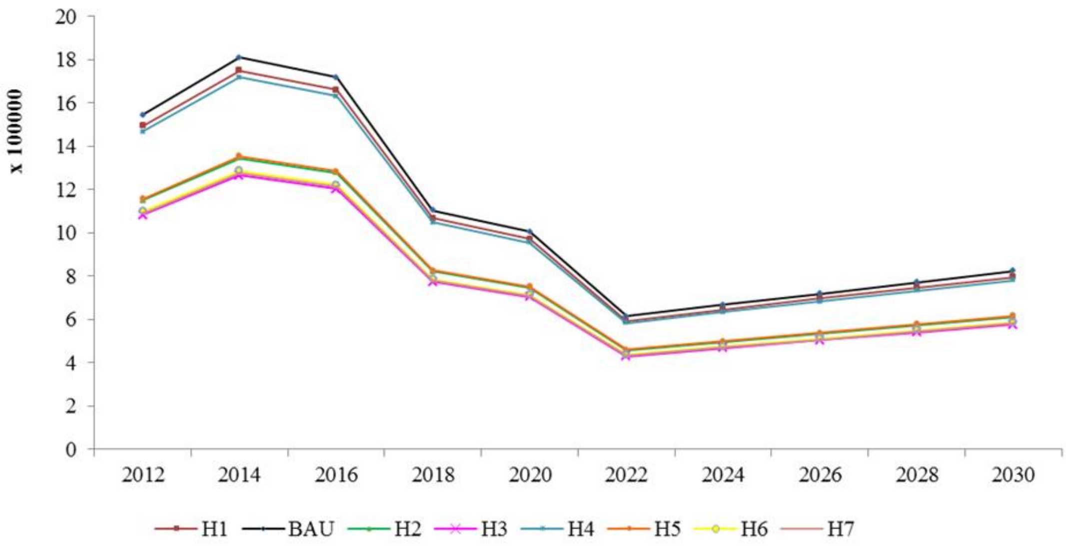


Figure 6-2 Emission forecasting of business as usual (BAU) and multiple actions (H1-H7) in 2012-2030 ($MtCO_2e$).

Figure 6-2 shows the results of comparing the performance of BAU and the multiple actions H1 to H7 between 2012 and 2030. The LFG of all scenarios is based on First Order Decay (FOD) and gradually increases from biodegradation according to the IPCCC Waste Model (IPCCC, 2006). The MSW has been buried since 2008 and with fully operated LFG recovery since 2012. The potential emission reduction of Bangkok's MSW management varies between 3.28% and 30% from the current situation. All multiple actions and BAU emission trends start to decrease in 2017 because the percentage of LFG gas reduced with no flaring.

Emission trend is increasing at a steady rate beginning in 2022 because LFG recovery reaches a stable rate and increases in MSW quantity add up in a landfill in every year. As expected, BAU has the highest emission. The multiple actions reduce the emissions which H3 is the best (pink line) between 2012 and 2030. The H7 and H6 scenarios are the second and third ranking options, respectively. All options intend to mitigate the emission and provide co-benefit to society and environment. The varying emission depending on the fitting options with limitation condition issues that the Bangkok's MSWM system employed.

Based on the results, the multiple actions of decentralized composting plants (clusters), changing the type of fuel in vehicles for waste, and campaign to reduce 25% of waste generation at sources are the most significant factors on emission reduction of Bangkok's MSW management. Even though landfilling has the highest emission in the Bangkok's MSW management system (Figure 6-1), landfill gas (LFG) recovery has reached the maximum efficiency of operation (50-55%). In addition, the most landfill emission is from electricity generation and flaring in renewable energy processes. A reduction of landfilling MSW can contribute significantly to emission reduction in the MSW management system. H3 option has the highest reduction of landfilling MSW. Not only disposal stage can enhance emission reduction, government policies and management at the source of waste generation can significantly influence the emission of Bangkok's waste management system.

To analyze the performance of multiple options implementation (H3), Table 6-2 shows the quantity of emission reduction during 2012-2030. Percentage of emission reduction is 30.01 from baseline (BAU) and total emission reduction since 2012 is 6,142,704 tCO_2e. However, H6 and H7 options also have high efficiencies with percentage of emission reduction at 28.89 and 29.48, respectively. According to BMA LCS plan, if H3 is employed in 2020, it will reduce emission by 0.3 $MtCO_2e$ from that of the current MSWM system. This is higher than the target LCS program by 0.1 $MtCO_2e$.

6.1.2 Investment Estimation

Besides investigating environmental performance assessment, Figure 6-3 shows their total investment estimation per unit of reduction of environment load indicators (GHG emission, energy consumption, wastes to landfilling, waste utilization). From the results of the investment estimation with reducing loads of environmental indicators show that the H2 option is better than the H3 option. The investment estimation per environmental indicators of H2 option shows at least cost in every environmental indicators.

Table 6-2 Emission reduction of multiple actions from Business As Usual (BAU)

Term	Emission (tCO_2e/10 years)							
	BAU	**H1**	**H4**	**H5**	**H2**	**H6**	**H7**	**H3**
Emission in 2012-2030	20,468,856	19,797,477	19,433,132	15,322,985	15,228,829	14,555,403	14,434,637	14,326,152
Emission Reduction	-	671,378	1,035,724	5,145,870	5,240,027	5,913,452	6,034,219	6,142,704
Percentage Reduction of BAU	-	3.28	5.06	25.14	25.6	28.89	29.48	30.01

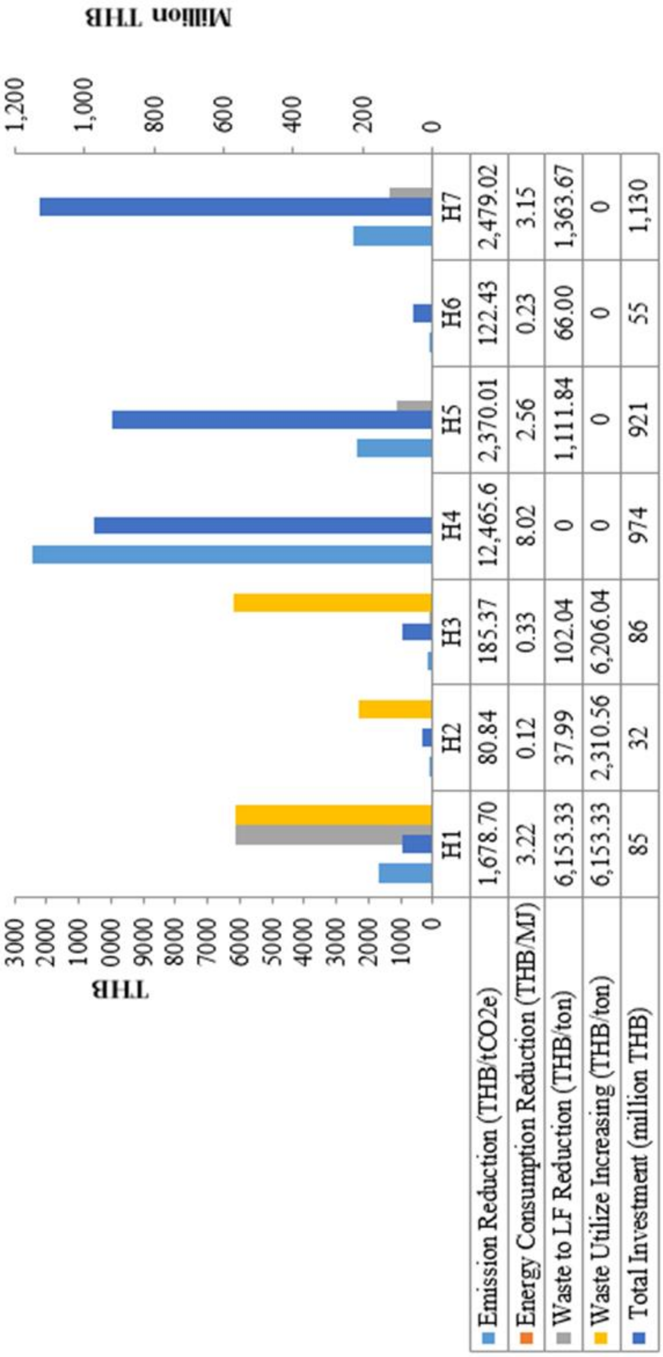


Figure 6-3 Total investment and per unit reduction of loading environmental indicators of multiple actions (THB/unit of environment indicators reduction)

6.2 Analysis of Advantage and Disadvantage of Management Scenarios

To understand effects of implementations of MSWM options, pros and cons analysis was performed. The results are shown in Table 6-3 and Figure 6-4. Within the single option scenarios, the campaign of reducing waste (S4) is the best option because of it has the highest scoring (12/12). The campaign to reduce wastes mainly avoid generation of wastes in the first place through changing behavior and supporting the target using waste bank program (Department of Environment, Climate Change and Water NSW, 2011). In this case, mass media is used to promote the campaign of waste generation reduction. It is not a high technique which scoring is moderate degree and most employment in developing countries (Mongkolnchaiarunya J., 2005). On the investment cost, it is according to the technologies employment that mass media are used such as newspaper, spot on T.V. program and manually procedure for waste bank program around 1 million Thai Baht/year. The social impact is positive because the campaign asks for collaboration rather than issuing a command similar to the successful BMA's policy of "Magic Eye campaign." The policy of waste prevention is well-known by waste management hierarchy and Bangkok also employed this technique. However, it seems to be unsuccessful because of the low percentage of recycling and increasing waste generation trend annually. It can be claimed that the limitation is low in implementation with Bangkok's MSW management system. On the other hand, establishing more transfer stations (S2) is the least preferred option. Its score is 6 of 12. Because this option involves high investment in term of construction cost at approximately 920 million Thai Baht and producing negative social impact according to “NIMBY” principle while the emission reduction is not significant.

For the multiple options, changing fuel type used in transport vehicles for waste and campaign (H6) has the lowest limitation to implementing (the highest scoring) with the score of 10 of 12. The weakness is in the technology, investment cost, and policy and organization responsibility issues in changing fuel of vehicle for waste transport. It needs some know-how in term of technology. Despite the challenge, it is the favorite option utilized at present with the high cost at approximately 54 million Thai Baht. It appears to be difficult to implement with Bangkok’s metabolism because of the vehicles for waste transport are outsourced through contracts which are difficult to change to the natural gas vehicles with immediate effects. However, its environmental indicator shows not the best case. The emission reduction of H6 is in the second ranking. Nevertheless, it has some limitation in term of technology and investment cost of changing type of fuels, and it has to improve the existing government policy.

The best option for implementation that can be applied immediately is the H6 option. Meanwhile, establishing more transfer stations and campaign (H5) is the second best multiple actions due to its relatively low limitation to implementation in a short period and its impacts are good for the environment. H3 is the best option with regarding environmental performance. It seems high limitation implementation in immediately because of all favorite issues have a low scoring. Then, H6 is the best recommendation for implementing as low carbon Bangkok's MSW management, however; some limitations exist. Nevertheless, H6 can reduce GHG emission higher (0.29 $MtCO_2e$) than that of BMA's LCS plan (0.2 $MtCO_2e$) in 2020.

Table 6-3 Explication of weighing result of scenarios in advantage and disadvantage analysis

Scenarios	Technology	Investment cost	Social	Policy	Total Scoring
S1	2	3	1	2	**8**
S2	2	1	1	2	**6**
S3	2	2	3	1	**8**
S4	3	3	3	3	**12**
H1	2	2.5	2	1.5	**8**
H2	2.5	3	2	2	**9.5**
H3	2.33	2.67	2.33	2	**9.33**
H4	2	1.5	2	1.5	**7**
H5	2.5	2.5	2	2.5	**9.5**
H6	2.5	2.5	3	2	**10**
H7	2.33	2	2.33	2	**8.66**

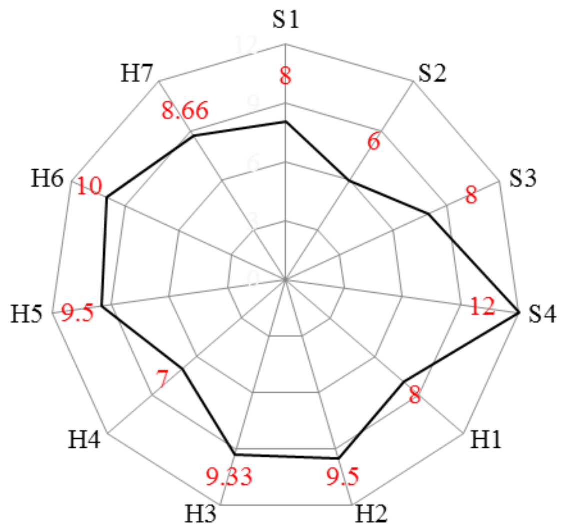


Figure 6-4 Weighing result of advantage and disadvantage analysis

In summary, key findings of Bangkok's low carbon MSWM analysis include (a) The current Bangkok's MSWM system can reduce GHG emission by 29.84% through combining actions of establishing transfer stations, changing the type of fuel, and the campaign of waste reduction rate by 25%. (b) The best option is probability the Bangkok's low carbon MSWM scheme based on the development of hot spots of stage MSWM is the combination actions of changing fuels used in transport vehicles for waste and waste reduction campaign (H6).

This Bangkok's low carbon MSWM scheme is to propose the framework low carbon MSWM for implementation in local areas and Bangkok for better MSWM system and achievement of low carbon society. The developed program to inform and support an implementation of low carbon MSWM scheme presents in the next chapter.

To promote low carbon MSWM in local areas of Bangkok, a suitable Bangkok's low carbon MSWM scheme and recommendation policies are significant components.

CHAPTER VII
PROGRAM FOR LOW CARBON OPTION RECOMMENDATION

7.1 Model Development and Operation

This study developed a tool for help in decision-making on implementation low carbon waste management in local areas/ at a district or provincial level. The model was developed based on waste management activities which are according to the IPCCC 2006 guideline and Clean Development Mechanism methodology (UNFCCC, 2013). The low carbon scheme from the previous chapter applied in the recommendation of the program. The program helps by calculating GHG emission reduction and GHG emission from various scenarios implementation and report on level of GHG reduction from each option. The program can be used by local authorities to estimate GHG emission from the current MSWM activities and identify optential options that help reducing GHG the most. It can disclose the performance of district's MSWM by comparison with average Bangkok's MSWM GHG emission in 2013. Finally, the program has a function to identify the potential low carbon policies to implement and its GHG emission reduction in the local areas.

7.2 Input Data

The program is designed to help estimate GHG emission of MSWM at the district level. The results are in term of tCO2e per year including calculation GHG emission reduction if implementing various low carbon MSWM option. Input data used in the program are as following:

1. Amounts of collected MSW (MSW_c) at district per year (ton/year).

2. Amounts of diesel consumption in collection system of the district per year (litter/year).

3. Numbers of backhoes at the transfer station which district are under geographic collection areas. However, the default value exists in the program by using four backhoes.

4. The quantity of landfill gas fed to the flare during the year measured in cubic meters which the program prepares the default value depending on the landfill sites.

5. Project emissions from flaring of the residual gas stream from landfilling in the year (tCO_2e). The program prepares the default value depending on the landfill sites.

6. The quantity of landfill gas fed into electricity generator (m^3/h).

7. The percentage of district's MSW_c of Bangkok's MSW_c in a year. The program prepares the information in the forth sheet.

7.3 Program Instruction

The program is designed based on Excel format. There are four parts of the outcome. The first part of the outcome is amount MSW estimation per year of each stage waste management. The second is GHG emission and CEI of current MSWM of district per year. The third is the identification of the weakness district's MSWM stage by comparison the current emission with average emission from all district in Bangkok. The fourth is a recommendation toward low carbon MSWM, which displays GHG emission reduction and total GHG emission of implementation. The program divides into three sheets according to the transfer station regions for calculation GHG emission of district's MSWM. The steps for using the program are as follow:

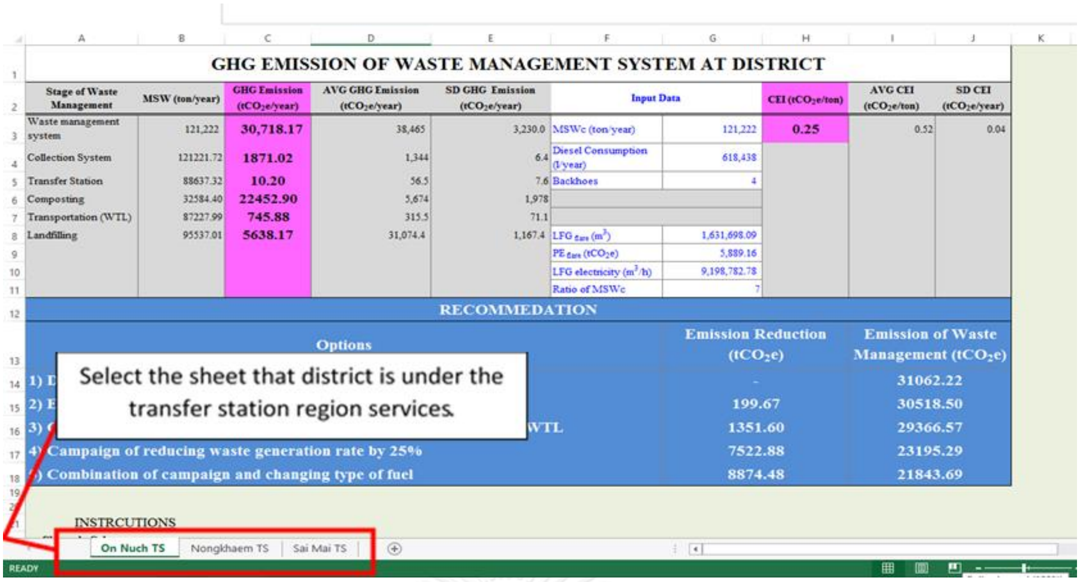


Figure 7-1 Transfer Station regions sheet selection for estimation GHG emission of districts' MSWM

STEP 1: Determination the transfer station regions sheet covers the district location as shown in Figure 7-1.

STEP 2: Input data in the white cell as following: MSW_c (ton/year), diesel consumption (l/year), backhoes at TS, LFG_{flare} (m^3), PE_{flare} (tCO_2e), $LFG_{electricity}$ (m^3/h), and ratio MSW_c of the district as shown in Figure 7-2.

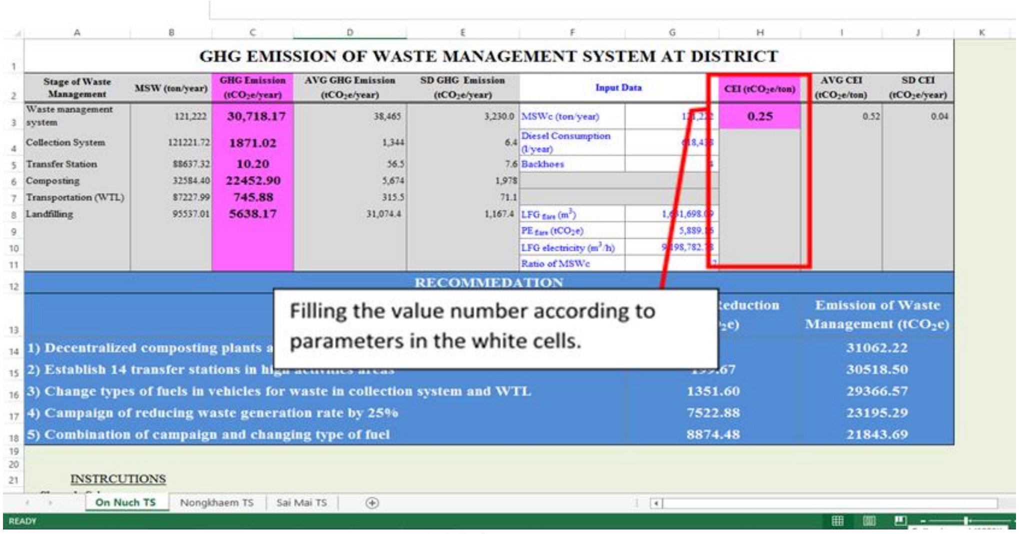


Figure7-2 The data input for estimation GHG emission of districts' MSWM

STEP 3: MSW quantity (ton/year) and the emission of each stage waste management and CEI display in the second, third, and eighth columns, respectively as shown in Figure 7-3.

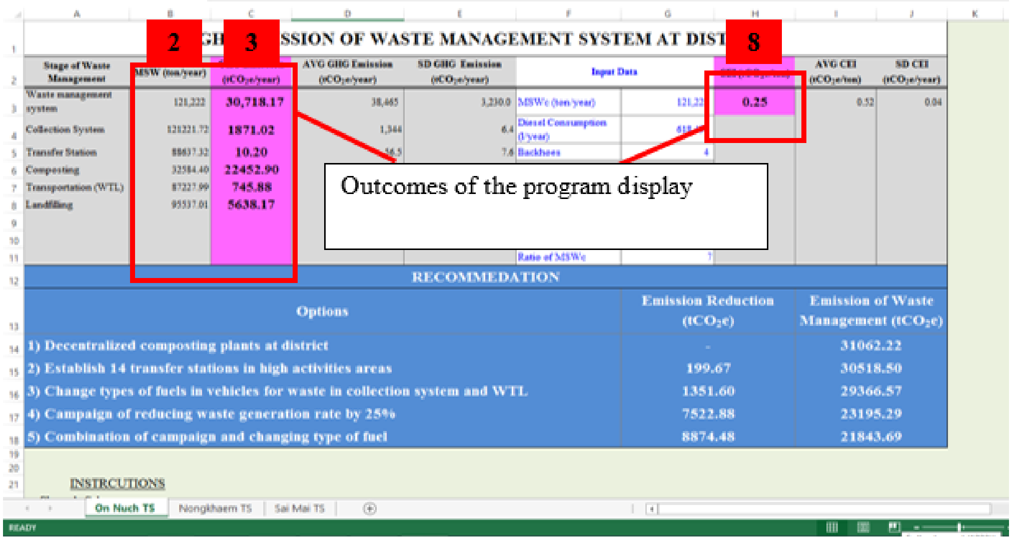


Figure 7-3 MSW and GHG emission of each stage MSWM and CEI outcomes

STEP 4: To assess the performance of waste management of the district, the emission comparison with average emission (the fourth and ninth cells) carried out. If the emission value of district is less than the average, it means the performance good. In opposite, the emission higher implies that MSWM has to improve by the recommend option. However, standard deviation (SD) also displays to show the dispersion of the data value. The comparison can do in each stage waste management and the whole system as shown in Figure 7-4.

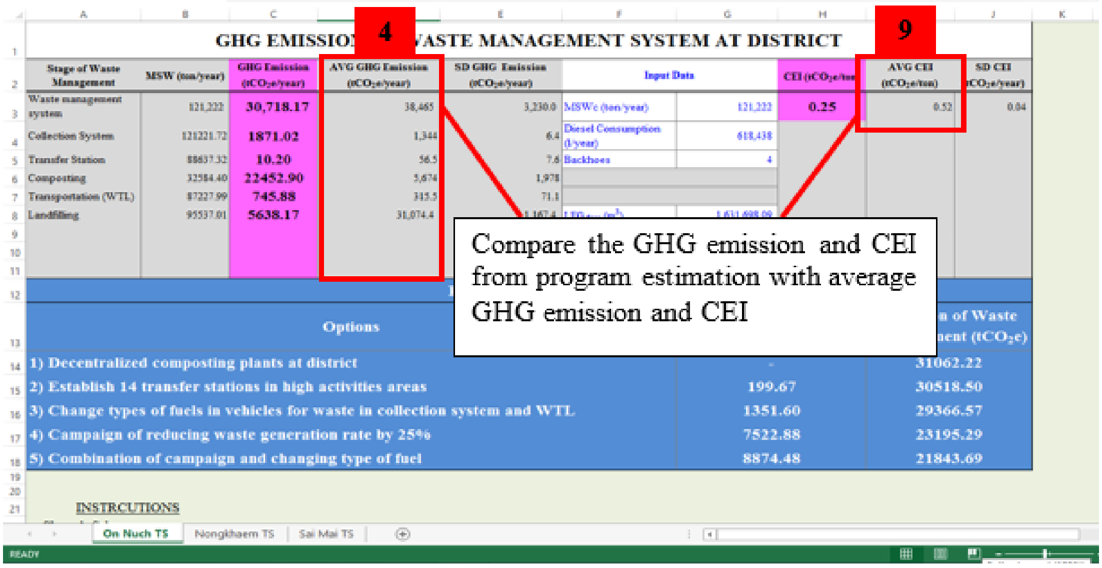


Figure 7-4 The assessment districts' MSWM performance by the program

STEP 5: The recommendation options (blue cell) mean that the potential emission reduction can achieve by four options as shown in Figure 7-5. Exception the option of decentralized composting is not reduction the emission. The combination of campaign and changed the type of fuel is recommended on emission reduction. It is also the low carbon management scheme recommendation. The summation emission of implementation option with waste management at district also displays in the right-hand cell.

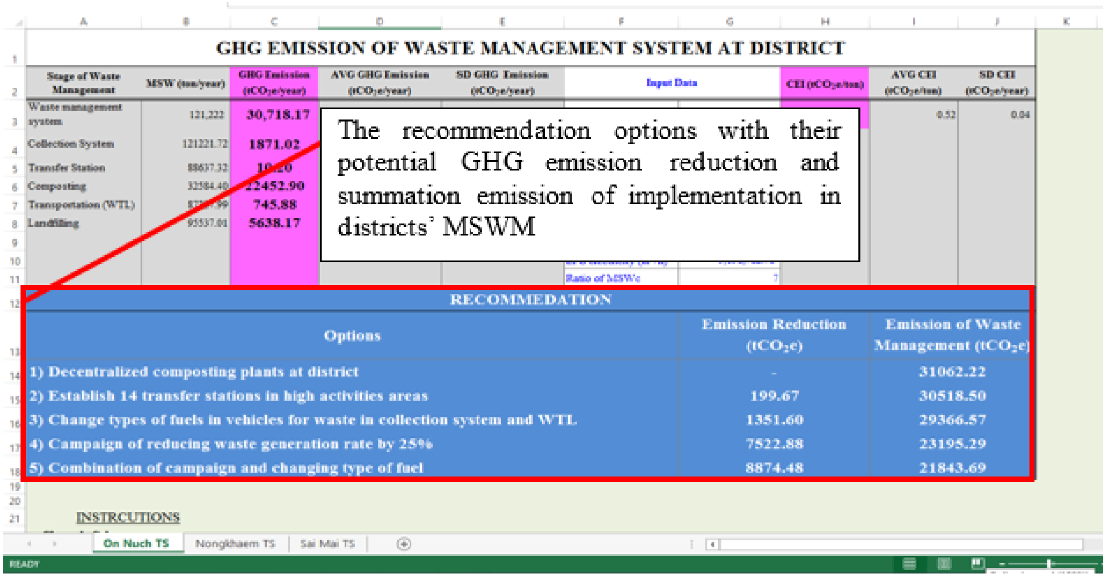


Figure 7-5 Recommendation options for districts' low carbon MSWM

STEP 6: Selection the most suitable recommendation option implements in the districts' MSWM to promote low carbon.

7.4 Output Data

The program estimates the amount of MSW and GHG emission of each waste management stage and CEI of the current districts' MSWM. By using the program, the output data from the program is as following:

GHG emission and CEI of the current districts' MSWM

The low carbon MSWM recommendation policies with GHG emission reduction value

The developed program helps to support the local authorities GHG emission reduction in the MSWM. The program provides choices and information for making a decision about low carbon MSWM. The significant information of the developed program for local authorities are net emission of MSWM system, the level emission when compares with avarage Bangkok's emission, and the amount of reduction emission. It can be adapted in 50 districts and support BMA to move forward low carbon society.

CHAPTER VIII
CONCLUSION

Consequence increasing urbanization makes increasing trend MSW generation. However, the existing Bangkok's MSWM system have been using. BMA attempted to develop sustainable MSWM by 3Rs policies, renewable energy at disposal and launched low-carbon society concept. Despite BMA set a target to move toward LCS, which MSWM is a contributor to emission reduction, the detail in action plans and potential impacts from various alternatives have not much.

The research started with analysis Bangkok's mass MSW metabolism in and geographic areas by using MFA and GIS. The result assists to gain more understanding the mass MSW and relation between the areas. It can be used to develop a suitable direction for improvement MSWM support the urbanization growth. The significant findings of Bangkok's mass MSW metabolism analysis are

- The trend of MSWc gradually increases for six years, even though; registered-population had been stable. This may be caused by non-registered population, flooding disaster impacted, urbanization, and economic growth to MSWc quantity. Because of they have increasing trend.

- Even though the local areas implement waste utilization and a transfer station has a composting plant, landfilling is still the highest flows with wastes sent directly to landfill without prior treatment.

- The MFA of local area scale provides a basis to explore the opportunity to decentralize composting by the local authority.

- Different terms of mass indicators on Bangkok's geographic display different dispersion of hot spot areas geographic.

- The MSW_c geographic areas show that the hot spot areas of MSW_c per capita and area (density) indicators are gathering at the center zone (commercial and government institute areas) of Bangkok. It also demonstrated that activities of individual local areas also may have an impact on MSW generation. On the other hand, the hot spot areas of MSW_c per year are scattered and located mostly in urban fringe which is typically residential areas. Improvement in public transportation and rises of condominium construction are attribution to the hot spots of MSW_c.

- Geographic areas result shows many districts have a stable level of indicators of MSW_c since 2008. Pathumwan is the only area that is the hot spot based on all indicators.
- Not only the 2011 flooding areas had increases of MSW_c, but some non-flooding areas also had increases of MSW_c.

The performance assessment of Bangkok's MSWM implemented to define the problem of stages waste management and areas by using MFA and GIS. The results used to design in Bangkok's low carbon MSWM scheme. The parameters of assessment were emission and energy consumption in term of net and intensity units. The hot spot analysis also implemented to identify and ranking the level of the burden on the environment by Bangkok's MSW metabolism. The benchmarking of emission and EC carried out to compare the efficiency MSWM with other cities. The significant findings are

- CDM projects and the redesigned policy used in collection systems by BMA are effective on reducing the energy consumption of Bangkok's MSWM.
- When considering energy consumption in the collection system, On Nuch TS region has the highest, however; it has the smallest areas of service.

It is worth noting that CEI in the collection system of three TS regions is the same (0.2 tCO_2e/ton).

- On Nuch TS regions has the highest emission compared to the other two TS because it has a high emission of a waste to landfill, collection system, and a composting plant.
- The relation between collection system and small size areas can influence on less emission in the districts.
- The results from CEI and emission of collection system in 2013 on geographic area confirm that MSW_c volume is individual with emission if the area has an effective MSWM.
- Benchmarking of emission results shows that Bangkok's MSWM has a high emission (relatively lower performance) as compared to both smaller and larger cities. In addition, to achieve low carbon for BKK's MSWM, a unique MSWM system should be designed and implemented similar to which the comparing cities have done.

- The energy consumption in collection system stage (80%) has quite an effect on the total EC of Bangkok's MSWM.
- The result of EI on geographic area shows clearly that energy consumption of Bangkok's MSWM does not depend on with MSW_c volume.
- Results from benchmarking of EC show that Porto, Portugal generates energy from MSWM higher than energy consumption. It has been according to the system designs which is suitable and unique to the city. However, it should be noted that Bangkok's MSWM has higher EC than Porto, while less than that of Hangzhou, China.
- The emission and EC hot spots of Bangkok's MSW metabolism are landfills (82%) and collection systems (80%).
- The hot spot areas of MSWM can be categorized into three groups are

  I. The hot spot district areas identified by *net indicators* (MSWc quantity, net GHG emission, and EC) are Pathumwan, Wattana, Dindang, Bangkapi, and Prawet.

II. The hot spot district areas identified by *intensity indicators* (MSW_c per capita and EI) are Phranakorn and Bangrak. However, only Wattana and Pathumwan are a hot spot of MSW_c per capita.

III. The other hot spot areas identified by *individual indicator except CEI* are Bangkae, Bangkuntian, Klongtoey, Chatuchak, Bangkhen, Ladkrabang, Rachatewi, Huaykwang, Bangbon, Rachatewi, Yannawa, Bangna, Suanluang, Bangsue, Wangthonglang, Taweewattana, Satorn.

The outcomes from performance assessment and benchmarking of Bangkok's MSWM showed an effective MSWM of the individual district is a key influencing factor. The main contribution of the landfill and CS hot spots in MSW management to help to develop Bangkok's low carbon MSWM scheme. It was designed by scenarios development including a consideration of implementation of concerning issues in current Bangkok's MSWM system. This strategy is to support sustainable urbanization growth in Bangkok. Not only hot spots analysis was used to design in scenarios, but also the MFA of local area scales explored on suitable operations to decentralized waste management in local areas. The performance of single and multiple actions (11 scenarios) were evaluated via a set of parameters including GHG emission, energy consumption, the amount of waste to landfill and waste utilization. The key finding from investigation of Bangkok's low carbon MSWM scheme are

- The current Bangkok's MSWM system can reduce GHG emission by 29.84% through combining actions of establishing transfer stations, changing the type of fuel, and the campaign of waste reduction rate by 25%.
- The best option is probability the Bangkok's low carbon MSWM scheme based on the development of hot spots of stage MSWM is the combination actions of changing fuels used in transport vehicles for waste and waste reduction campaign (H6). The reduction emission is 28.89%.

The methodologies and the results can be used as a BMA's database/key information to prioritize areas that require attention on MSWM enhancement. Additionally, the study also benchmarks the results with that of other cities. From benchmarking performance with other cities, the results indicate that other cities developed unique MSWM system which depends on waste characteristics and metabolism that can significantly influence a reduction of emission and energy consumption. The findings also enhance our understanding of indicators used as the basis for system assessment. The key aspect is that only one indicator may not be sufficient to characterize a system. A combination of indicators can help to improve our understanding of sources of problems and solutions.

Based on the overview of Bangkok's MSW metabolism, four individual options that can help BMA to achieve low carbon MSW management were proposed in the study. The scenario development analysis is recommended to be performed before set up of waste reduction policy that can achieve a reduction of 25% waste generation at sources. In combination with other options to further reduce GHG, decentralized composting, changing fuel type used in the vehicles for waste collection along with the campaign of waste reduction rate by 25% (H6) are the most practical options to reduce GHG significantly which emission and EC reduction is 28.89 and 24.21%. Evidence from advantage and disadvantage analysis performed in this study suggest that Changing fuel type and waste reduction campaign is the most suitable for low carbon Bangkok's MSW management scheme. However, this scheme has some limitations. The weakness is in *the technology* by need some know-how in term of technology; *investment cost* by high cost at approximately 54 million Thai Baht; and *policy and organization responsibility issues* because of the vehicles for waste transport are outsourced through contracts which are difficult to change to the natural gas vehicles with immediate effects.

Finally, the developed program to inform and support an implementation of low carbon MSWM scheme performed to promote low carbon MSWM in local areas of Bangkok. The functions of the program help evaluates district's MSWM performance by comparing between estimation of districts' GHG emission and average Bangkok's MSWM emission.

Based on low carbon Bangkok's MSWM scheme, the waste sector can help reducing emission by 15.34 $MtCO_2e$ over ten years period which is a part of LCS plan of Bangkok. These findings enhance our understanding of how to improve waste management system that not only focuses on technologies in term of treatment and disposal but also considers the potential emission avoidance in all waste management stages. The information and results of Bangkok's MSW metabolism can be used to develop suitable options toward low carbon waste management for other cities which have similar limitations to implementation to that of Bangkok.

For future work, an investigation of costs of each option and influence of land uses to Bangkok's MSW generation will be very useful to help developing an effective decision support tool and suitable policies. In addition, the scenarios development will update in accordance the BMA's plan launched such as incineration.

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APPENDICES

QUANTITY OF WASTE IN COMMUNITIES BASED ON MANAGEMENT (CBM) IN 2008-2012.

	CBM in 2013				CBM in 2012	CBM in 2011	CBM in 2010	CBM in 2009	CBM in 2008
District	**Food-waste by composting (ton/year)**	**Food stuff (ton/year)**	**Total**	**Ratio composting**	**Food-waste by composting (ton/year)**	**Food-waste by composting (ton/year)**	**Food-waste by composting (ton/year)**	**Food-waste by composting (ton/year)**	**Food-waste by composting (ton/year)**
Chatuchak	60.35	0.72	61.07	1.86	2.98	2.36	1.69	1.48	0.92
Bangkapi	3.93	0.26	4.19	0.12	0.19	0.15	0.11	0.10	0.06
Klongtoey	99.68	3.2	102.88	3.08	4.93	3.89	2.79	2.45	1.53
Bangkae	12.63	0.47	13.1	0.39	0.62	0.49	0.35	0.31	0.19
Bangkuntein	12.03	0.94	12.97	0.37	0.59	0.47	0.34	0.30	0.18
Bangkane	12.39	0.4	12.79	0.38	0.61	0.48	0.35	0.30	0.19
Dindang	8.2	19.24	27.44	0.25	0.41	0.32	0.23	0.20	0.13
Wattana	11.11	1.83	12.94	0.34	0.55	0.43	0.31	0.27	0.17
Prawet	25.11	1.9	27.01	0.78	1.24	0.98	0.70	0.62	0.38
Pathumwan	72.15	7.3	79.45	2.23	3.57	2.82	2.02	1.77	1.10
Ladkrabung	25.4	1.1	26.5	0.78	1.26	0.99	0.71	0.62	0.39
Chomthong	7.66	2	9.66	0.24	0.38	0.30	0.21	0.19	0.12
Phranakorn	709.67	2.44	712.11	21.93	35.09	27.71	19.85	17.41	10.86
Bangbon	0.18	0.6	0.78	0.01	0.01	0.01	0.01	0.00	0.00
Wangthonglang	107.07	7.8	114.87	3.31	5.29	4.18	3.00	2.63	1.64
Suanluang	31.42	6.59	38.01	0.97	1.55	1.23	0.88	0.77	0.48
Bangna	48.89	0.2	49.09	1.51	2.42	1.91	1.37	1.20	0.75
Bangkoknoi	35.68	0.22	35.9	1.10	1.76	1.39	1.00	0.88	0.55
Dusit	19.93	0.8	20.73	0.62	0.99	0.78	0.56	0.49	0.31
Ratchatewi	71.02	7.9	78.92	2.19	3.51	2.77	1.99	1.74	1.09
Thonburi	1.18	3.74	4.92	0.04	0.06	0.05	0.03	0.03	0.02
Minburi	9.89	6.59	16.48	0.31	0.49	0.39	0.28	0.24	0.15
Saimai	260	1.3	261.3	8.03	12.86	10.15	7.27	6.38	3.98
Nongkaem	107.18	0.14	107.32	3.31	5.30	4.19	3.00	2.63	1.64
Yannawa	22.58	3	25.58	0.70	1.12	0.88	0.63	0.55	0.35
Bangsue	79.7	12	91.7	2.46	3.94	3.11	2.23	1.96	1.22
Sathorn	26.35	0.8	27.15	0.81	1.30	1.03	0.74	0.65	0.40
Donmuang	85.5	0.3	85.8	2.64	4.23	3.34	2.39	2.10	1.31
Lardprao	38	5	43	1.17	1.88	1.48	1.06	0.93	0.58
Phasicharoen	7.2	0.1	7.3	0.22	0.36	0.28	0.20	0.18	0.11
Bangrak	108.79	15	123.79	3.36	5.38	4.25	3.04	2.67	1.67
Phayathai	15.3	5.5	20.8	0.47	0.76	0.60	0.43	0.38	0.23
Huaykwang	12.8	6.91	19.71	0.40	0.63	0.50	0.36	0.31	0.20
Buengkum	32.32	1.25	33.57	1.00	1.60	1.26	0.90	0.79	0.49
Laksi	143.12	3.2	146.32	4.42	7.08	5.59	4.00	3.51	2.19
Bangplad	31.21	19.41	50.62	0.96	1.54	1.22	0.87	0.77	0.48
Prakanong	46.59	0.45	47.04	1.44	2.30	1.82	1.30	1.14	0.71
Klongsamwa	76.13	1.5	77.63	2.35	3.76	2.97	2.13	1.87	1.17
Ratburanah	13.97	7.9	21.87	0.43	0.69	0.55	0.39	0.34	0.21
Tungkru	72.33	0.1	72.43	2.24	3.58	2.82	2.02	1.77	1.11
Talingchan	4.66	2.82	7.48	0.14	0.23	0.18	0.13	0.11	0.07
Kannayao	8.59	1	9.59	0.27	0.42	0.34	0.24	0.21	0.13
Sapansoong	8.04	6.5	14.54	0.25	0.40	0.31	0.22	0.20	0.12
Taweewattana	3.49	3.4	6.89	0.11	0.17	0.14	0.10	0.09	0.05
Nongchok	3.43	1.83	5.26	0.11	0.17	0.13	0.10	0.08	0.05
Pom Prap Sattru Phai	24.52	0.78	25.3	0.76	1.21	0.96	0.69	0.60	0.38
Bangkok Yai	72.26	0.1	72.36	2.23	3.57	2.82	2.02	1.77	1.11
Samphantawong	27	0.32	27.32	0.83	1.34	1.05	0.76	0.66	0.41
Bang Kho Laem	12.29	5.87	18.16	0.38	0.61	0.48	0.34	0.30	0.19
Klongsan	507.22	2.44	509.66	15.67	25.08	19.81	14.19	12.44	7.77
Total	**3,236.14**	**185.16**	**3,421.30**	**100.00**	**160.03**	**126.37**	**90.54**	**79.4**	**49.543**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2008

Year / District	2008														
	Ratio of MSW collected	*MSW Collected (ton)*					$\text{Composting}_{\text{Local Area}}$	Collection System	$\text{TS}_{\text{Wrapping}}$	$\text{Composting}_{\text{TS}}$	WTL	LF	**CI (tCO2e/ton)**	**Total (tCO_2e)**
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkapi	7.33	105,965.38	76,280.92	28,483.49	0.25	0.06	0.0079	1,711.50	70.83	3,733.31	652.27	39.77	0.06	6,207.68
Klongtoey	7.46	107,875.35	77,655.84	28,996.89	6.46	1.53	0.1995	2,139.94	72.11	3,800.60	664.03	40.49	0.06	6,717.16
Dindang	6.06	87,557.53	63,029.72	23,535.46	0.53	0.13	0.0164	1,677.95	58.52	3,084.77	538.96	32.86	0.06	5,393.07
Wattana	5.49	79,340.39	57,114.48	21,326.70	0.72	0.17	0.0222	1,374.49	53.03	2,795.27	488.38	29.78	0.06	4,740.95
Prawet	5.38	77,778.74	55,990.30	20,906.93	1.63	0.38	0.0503	1,355.08	51.99	2,740.25	478.77	29.19	0.06	4,655.28
Pathumwan	5.92	85,592.34	61,615.05	23,007.22	4.67	1.10	0.1444	1,502.35	57.21	3,015.54	526.86	32.12	0.06	5,134.09
Ladkrabung	4.97	71,872.58	51,738.66	19,319.35	1.65	0.39	0.0508	1,328.33	48.04	2,532.17	442.41	26.98	0.06	4,377.93
Phranakorn	4.97	71,878.33	51,742.79	19,320.90	45.97	10.86	1.4206	1,740.64	48.04	2,532.37	442.45	26.98	0.07	4,790.49
Wangthonglang	4.78	69,055.35	49,710.63	18,562.08	6.94	1.64	0.2143	1,669.66	46.16	2,432.92	425.07	25.92	0.07	4,599.72
Suanluang	5.02	72,588.02	52,253.68	19,511.66	2.04	0.48	0.0629	1,140.46	48.52	2,557.38	446.82	27.24	0.06	4,220.41
Bangna	4.92	71,120.20	51,197.04	19,117.11	3.17	0.75	0.0979	1,055.29	47.54	2,505.66	437.78	26.69	0.06	4,072.96
Ratchatewi	4.36	63,029.27	45,372.65	16,942.27	4.60	1.09	0.1422	1,424.29	42.13	2,220.61	387.98	23.66	0.07	4,098.66
Yannawa	4.24	61,323.55	44,144.76	16,483.77	1.46	0.35	0.0452	1,787.28	40.99	2,160.51	377.48	23.02	0.07	4,389.28
Sathorn	4.04	58,322.70	41,984.55	15,677.14	1.71	0.40	0.0527	1,511.26	38.98	2,054.79	359.01	21.89	0.07	3,985.93
Lardprao	3.61	52,176.11	37,559.83	14,024.94	2.46	0.58	0.0761	884.19	34.88	1,838.24	321.17	19.58	0.06	3,098.06
Bangrak	3.98	57,486.56	41,382.64	15,452.39	7.05	1.67	0.2178	1,304.36	38.42	2,025.33	353.86	21.58	0.07	3,743.55
Phayathai	3.67	53,064.23	38,199.16	14,263.67	0.99	0.23	0.0306	1,535.65	35.47	1,869.53	326.64	19.92	0.07	3,787.20
Huaykwang	4.06	58,661.44	42,228.40	15,768.20	0.83	0.20	0.0256	1,460.83	39.21	2,066.72	361.09	22.02	0.07	3,949.87
Prakanong	3.61	52,180.33	37,562.87	14,026.07	3.02	0.71	0.0933	821.15	34.88	1,838.39	321.20	19.58	0.06	3,035.19
Sapansoong	2.36	34,144.97	24,579.82	9,178.17	0.52	0.12	0.0161	690.38	22.82	1,202.97	210.18	12.82	0.06	2,139.18
Pom Prap Sattru Pha	2.25	32,568.82	23,445.20	8,754.50	1.59	0.38	0.0491	451.92	21.77	1,147.44	200.48	12.22	0.06	1,833.84
Samphantawong	1.51	21,776.47	15,676.15	5,853.52	1.75	0.41	0.0540	491.38	14.56	767.22	134.05	8.17	0.06	1,415.37
Total	**100**	**1,445,358.66**	**1,040,465.14**	**388,512.41**	**100.00**	***23.63***	**3.09**	**29,058.40**	**966.1**	**50,921.99**	**8,896.92**	**542.47**	0.06	**90,385.88**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2009

Year / District	2009														
	Ratio of MSW collected	*MSW Collected (ton)*					$Composting_{Local Area}$	Collection System	$TS_{Wrapping}$	$Composting_{TS}$	WTL	LF	CI ($tCO2e$/ ton)	Total (tCO_2e)
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkapi	7.45	106,336.07	76,547.76	28,583.14	0.25	0.10	0.0136	1,717.49	71.97	5,070.63	654.55	7,736.26	0.14	15,250.90
Klongtoey	7.36	104,987.44	75,576.93	28,220.62	6.46	2.45	0.3461	2,082.65	71.06	5,006.32	646.25	7,638.14	0.15	15,444.42
Dindang	6.00	85,668.42	61,669.82	23,027.67	0.53	0.20	0.0285	1,641.74	57.98	4,085.09	527.33	6,232.63	0.15	12,544.78
Wattana	5.63	80,427.35	57,896.95	21,618.87	0.72	0.27	0.0386	1,393.32	54.44	3,835.17	495.07	5,851.32	0.14	11,629.33
Prawet	5.51	78,642.45	56,612.06	21,139.09	1.63	0.62	0.0872	1,370.13	53.23	3,750.06	484.08	5,721.47	0.14	11,378.96
Pathumwan	5.62	80,231.17	57,755.72	21,566.14	4.67	1.77	0.2505	1,408.25	54.30	3,825.82	493.86	5,837.05	0.14	11,619.29
Ladkrabung	4.93	70,439.75	50,707.21	18,934.20	1.65	0.62	0.0882	1,301.85	47.68	3,358.91	433.59	5,124.70	0.15	10,266.73
Phranakorn	4.90	69,985.06	50,379.89	18,811.98	45.97	17.41	2.4642	1,694.80	47.37	3,337.23	430.79	5,091.62	0.15	10,601.81
Wangthonglang	4.80	68,576.48	49,365.90	18,433.36	6.94	2.63	0.3718	1,658.08	46.42	3,270.06	422.12	4,989.14	0.15	10,385.82
Suanluang	5.19	74,034.16	53,294.70	19,900.38	2.04	0.77	0.1091	1,163.18	50.11	3,530.31	455.72	5,386.20	0.14	10,585.52
Bangna	4.83	68,976.78	49,654.07	18,540.96	3.17	1.20	0.1698	1,023.48	46.69	3,289.15	424.59	5,018.26	0.14	9,802.17
Ratchatewi	4.45	63,480.57	45,697.53	17,063.58	4.60	1.74	0.2466	1,434.49	42.97	3,027.07	390.76	4,618.40	0.15	9,513.67
Yannawa	4.27	60,939.14	43,868.04	16,380.44	1.46	0.55	0.0784	1,776.08	41.25	2,905.88	375.11	4,433.50	0.16	9,531.81
Sathorn	4.08	58,281.29	41,954.74	15,666.01	1.71	0.65	0.0915	1,510.19	39.45	2,779.14	358.75	4,240.13	0.15	8,927.66
Lardprao	3.71	52,995.70	38,149.82	14,245.24	2.46	0.93	0.1319	898.08	35.87	2,527.09	326.22	3,855.59	0.14	7,642.85
Bangrak	3.95	56,354.93	40,568.02	15,148.21	7.05	2.67	0.3778	1,278.68	38.14	2,687.28	346.89	4,099.98	0.15	8,450.99
Phayathai	3.79	54,163.03	38,990.15	14,559.02	0.99	0.38	0.0531	1,567.45	36.66	2,582.76	333.40	3,940.52	0.16	8,460.79
Huaykwang	3.78	53,896.05	38,797.96	14,487.26	0.83	0.31	0.0444	1,342.16	36.48	2,570.03	331.76	3,921.09	0.15	8,201.52
Prakanong	3.61	51,475.92	37,055.79	13,836.73	3.02	1.14	0.1618	810.06	34.84	2,454.62	316.86	3,745.02	0.14	7,361.41
Sapansoong	2.38	33,962.76	24,448.65	9,129.19	0.52	0.20	0.0279	686.70	22.99	1,619.51	209.06	2,470.89	0.15	5,009.14
Pom Prap Sattru Pha	2.23	31,771.40	22,871.16	8,540.15	1.59	0.60	0.0851	440.86	21.50	1,515.02	195.57	2,311.46	0.14	4,484.41
Samphantawong	1.52	21,725.99	15,639.81	5,839.95	1.75	0.66	0.0938	490.24	14.71	1,036.00	133.73	1,580.63	0.15	3,255.31
Total	**100**	**1,427,351.91**	**1,027,502.68**	**383,672.19**	**100.00**	*37.87*	**5.36**	**28,689.97**	**966.10**	**68,063.14**	**8,786.08**	**103,844**	0.15	**210,349.29**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2010

Year / District	2010													
	Ratio of MSW collected	MSW Collected (ton)					$Composting_{Local\ Area}$	Collection System	$TS_{Wrapping}$	$Composting_{TS}$	WTL	LF	CI ($tCO2e$/ton)	Total (tCO_2e)
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO2e	tCO2e		
Bangkapi	7.30	102,314.87	73,653.04	27,502.24	0.25	0.11	0.0167	1,652.54	70.54	5,982.29	629.80	14,381.82	0.22	22,717.00
Klongtoey	7.24	101,396.49	72,991.93	27,255.38	6.46	2.79	0.4243	2,011.42	69.91	5,928.59	624.15	14,252.73	0.23	22,886.80
Dindang	5.96	83,472.87	60,089.31	22,437.51	0.53	0.23	0.0349	1,599.67	57.55	4,880.61	513.82	11,733.31	0.23	18,784.96
Wattana	5.76	80,695.02	58,089.63	21,690.82	0.72	0.31	0.0473	1,397.96	55.63	4,718.19	496.72	11,342.84	0.22	18,011.35
Prawet	5.61	78,607.18	56,586.67	21,129.61	1.63	0.70	0.1069	1,369.51	54.19	4,596.12	483.87	11,049.37	0.22	17,553.06
Pathumwan	5.48	76,843.79	55,317.26	20,655.61	4.67	2.02	0.3071	1,348.79	52.98	4,493.01	473.01	10,801.50	0.22	17,169.30
Ladkrabung	5.11	71,626.50	51,561.51	19,253.20	1.65	0.71	0.1081	1,323.79	49.38	4,187.96	440.90	10,068.13	0.22	16,070.16
Phranakorn	5.01	70,271.63	50,586.19	18,889.01	45.97	19.85	3.0205	1,701.74	48.45	4,108.74	432.56	9,877.69	0.23	16,169.17
Wangthonglang	4.85	67,960.34	48,922.37	18,267.74	6.94	3.00	0.4557	1,643.18	46.85	3,973.60	418.33	9,552.80	0.23	15,634.77
Suanluang	5.02	70,351.88	50,643.95	18,910.59	2.04	0.88	0.1337	1,105.33	48.50	4,113.43	433.05	9,888.97	0.22	15,589.28
Bangna	4.77	66,861.00	48,130.99	17,972.24	3.17	1.37	0.2081	992.09	46.10	3,909.32	411.56	9,398.27	0.22	14,757.35
Ratchatewi	4.26	59,713.75	42,985.92	16,051.06	4.60	1.99	0.3023	1,349.37	41.17	3,491.43	367.57	8,393.62	0.23	13,643.16
Yannawa	4.21	58,941.55	42,430.04	15,843.49	1.46	0.63	0.0961	1,717.86	40.64	3,446.28	362.82	8,285.08	0.24	13,852.67
Sathorn	4.15	58,161.65	41,868.62	15,633.85	1.71	0.74	0.1122	1,507.09	40.10	3,400.68	358.01	8,175.45	0.23	13,481.33
Lardprao	3.89	54,488.82	39,224.67	14,646.59	2.46	1.06	0.1617	923.39	37.57	3,185.93	335.41	7,659.19	0.22	12,141.47
Bangrak	3.88	54,424.08	39,178.07	14,629.19	7.05	3.04	0.4630	1,234.87	37.52	3,182.14	335.01	7,650.09	0.23	12,439.63
Phayathai	3.86	54,133.12	38,968.61	14,550.98	0.99	0.43	0.0651	1,566.59	37.32	3,165.13	333.22	7,609.19	0.23	12,711.44
Huaykwang	3.84	53,872.89	38,781.28	14,481.03	0.83	0.36	0.0545	1,341.58	37.14	3,149.92	331.62	7,572.61	0.23	12,432.86
Prakanong	3.54	49,642.92	35,736.27	13,344.02	3.02	1.30	0.1983	781.22	34.23	2,902.59	305.58	6,978.02	0.22	11,001.64
Sapansoong	2.43	34,003.69	24,478.11	9,140.19	0.52	0.22	0.0342	687.53	23.44	1,988.18	209.31	4,779.71	0.23	7,688.16
Pom Prap Sattru Pha	2.30	32,207.60	23,185.17	8,657.40	1.59	0.69	0.1044	446.91	22.20	1,883.16	198.25	4,527.24	0.22	7,077.77
Samphantawong	1.52	21,309.60	15,340.07	5,728.02	1.75	0.76	0.1149	480.85	14.69	1,245.96	131.17	2,995.37	0.23	4,868.04
Total	**100**	**1,401,301.24**	**1,008,749.68**	**376,669.77**	**100.00**	***43.19***	**6.57**	**28,183.25**	**966.10**	**81,933.28**	**8,625.72**	**196,973**	0.23	**316,681.36**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2011

Year / District	2011													
	Ratio of MSW collected	MSW Collected (ton)					$Composting_{Local\ Area}$	Collection System	$TS_{Wrapping}$	$Composting_{TS}$	WTL	LF	**CI (tCO2e/ton)**	**Total (tCO_2e)**
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkapi	7.28	103,590.17	74,571.08	27,845.04	0.25	0.15	0.0252	1,673.14	70.37	6,907.87	637.65	19,993.09	0.28	29,282.13
Klongtoey	7.28	103,491.31	74,499.92	27,818.46	6.46	3.89	0.6392	2,052.97	70.30	6,901.28	637.04	19,974.01	0.29	29,635.61
Dindang	5.92	84,144.16	60,572.55	22,617.95	0.53	0.32	0.0526	1,612.53	57.16	5,611.12	517.95	16,239.98	0.29	24,038.74
Wattana	5.96	84,791.00	61,038.19	22,791.82	0.72	0.43	0.0712	1,468.92	57.60	5,654.26	521.93	16,364.82	0.28	24,067.53
Prawet	5.50	78,276.71	56,348.77	21,040.78	1.63	0.98	0.1610	1,363.75	53.17	5,219.85	481.83	15,107.55	0.28	22,226.16
Pathumwan	5.61	79,752.66	57,411.26	21,437.52	4.67	2.82	0.4627	1,399.85	54.18	5,318.28	490.92	15,392.41	0.28	22,655.63
Ladkrabung	5.21	74,133.96	53,366.55	19,927.21	1.65	0.99	0.1629	1,370.13	50.36	4,943.60	456.33	14,307.99	0.29	21,128.41
Phranakorn	4.89	69,543.25	50,061.85	18,693.23	45.97	27.71	4.5510	1,684.10	47.24	4,637.47	428.07	13,421.97	0.29	20,218.85
Wangthonglang	5.01	71,218.89	51,268.09	19,143.64	6.94	4.18	0.6866	1,721.97	48.38	4,749.21	438.39	13,745.38	0.29	20,703.32
Suanluang	4.80	68,324.37	49,184.42	18,365.59	2.04	1.23	0.2015	1,073.47	46.41	4,556.19	420.57	13,186.73	0.28	19,283.37
Bangna	4.87	69,292.28	49,881.18	18,625.76	3.17	1.91	0.3135	1,028.17	47.07	4,620.73	426.53	13,373.54	0.28	19,496.03
Ratchatewi	4.47	63,507.55	45,716.95	17,070.83	4.60	2.77	0.4554	1,435.10	43.14	4,234.98	390.92	12,257.07	0.29	18,361.21
Yannawa	4.08	58,079.10	41,809.19	15,611.66	1.46	0.88	0.1448	1,692.72	39.45	3,872.98	357.51	11,209.37	0.30	17,172.04
Sathorn	3.99	56,674.40	40,798.00	15,234.08	1.71	1.03	0.1690	1,468.55	38.50	3,779.31	348.86	10,938.26	0.29	16,573.48
Lardprao	4.04	57,439.32	41,348.64	15,439.69	2.46	1.48	0.2437	973.39	39.02	3,830.32	353.57	11,085.89	0.28	16,282.19
Bangrak	3.92	55,685.21	40,085.91	14,968.18	7.05	4.25	0.6977	1,263.49	37.83	3,713.35	342.77	10,747.35	0.29	16,104.78
Phayathai	3.82	54,336.13	39,114.75	14,605.55	0.99	0.60	0.0981	1,572.46	36.91	3,623.39	334.47	10,486.97	0.30	16,054.20
Huaykwang	3.83	54,535.24	39,258.09	14,659.07	0.83	0.50	0.0821	1,358.08	37.05	3,636.66	335.69	10,525.40	0.29	15,892.88
Prakanong	3.48	49,482.95	35,621.11	13,301.02	3.02	1.82	0.2988	778.70	33.61	3,299.75	304.59	9,550.30	0.28	13,966.96
Sapansoong	2.31	32,785.73	23,601.35	8,812.80	0.52	0.31	0.0516	662.90	22.27	2,186.30	201.81	6,327.71	0.29	9,401.00
Pom Prap Sattru Pha	2.24	31,841.21	22,921.42	8,558.92	1.59	0.96	0.1572	441.83	21.63	2,123.32	196.00	6,145.41	0.28	8,928.19
Samphantawong	1.49	21,242.35	15,291.65	5,709.94	1.75	1.05	0.1731	479.33	14.43	1,416.54	130.76	4,099.81	0.29	6,140.87
Total	**100**	**1,422,167.95**	**1,023,770.92**	**382,278.74**	**100.00**	***60.28***	**9.90**	**28,575.54**	966.10	**94,836.76**	**8,754.17**	**274,481**	0.29	**407,613.57**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2012

Year / District	2012													
	Ratio of MSW collected	MSW Collected (ton)					$Composting_{Local\ Area}$	Collection System	$TS_{Wrapping}$	$Composting_{TS}$	WTL	LF	**CI (tCO_2e/ton)**	**Total (tCO_2e)**
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkapi	7.46	116,852.28	84,118.03	31,409.89	0.25	0.19	0.0337	1,887.34	72.05	8,238.45	719.29	35,981.30	0.40	46,898.42
Klongtoey	7.24	113,366.98	81,609.08	30,473.04	6.46	4.93	0.8537	2,248.88	69.90	7,992.72	697.83	34,908.10	0.41	45,917.43
Dindang	5.91	92,598.24	66,658.36	24,890.41	0.53	0.41	0.0702	1,774.55	57.09	6,528.46	569.99	28,512.96	0.40	37,443.05
Wattana	6.15	96,420.35	69,409.77	25,917.79	0.72	0.55	0.0951	1,670.39	59.45	6,797.93	593.52	29,689.87	0.40	38,811.16
Prawet	5.37	84,074.11	60,522.13	22,599.12	1.63	1.24	0.2150	1,464.76	51.84	5,927.48	517.52	25,888.20	0.40	33,849.80
Pathumwan	6.13	96,094.56	69,175.24	25,830.22	4.67	3.57	0.6179	1,686.69	59.25	6,774.96	591.51	29,589.55	0.40	38,701.97
Ladkrabung	5.22	81,751.98	58,850.50	21,974.93	1.65	1.26	0.2175	1,510.92	50.41	5,763.77	503.23	25,173.17	0.40	33,001.49
Phranakorn	4.46	69,830.96	50,268.96	18,770.56	45.97	35.09	6.0778	1,691.06	43.06	4,923.30	429.85	21,502.44	0.41	28,589.70
Wangthonglang	5.04	78,974.86	56,851.35	21,228.44	6.94	5.29	0.9170	1,909.50	48.69	5,567.97	486.13	24,318.04	0.41	32,330.33
Suanluang	4.98	77,954.08	56,116.52	20,954.06	2.04	1.55	0.2691	1,224.77	48.06	5,496.00	479.85	24,003.72	0.40	31,252.40
Bangna	4.68	73,261.07	52,738.18	19,692.58	3.17	2.42	0.4187	1,087.06	45.17	5,165.13	450.96	22,558.64	0.40	29,306.95
Ratchatewi	4.54	71,190.66	51,247.76	19,136.05	4.60	3.51	0.6082	1,608.71	43.89	5,019.16	438.21	21,921.12	0.41	29,031.10
Yannawa	3.99	62,458.04	44,961.44	16,788.72	1.46	1.12	0.1934	1,820.34	38.51	4,403.48	384.46	19,232.16	0.41	25,878.96
Sathorn	4.00	62,626.88	45,082.99	16,834.11	1.71	1.30	0.2257	1,622.79	38.61	4,415.39	385.50	19,284.15	0.41	25,746.44
Lardprao	3.79	59,419.07	42,773.79	15,971.85	2.46	1.88	0.3254	1,006.94	36.64	4,189.23	365.75	18,296.39	0.40	23,894.95
Bangrak	3.73	58,521.20	42,127.45	15,730.50	7.05	5.38	0.9317	1,327.84	36.08	4,125.92	360.23	18,019.92	0.41	23,869.99
Phayathai	3.74	58,541.32	42,141.93	15,735.91	0.99	0.76	0.1310	1,694.16	36.09	4,127.34	360.35	18,026.12	0.41	24,244.06
Huaykwang	4.24	66,494.25	47,866.98	17,873.65	0.83	0.63	0.1096	1,655.89	41.00	4,688.05	409.31	20,474.99	0.41	27,269.23
Prakanong	3.42	53,539.86	38,541.55	14,391.51	3.02	2.30	0.3990	842.54	33.01	3,774.72	329.57	16,486.06	0.40	21,465.90
Sapansoong	2.42	37,885.63	27,272.59	10,183.66	0.52	0.40	0.0689	766.02	23.36	2,671.05	233.21	11,665.79	0.41	15,359.42
Pom Prap Sattru Pha	2.11	33,087.79	23,818.79	8,894.00	1.59	1.21	0.2100	459.13	20.40	2,332.79	203.67	10,188.43	0.40	13,204.42
Samphantawong	1.40	21,944.81	15,797.33	5,898.76	1.75	1.34	0.2312	495.18	13.53	1,547.18	135.08	6,757.27	0.41	8,948.24
Total	**100.00**	**1,566,888.98**	**1,127,950.73**	**421,179.76**	**100.00**	***76.33***	**13.22**	**31,455.44**	**966.10**	**110,470.49**	**9,645.00**	**482,478.38**	0.41	**635,015.41**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2013

Year / District	2013													
	Ratio of MSW collected	MSW Collected (ton)					$Composting_{Local Area}$	Collection System	$TS_{Wrapping}$	$Composting_{TS}$	WTL	LF	CI ($tCO2e$/ton)	Total (tCO_2e)
		Total	*Landfill*	*Composting*	*Ratio CBM*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkapi	7.29	121,221.72	88,637.32	32,584.40	0.25	3.93	4.6526	1,871.02	70.41	9,097.05	746.18	53,762.05	0.54	65,546.71
Klongtoey	7.47	124,199.50	90,814.67	33,384.83	6.46	99.68	118.0072	2,849.66	72.14	9,320.52	764.51	55,082.70	0.55	68,089.52
Dindang	5.96	99,180.00	72,520.42	26,659.58	0.53	8.2	9.7077	1,823.31	57.61	7,442.94	610.50	43,986.50	0.54	53,920.86
Wattana	6.28	104,435.06	76,362.92	28,072.14	0.72	11.11	13.1527	1,695.89	60.66	7,837.30	642.85	46,317.13	0.54	56,553.83
Prawet	5.72	95,208.17	69,616.21	25,591.96	1.63	25.11	29.7267	1,601.32	55.30	7,144.87	586.05	42,224.99	0.54	51,612.53
Pathumwan	6.27	104,253.97	76,230.50	28,023.47	4.67	72.15	85.4155	1,518.71	60.55	7,823.71	641.74	46,236.82	0.54	56,281.53
Ladkrabung	5.34	88,903.40	65,006.17	23,897.23	1.65	25.4	30.0700	1,492.11	51.64	6,671.73	547.25	39,428.81	0.54	48,191.54
Phranakorn	4.31	71,713.05	52,436.58	19,276.47	45.97	709.67	840.1499	1,774.53	41.65	5,381.69	441.43	31,804.86	0.55	39,444.17
Wangthonglang	4.97	82,652.84	60,435.76	22,217.08	6.94	107.07	126.7559	1,898.00	48.01	6,202.66	508.77	36,656.68	0.55	45,314.12
Suanluang	5.03	83,642.33	61,159.27	22,483.06	2.04	31.42	37.1969	1,225.45	48.58	6,276.92	514.86	37,095.52	0.54	45,161.33
Bangna	4.73	78,707.49	57,550.92	21,156.57	3.17	48.89	57.8789	1,327.13	45.72	5,906.58	484.48	34,906.91	0.54	42,670.83
Ratchatewi	4.49	74,730.65	54,643.05	20,087.60	4.60	71.02	84.0777	1,601.49	43.41	5,608.14	460.01	33,143.17	0.55	40,856.22
Yannawa	3.91	65,118.84	47,614.90	17,503.94	1.46	22.58	26.7316	1,810.12	37.82	4,886.83	400.84	28,880.32	0.55	36,015.92
Sathorn	3.80	63,128.97	46,159.90	16,969.07	1.71	26.35	31.1947	1,526.78	36.67	4,737.50	388.59	27,997.81	0.55	34,687.35
Lardprao	3.71	61,675.94	45,097.45	16,578.49	2.46	38	44.9867	1,061.66	35.82	4,628.45	379.65	27,353.39	0.54	33,458.97
Bangrak	3.69	61,312.31	44,831.56	16,480.75	7.05	108.79	128.7921	1,491.53	35.61	4,601.17	377.41	27,192.12	0.55	33,697.83
Phayathai	3.46	57,523.47	42,061.16	15,462.31	0.99	15.3	18.1131	1,587.49	33.41	4,316.83	354.09	25,511.76	0.55	31,803.58
Huaykwang	4.37	72,635.95	53,111.41	19,524.54	0.83	12.8	15.1534	1,214.65	42.19	5,450.94	447.11	32,214.17	0.54	39,369.06
Prakanong	3.41	56,753.20	41,497.94	15,255.26	3.02	46.59	55.1560	852.72	32.96	4,259.03	349.34	25,170.14	0.54	30,664.20
Sapansoong	2.50	41,665.98	30,466.16	11,199.82	0.52	8.04	9.5182	776.34	24.20	3,126.81	256.48	18,478.94	0.54	22,662.76
Pom Prap Sattru Pha	1.98	33,003.20	24,131.94	8,871.26	1.59	24.52	29.0282	573.09	19.17	2,476.72	203.15	14,636.98	0.54	17,909.10
Samphantawong	1.30	21,653.00	15,832.67	5,820.33	1.75	27	31.9642	495.83	12.58	1,624.94	133.29	9,603.14	0.55	11,869.78
Total	**100.00**	**1,663,319.04**	**1,216,218.88**	**447,100.16**	**100.00**	**1,543.62**	**1,827.43**	**32,068.83**	**966.10**	**124,823.31**	**10,238.58**	**737,684.92**	0.54	**905,781.74**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2008

Year / District	2008												
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	Ratio of CBM	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI (tCO_2e/ton)	**Total (tCO_2e)**
				Total	*Landfill*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkae	10.27	5.76	0.75	91,510.86	90,046.69	0.1897	0.0251	1,449.54	99.20	226.90	4.12	0.02	1,779.76
Bangkuntein	9.42	5.28	0.71	83,952.21	82,608.97	0.1878	0.0239	1,945.45	91.00	208.16	3.78	0.03	2,248.39
Chomthong	7.99	4.48	0.45	71,214.45	70,075.02	0.1399	0.0152	951.95	77.19	176.58	3.21	0.02	1,208.93
Bangbon	7.60	4.26	0.01	67,738.39	66,654.58	0.0113	0.0004	1,426.18	73.43	167.96	3.05	0.03	1,670.61
Bangkoknoi	7.37	4.13	2.11	65,655.00	64,604.52	0.5199	0.0709	1,222.60	71.17	162.79	2.96	0.02	1,459.52
Thonburi	7.05	3.95	0.07	62,813.51	61,808.49	0.0712	0.0023	2,374.68	68.09	155.75	2.83	0.04	2,601.34
Nongkaem	6.24	3.50	6.33	55,573.35	54,684.18	1.5541	0.2128	1,177.22	60.24	137.79	2.50	0.03	1,377.76
Phasicharoen	6.30	3.53	0.43	56,190.56	55,291.51	0.1057	0.0143	705.01	60.91	139.32	2.53	0.02	907.77
Bangplad	5.89	3.30	1.84	52,518.26	51,677.97	0.7330	0.0620	1,358.50	56.93	130.22	2.37	0.03	1,548.01
Ratburanah	5.00	2.75	0.83	44,559.30	43,026.46	0.3167	0.0277	933.25	48.30	110.48	1.97	0.03	1,094.00
Tungkru	4.64	2.60	4.27	41,313.04	40,652.03	1.0488	0.1436	280.40	44.78	102.44	1.86	0.01	429.47
Talingchan	4.44	2.49	0.28	39,556.01	38,923.11	0.1083	0.0093	618.12	42.88	98.08	1.78	0.02	760.86
Taweewattana	3.45	1.94	0.21	30,776.86	30,284.43	0.0998	0.0069	1,101.73	33.36	76.31	1.39	0.04	1,212.79
Bangkok Yai	3.69	2.07	4.27	32,882.79	32,356.67	1.0478	0.1435	999.40	35.64	81.53	1.48	0.03	1,118.06
Bang Kho Laem	5.48	3.07	0.73	48,849.87	48,068.27	0.2630	0.0244	907.12	52.95	121.12	2.20	0.02	1,083.40
Klongsan	5.18	2.90	29.97	46,155.75	45,417.26	7.3803	1.0072	1,096.76	50.03	114.44	2.08	0.03	1,263.31
Chatuchak	16.38	7.20	3.57	116,654.43	112,641.52	0.8843	0.1198	584.43	158.24	324.49	5.16	0.01	1,072.31
Klongsamwa	5.64	2.52	4.50	40,145.57	39,503.24	1.1241	0.1512	717.32	54.46	111.67	1.81	0.02	885.26
Bangkane	11.83	5.20	0.73	84,222.44	81,325.19	0.1852	0.0246	1,108.86	114.25	234.27	3.72	0.02	1,461.10
Dusit	8.81	3.87	1.18	62,770.93	60,611.61	0.3002	0.0396	947.83	85.15	174.60	2.77	0.02	1,210.36
Minburi	8.67	3.81	0.58	61,757.95	59,633.48	0.2386	0.0196	1,327.19	83.78	171.79	2.73	0.03	1,585.49
Saimai	8.28	3.64	15.36	58,934.41	56,907.07	3.7838	0.5163	402.66	79.95	163.93	2.60	0.01	649.15
Bangsue	8.31	3.65	4.71	59,161.14	57,126.00	1.3279	0.1583	1,690.42	80.25	164.56	2.61	0.03	1,937.85
Donmuang	8.01	3.52	5.05	57,056.73	55,093.98	1.2424	0.1698	2,726.05	77.40	158.71	2.52	0.05	2,964.68
Buengkum	7.70	3.39	1.91	54,870.97	52,983.41	0.4861	0.0642	1,504.96	74.43	152.63	2.42	0.03	1,734.45
Laksi	7.03	3.09	8.46	50,084.65	48,361.74	2.1188	0.2842	1,168.83	67.94	139.32	2.21	0.03	1,378.30
Kannayao	4.94	2.17	0.51	35,187.26	33,976.82	0.1389	0.0171	600.45	47.73	97.88	1.56	0.02	747.61
Nongchok	4.40	1.93	0.20	31,344.76	30,266.50	0.0762	0.0068	744.45	42.52	87.19	1.39	0.03	875.54
Total Nongkaem TS	55.58	56.00	56.92	891,260.21	876,180.16	13.7773	1.9130	18,547.90	966.1	2,209.87	40.10	0.02	***21,763.98***
Total Saimai TS	44.42	44.00	43.08	712,191.24	688,430.54	11.9067	1.4480	13,523.45	966.1	1,981.05	31.51	0.02	***16,502.11***
Total	100.00	100.00	100.00	1,603,451.45	1,564,610.70	25.6839	3.3610	32,071.36	1,932.20	4,190.92	71.61	0.02	***38,266***

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2009

Year / District	2009											
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI (tCO_2e/ ton)	Total (tCO_2e)
			Total	Landfill	CBM	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkae	10.26	5.72	91,574.29	90,109.10	0.304	0.0435	1,450.55	99.15	227.06	14,534.97	0.18	16,311.73
Bangkuntein	9.73	5.43	86,799.27	85,410.48	0.301	0.0414	2,011.42	93.98	215.22	13,777.06	0.19	16,097.68
Chomthong	7.85	4.38	70,028.29	68,907.84	0.224	0.0264	936.10	75.82	173.64	11,115.12	0.18	12,300.67
Bangbon	7.68	4.28	68,519.66	67,423.35	0.018	0.0006	1,442.63	74.19	169.89	10,875.66	0.19	12,562.37
Bangkoknoi	7.53	4.20	67,186.92	66,111.93	0.833	0.1227	1,251.13	72.75	166.59	10,664.13	0.18	12,154.59
Thonburi	6.93	3.86	61,792.87	60,804.18	0.114	0.0041	2,336.09	66.91	153.22	9,807.97	0.20	12,364.18
Nongkaem	6.45	3.60	57,571.50	56,650.36	2.491	0.3687	1,219.55	62.33	142.75	9,137.94	0.19	10,562.57
Phasicharoen	6.28	3.50	56,040.72	55,144.07	0.169	0.0248	703.13	60.68	138.95	8,894.97	0.18	9,797.72
Bangplad	5.84	3.26	52,111.16	51,277.38	1.175	0.1074	1,347.97	56.42	129.21	8,271.25	0.19	9,804.85
Ratburanah	4.82	2.64	42,986.38	41,516.25	0.5075	0.0481	900.30	46.54	106.58	6,696.74	0.19	7,750.17
Tungkru	4.62	2.58	41,204.82	40,545.54	1.681	0.2488	279.66	44.61	102.17	6,540.16	0.17	6,966.60
Talingchan	4.51	2.52	40,242.58	39,598.70	0.174	0.0160	628.85	43.57	99.78	6,387.43	0.18	7,159.63
Taweewattana	3.53	1.97	31,462.86	30,959.45	0.16	0.0120	1,126.29	34.07	78.01	4,993.89	0.20	6,232.25
Bangkok Yai	3.67	2.05	32,746.94	32,222.99	1.679	0.2486	995.27	35.46	81.20	5,197.70	0.20	6,309.62
Bang Kho Laem	5.30	2.96	47,320.56	46,563.43	0.421	0.0423	878.72	51.24	117.33	7,510.87	0.18	8,558.16
Klongsan	5.01	2.79	44,689.45	43,974.42	11.83	1.7450	1,061.92	48.39	110.81	7,093.25	0.19	8,314.37
Chatuchak	16.69	7.38	120,313.02	116,198.31	1.4173	0.2076	602.76	161.26	334.67	18,743.27	0.17	19,841.95
Klongsamwa	5.73	2.58	41,318.27	40,657.18	1.802	0.2619	738.28	55.38	114.93	6,558.17	0.18	7,466.76
Bangkane	11.67	5.16	84,091.15	81,215.23	0.2968	0.0426	1,107.13	112.71	233.91	13,100.35	0.18	14,554.10
Dusit	8.61	3.81	62,063.77	59,941.19	0.4811	0.0686	937.15	83.19	172.64	9,668.76	0.18	10,861.74
Minburi	8.43	3.73	60,762.53	58,684.45	0.3825	0.0340	1,305.80	81.44	169.02	9,466.04	0.19	11,022.31
Saimai	8.41	3.72	60,617.96	58,544.83	6.0641	0.8945	414.17	81.25	168.62	9,443.52	0.17	10,107.55
Bangsue	8.17	3.61	58,904.87	56,890.32	2.1281	0.2742	1,683.10	78.95	163.85	9,176.64	0.20	11,102.55
Donmuang	7.75	3.43	55,873.21	53,962.35	1.9912	0.2941	2,669.50	74.89	155.42	8,704.35	0.22	11,604.16
Buengkum	7.66	3.39	55,247.08	53,357.63	0.7791	0.1112	1,515.27	74.05	153.68	8,606.81	0.19	10,349.81
Laksi	7.27	3.22	52,401.99	50,609.84	3.3957	0.4924	1,222.91	70.24	145.76	8,163.58	0.19	9,602.49
Kannayao	5.02	2.22	36,180.30	34,942.93	0.2226	0.0296	617.40	48.49	100.64	5,636.44	0.18	6,402.97
Nongchok	4.58	2.03	33,010.40	31,881.44	0.1221	0.0118	784.01	44.25	91.82	5,142.61	0.19	6,062.68
Total Nongkaem TS	55.32	55.73	892,278.27	877,219.47	22.08	3.3141	18,569.57	966.1	2,212.40	141,499	0.19	***163,247.18***
Total Saimai TS	44.68	44.27	720,784.55	696,885.71	19.08	2.5086	13,597.47	966.1	2,004.95	112,411	0.19	***128,979.05***
Total	100.00	100.00	1,613,062.82	1,574,105.18	41.16	5.8228	32,167.05	1,932.20	4,217.35	253,910	0.19	***292,226.24***

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2010

Year / District	2010											
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI (tCO2e/ ton)	Total (tCO_2e)
			Total	*Landfill*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO2e		
Bangkae	10.29	5.73	91,789.88	90,321.24	0.34667	0.0533	1,453.96	99.36	227.59	30,251.92	0.35	32,032.84
Bangkuntein	10.02	5.58	89,416.14	87,985.48	0.34323	0.0507	2,072.07	96.79	221.71	29,469.58	0.36	31,860.15
Chomthong	7.80	4.34	69,568.54	68,455.44	0.25564	0.0323	929.95	75.31	172.50	22,928.25	0.35	24,106.01
Bangbon	7.73	4.31	69,018.57	67,914.27	0.02064	0.0008	1,453.13	74.71	171.13	22,747.00	0.36	24,445.97
Bangkoknoi	7.42	4.13	66,224.14	65,164.55	0.95004	0.1505	1,233.20	71.69	164.20	21,826.01	0.36	23,295.10
Thonburi	6.78	3.78	60,527.94	59,559.49	0.1302	0.0050	2,288.27	65.52	150.08	19,948.67	0.38	22,452.55
Nongkaem	6.50	3.62	57,993.33	57,065.44	2.84008	0.4520	1,228.49	62.78	143.79	19,113.32	0.36	20,548.38
Phasicharoen	6.21	3.46	55,426.05	54,539.23	0.19318	0.0304	695.42	60.00	137.43	18,267.20	0.35	19,160.05
Bangplad	5.81	3.23	51,816.05	50,986.99	1.33959	0.1316	1,340.33	56.09	128.48	17,077.43	0.36	18,602.33
Ratburanah	4.81	2.63	42,954.01	41,484.98	0.5788	0.0589	899.63	46.50	106.50	13,894.85	0.36	14,947.48
Tungkru	4.67	2.60	41,696.25	41,029.11	1.91676	0.3050	283.00	45.14	103.39	13,742.16	0.35	14,173.68
Talingchan	4.55	2.54	40,608.27	39,958.54	0.19795	0.0197	634.56	43.96	100.69	13,383.59	0.35	14,162.80
Taweewattana	3.64	2.03	32,444.06	31,924.96	0.18233	0.0147	1,161.41	35.12	80.44	10,692.85	0.37	11,969.82
Bangkok Yai	3.61	2.01	32,245.60	31,729.67	1.91491	0.3047	980.03	34.91	79.95	10,627.44	0.37	11,722.33
Bang Kho Laem	5.21	2.90	46,484.99	45,741.23	0.48058	0.0518	863.21	50.32	115.26	15,320.43	0.36	16,349.21
Klongsan	4.96	2.76	44,241.57	43,533.70	13.4875	2.1389	1,051.28	47.89	109.70	14,581.04	0.36	15,789.91
Chatuchak	17.00	7.53	122,823.21	118,622.66	1.6161	0.2545	615.33	164.20	341.65	39,731.10	0.34	40,852.29
Klongsamwa	6.15	2.77	44,411.36	43,700.78	2.05437	0.3210	793.54	59.37	123.54	14,637.00	0.36	15,613.46
Bangkane	11.81	5.23	85,332.92	82,414.53	0.3385	0.0522	1,123.48	114.08	237.36	27,603.67	0.35	29,078.59
Dusit	8.56	3.79	61,852.14	59,736.80	0.5486	0.0840	933.96	82.69	172.05	20,008.06	0.35	21,196.76
Minburi	8.37	3.70	60,448.32	58,380.99	0.4361	0.0417	1,299.05	80.81	168.14	19,553.95	0.36	21,101.95
Saimai	7.96	3.52	57,492.90	55,526.64	6.9149	1.0964	392.81	76.86	159.92	18,597.92	0.35	19,227.52
Bangsue	8.05	3.57	58,195.91	56,205.61	2.4267	0.3361	1,662.84	77.80	161.88	18,825.33	0.37	20,727.86
Donmuang	7.72	3.42	55,792.29	53,884.19	2.2706	0.3605	2,665.64	74.59	155.19	18,047.80	0.39	20,943.22
Buengkum	7.63	3.38	55,116.07	53,231.10	0.8884	0.1363	1,511.68	73.69	153.31	17,829.06	0.37	19,567.74
Laksi	7.34	3.25	53,070.79	51,255.77	3.8722	0.6035	1,238.52	70.95	147.62	17,167.45	0.36	18,624.54
Kannayao	4.91	2.17	35,487.68	34,274.00	0.2538	0.0362	605.58	47.44	98.71	11,479.63	0.36	12,231.36
Nongchok	4.51	2.00	32,609.42	31,494.18	0.1392	0.0145	774.48	43.60	90.71	10,548.56	0.36	11,457.35
Total Nongkaem TS	55.26	55.67	892,455.39	877,394.34	25.18	4.0623	18,567.93	966.1	2,212.84	293,871.74	0.36	315,618.61
Total Saimai TS	44.74	44.33	722,633.01	698,727.25	21.76	3.0749	13,616.91	966.1	2,010.10	234,029.54	0.36	250,622.65
Total	100.00	100.00	1,615,088.40	1,576,121.59	46.94	7.1372	32,184.84	1,932.20	4,222.93	527,901.28	0.36	**566,241**

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2011

Year / District	2011											
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI ($tCO2e$/ton)	Total (tCO_2e)
			Total	*Landfill*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO2e	tCO_2e		
Bangkae	10.45	5.81	94,322.66	92,813.50	0.48386	0.0795	1,494.08	101.00	233.87	54,378.57	0.61	56,207.53
Bangkuntein	10.36	5.76	93,473.71	91,978.13	0.47906	0.0757	2,166.09	100.10	231.77	53,889.13	0.61	56,387.09
Chomthong	7.78	4.32	70,150.38	69,027.97	0.3568	0.0482	937.73	75.12	173.94	40,442.85	0.60	41,629.64
Bangbon	7.57	4.21	68,331.54	67,238.24	0.02881	0.0011	1,438.67	73.17	169.43	39,394.26	0.61	41,075.53
Bangkoknoi	7.51	4.17	67,759.05	66,674.91	1.32601	0.2246	1,261.78	72.56	168.01	39,064.21	0.61	40,566.56
Thonburi	6.58	3.66	59,361.12	58,411.34	0.18173	0.0074	2,244.16	63.57	147.19	34,222.66	0.63	36,677.58
Nongkaem	6.64	3.69	59,892.59	58,934.31	3.964	0.6748	1,268.72	64.14	148.50	34,529.07	0.61	36,010.42
Phasicharoen	6.05	3.36	54,596.53	53,722.99	0.26963	0.0453	685.01	58.46	135.37	31,475.80	0.60	32,354.64
Bangplad	5.78	3.21	52,116.95	51,283.08	1.86971	0.1965	1,348.11	55.81	129.22	30,046.28	0.62	31,579.43
Ratburanah	4.78	2.61	43,143.35	41,667.85	0.8078	0.0880	903.59	46.20	106.97	24,412.81	0.61	25,469.57
Tungkru	4.67	2.60	42,172.89	41,498.12	2.67529	0.4554	286.23	45.16	104.57	24,313.37	0.60	24,749.33
Talingchan	4.59	2.55	41,395.41	40,733.08	0.27628	0.0293	646.86	44.33	102.64	23,865.14	0.61	24,658.96
Taweewattana	3.71	2.06	33,509.66	32,973.51	0.25449	0.0220	1,199.56	35.88	83.09	19,318.87	0.63	20,637.40
Bangkok Yai	3.55	1.97	31,991.19	31,479.33	2.67271	0.4550	972.30	34.26	79.32	18,443.45	0.62	19,529.33
Bang Kho Laem	5.07	2.82	45,741.32	45,009.46	0.67076	0.0774	849.40	48.98	113.42	26,370.62	0.61	27,382.42
Klongsan	4.90	2.72	44,231.81	43,524.10	18.8249	3.1935	1,051.04	47.37	109.67	25,500.37	0.61	26,708.45
Chatuchak	16.78	7.45	123,318.95	119,101.44	2.2557	0.3800	617.81	162.08	343.03	69,780.43	0.60	70,903.35
Klongsamwa	6.31	2.86	46,406.51	45,664.01	2.86736	0.4793	829.19	60.99	129.09	26,754.12	0.61	27,773.39
Bangkane	11.79	5.24	86,669.71	83,705.61	0.4724	0.0780	1,141.08	113.91	241.08	49,042.34	0.60	50,538.41
Dusit	8.74	3.89	64,273.97	62,075.80	0.7657	0.1255	970.53	84.48	178.79	36,369.64	0.61	37,603.43
Minburi	8.40	3.73	61,733.22	59,621.94	0.6087	0.0623	1,326.66	81.14	171.72	34,931.94	0.61	36,511.46
Saimai	8.26	3.67	60,694.28	58,618.54	9.6514	1.6370	414.69	79.77	168.83	34,344.06	0.60	35,007.34
Bangsue	7.86	3.49	57,771.46	55,795.68	3.3871	0.5018	1,650.71	75.93	160.70	32,690.17	0.62	34,577.51
Donmuang	7.80	3.47	57,342.01	55,380.91	3.1691	0.5383	2,739.68	75.37	159.50	32,447.16	0.64	35,421.71
Buengkum	7.50	3.33	55,150.42	53,264.28	1.2399	0.2035	1,512.62	72.48	153.41	31,207.05	0.62	32,945.56
Laksi	7.30	3.24	53,624.45	51,790.49	5.4045	0.9011	1,251.44	70.48	149.16	30,343.57	0.61	31,814.65
Kannayao	4.87	2.16	35,772.32	34,548.91	0.3542	0.0541	610.43	47.02	99.51	20,241.88	0.61	20,998.84
Nongchok	4.39	1.95	32,303.76	31,198.97	0.1943	0.0216	767.22	42.46	89.86	18,279.19	0.61	19,178.73
Total Nongkaem TS	55.10	55.51	902,190.16	886,969.91	35.14	6.0651	18,753.34	966.1	2,236.98	519,667.45	0.61	***541,623.86***
Total Saimai TS	44.90	44.49	735,061.06	710,766.57	30.37	4.5910	13,832.08	966.1	2,044.67	416,431.54	0.61	***433,274.39***
Total	100.00	100.00	1,637,251.22	1,597,736.48	65.51	10.6561	32,585.42	1,932.20	4,281.64	936,098.99	0.61	***974,898***

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2012

Year / District	2012											
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI (tCO_2e/ ton)	Total (tCO_2e)
			Total	*Landfill*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkae	10.42	5.61	96,728.61	95,180.95	0.6127	0.1073	1,494.08	100.70	239.84	48,829.14	0.53	50,663.76
Bangkuntein	10.47	5.64	97,182.80	95,627.88	0.6067	0.1022	2,295.45	101.17	240.96	49,058.42	0.54	51,696.00
Chomthong	7.55	4.07	70,074.85	68,953.65	0.4518	0.0651	939.67	72.95	173.75	35,374.18	0.53	36,560.55
Bangbon	7.54	4.06	69,958.36	68,839.03	0.0365	0.0015	1,595.11	72.83	173.46	35,315.37	0.54	37,156.77
Bangkoknoi	7.79	4.19	72,305.35	71,148.46	1.6792	0.3030	1,323.04	75.27	179.28	36,500.14	0.54	38,077.74
Thonburi	6.45	3.47	59,870.67	58,912.74	0.2301	0.0100	2,025.16	62.33	148.45	30,223.05	0.55	32,458.99
Nongkaem	6.73	3.62	62,457.00	61,457.69	5.0199	0.9102	1,321.98	65.02	154.86	31,528.64	0.54	33,070.50
Phasicharoen	6.03	3.24	55,929.26	55,034.39	0.3415	0.0611	707.39	58.23	138.68	28,233.40	0.53	29,137.70
Bangplad	5.88	3.17	54,575.48	53,702.27	2.3677	0.2651	1,500.22	56.82	135.32	27,550.01	0.54	29,242.36
Ratburanah	4.61	2.61	42,775.41	44,196.41	1.0230	0.1186	923.02	44.53	106.06	22,673.37	0.54	23,746.98
Tungkru	4.58	2.47	42,528.13	41,847.68	3.3879	0.6143	296.17	44.27	105.45	21,468.44	0.52	21,914.33
Talingchan	4.69	2.53	43,539.77	42,843.13	0.3499	0.0396	684.01	45.33	107.96	21,979.12	0.53	22,816.41
Taweewattana	3.64	1.96	33,810.00	33,269.04	0.3223	0.0296	1,198.04	35.20	83.83	17,067.48	0.55	18,384.55
Bangkok Yai	3.52	1.90	32,697.77	32,174.61	3.3846	0.6137	1,007.53	34.04	81.07	16,506.02	0.55	17,628.66
Bang Kho Laem	5.15	2.77	47,786.66	47,022.07	0.8494	0.1044	869.72	49.75	118.49	24,122.97	0.54	25,160.93
Klongsan	4.93	7.42	45,777.54	125,814.26	23.8392	4.3076	1,167.25	47.66	113.51	64,544.45	0.52	65,872.87
Chatuchak	15.91	5.18	130,269.48	87,779.24	2.8565	0.5125	691.75	153.69	362.36	45,031.96	0.53	46,239.76
Klongsamwa	6.49	3.08	53,176.12	52,325.30	3.6311	0.6465	1,026.72	62.73	147.92	26,843.60	0.54	28,080.97
Bangkane	11.10	3.75	90,887.60	63,592.42	0.5982	0.1052	1,207.96	107.22	252.81	32,623.79	0.54	34,191.79
Dusit	8.04	3.73	65,844.29	63,203.30	0.9696	0.1693	982.74	77.68	183.15	32,424.17	0.53	33,667.74
Minburi	7.99	4.05	65,441.40	68,644.66	0.7708	0.0840	1,430.60	77.20	182.03	35,215.66	0.54	36,905.49
Saimai	8.68	3.43	71,075.44	58,233.27	12.2222	2.2081	491.85	83.85	197.71	29,874.47	0.53	30,647.87
Bangsue	7.36	4.35	60,295.37	73,849.68	4.2892	0.6769	1,803.14	71.13	167.72	37,885.91	0.54	39,927.90
Donmuang	9.34	3.66	76,464.78	62,040.80	4.0133	0.7261	3,010.85	90.21	212.70	31,827.79	0.57	35,141.54
Buengkum	7.84	3.33	64,237.73	56,507.14	1.5702	0.2745	1,630.95	75.78	178.69	28,988.94	0.55	30,874.36
Laksi	7.14	2.44	58,508.12	41,312.49	6.8441	1.2155	1,326.04	69.03	162.75	21,193.88	0.55	22,751.69
Kannayao	5.59	2.10	45,761.45	35,674.65	0.4486	0.0730	641.35	53.99	127.29	18,301.59	0.54	19,124.22
Nongchok	4.51	2.18	36,937.93	36,937.93	0.2460	0.0291	805.77	43.58	102.75	18,949.67	0.54	19,901.76
Total Nongkaem TS	100.00	58.72	927,997.66	996,024.27	44.50	7.6533	19,347.84	966.1	2,300.97	510,974.19	0.54	***533,589.10***
Total Saimai TS	100.00	41.28	818,899.71	700,100.89	38.46	6.7206	15,049.71	966.1	2,277.87	359,161.42	0.54	***377,455.10***
Total	-	100.00	1,746,897.37	1,696,125.16	82.96	14.3739	34,397.56	1,932.20	4,578.84	870,135.61	0.54	***911,044***

GHG EMISSION ESTIMATION OF DISTRICTS UNDER NONG KHAME & SAI MAI TS IN 2013

Year / District	2013											
	Ratio of MSW collected @TS	Ratio of MSW collected @LF	MSW Collected (ton)			Composting Local Area	Collection System	TS	WTL	LF	CI ($tCO2e$/ton)	Total (tCO_2e)
			Total	*Landfill*	*CBM*	tCO_2e	tCO_2e	tCO_2e	tCO_2e	tCO_2e		
Bangkae	10.23	5.51	96,731.50	95,183.80	12.63	89.67	1,494.13	98.80	239.97	44,183.96	0.48	46,016.85
Bangkuntein	10.91	5.88	103,186.88	101,535.89	12.03	85.41	2,437.26	105.39	255.98	47,132.57	0.49	49,931.21
Chomthong	7.84	4.23	74,178.08	72,991.23	7.66	54.38	994.69	75.76	184.02	33,882.25	0.48	35,136.72
Bangbon	7.92	4.27	74,943.88	73,744.78	0.18	1.28	1,708.78	76.54	185.92	34,232.04	0.49	36,203.29
Bangkoknoi	7.24	3.91	68,516.74	67,420.47	35.68	253.32	1,253.71	69.98	169.97	31,296.33	0.49	32,789.99
Thonburi	6.28	3.39	59,427.76	58,476.92	1.18	8.38	2,010.18	60.70	147.43	27,144.76	0.50	29,363.06
Nongkaem	6.60	3.56	62,470.15	61,470.63	107.18	760.95	1,322.26	63.80	154.97	28,534.43	0.49	30,075.46
Phasicharoen	6.08	3.28	57,463.99	56,544.57	7.2	51.12	726.81	58.69	142.55	26,247.77	0.48	27,175.82
Bangplad	5.53	2.98	52,302.50	51,465.66	31.21	221.58	1,437.73	53.42	129.75	23,890.16	0.50	25,511.07
Ratburanah	4.52	2.39	42,707.99	41,238.84	13.97	99.18	921.56	43.62	105.86	19,142.91	0.49	20,213.95
Tungkru	4.80	2.59	45,446.76	44,719.61	72.33	513.52	316.50	46.42	112.74	20,758.67	0.47	21,234.33
Talingchan	4.73	2.55	44,741.69	44,025.82	4.66	33.08	702.89	45.70	110.99	20,436.62	0.48	21,296.20
Taweewattana	3.72	2.00	35,148.68	34,586.30	3.49	24.78	1,245.47	35.90	87.20	16,054.83	0.50	17,423.40
Bangkok Yai	3.36	1.81	31,822.03	31,312.88	72.26	513.03	980.55	32.50	78.94	14,535.32	0.50	15,627.31
Bang Kho Laem	5.33	2.87	50,399.72	49,593.32	12.29	87.26	917.28	51.48	125.03	23,021.03	0.49	24,114.82
Klongsan	4.91	2.65	46,420.76	45,678.03	507.22	3601.12	1,183.65	47.41	115.16	21,203.57	0.49	22,549.79
Chatuchak	16.36	7.53	134,690.30	130,056.95	60.35	428.47	715.22	158.03	374.58	60,371.94	0.47	61,619.78
Klongsamwa	7.41	3.48	61,035.00	60,058.44	76.13	540.50	1,178.45	71.61	169.98	27,878.90	0.49	29,298.95
Bangkane	11.29	5.20	92,979.20	89,780.72	12.39	87.97	1,235.76	109.09	258.58	41,675.87	0.48	43,279.30
Dusit	7.91	3.64	65,105.56	62,865.93	19.93	141.50	971.72	76.39	181.06	29,182.12	0.48	30,411.29
Minburi	8.38	3.86	69,022.43	66,648.06	9.89	70.22	1,508.88	80.98	191.95	30,937.77	0.49	32,719.59
Saimai	8.21	3.78	67,582.79	65,257.94	260	1845.93	467.68	79.29	187.95	30,292.49	0.48	31,027.41
Bangsue	7.11	3.27	58,537.55	56,523.86	79.7	565.85	1,750.57	68.68	162.80	26,238.16	0.50	28,220.21
Donmuang	7.43	3.42	61,173.89	59,069.51	85.5	607.03	2,408.76	71.77	170.13	27,419.84	0.51	30,070.50
Buengkum	8.35	3.85	68,763.52	66,398.05	32.32	229.46	1,745.85	80.68	191.23	30,821.72	0.49	32,839.49
Laksi	6.95	3.20	57,232.42	55,263.62	143.12	1016.11	1,297.13	67.15	159.17	25,653.16	0.49	27,176.61
Kannayao	5.71	2.63	46,979.62	45,363.52	8.59	60.99	658.43	55.12	130.65	21,057.57	0.48	21,901.77
Nongchok	4.89	2.25	40,305.62	38,919.11	3.43	24.35	879.23	47.29	112.09	18,066.10	0.49	19,104.72
Total Nongkaem TS	53.46	54.80	945,909.11	929,988.74	963.33	6839.37	19,653.47	966.1	2,346.48	431,697.22	0.49	454,663.28
Total Saimai TS	46.54	46.54	823,407.90	796,205.71	729.19	5177.04	14,817.69	966.1	2,290.17	369,595.65	0.49	387,669.62
Total	100.00	154.80	1,769,317.01	1,726,194.45	1,692.52	12,016.42	34,471.16	1,932.20	4,636.66	801,292.88	0.49	**842,333**

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2008 AND 2009

Year / District	2008						2009					
	Ratio of MSWc	MSWc (ton/year)	Energy				Ratio of MSWc	MSWc (ton/year)	Energy			
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)
Bangkapi	7.3	105,965	565,711	19,347,313	8,746,492	265	7.4	106,336	567,690	19,414,994	8,781,490	265.2
Klongtoey	7.5	107,875	707,324	24,190,475	8,904,143	307	7.4	104,987	688,388	23,542,877	8,670,117	306.8
Dindang	6.1	87,558	554,619	18,967,968	7,227,089	299	6.0	85,668	542,653	18,558,722	7,074,706	299.2
Wattana	5.5	79,340	454,317	15,537,645	6,548,838	278	5.6	80,427	460,541	15,750,511	6,641,885	278.4
Prawet	5.4	77,779	447,900	15,318,192	6,419,937	279	5.5	78,642	452,874	15,488,296	6,494,484	279.5
Pathumwan	5.9	85,592	496,579	16,983,015	7,064,880	281	5.6	80,231	465,476	15,919,265	6,625,684	281.0
Ladkrabung	5.0	71,873	439,061	15,015,870	5,932,437	291	4.9	70,440	430,308	14,716,519	5,817,085	291.5
Phranakorn	5.0	71,878	575,343	19,676,733	5,932,911	356	4.9	69,985	560,189	19,158,449	5,779,536	356.3
Wangthonglang	4.8	69,055	551,879	18,874,276	5,699,900	356	4.8	68,576	548,052	18,743,391	5,663,212	355.9
Suanluang	5.0	72,588	376,961	12,892,062	5,991,490	260	5.2	74,034	384,471	13,148,905	6,113,920	260.2
Bangna	4.9	71,120	348,809	11,929,280	5,870,335	250	4.8	68,977	338,297	11,569,755	5,696,270	250.3
Ratchatewi	4.4	63,029	470,777	16,100,559	5,202,501	338	4.4	63,481	474,147	16,215,842	5,242,379	338.0
Yannawa	4.2	61,324	590,757	20,203,905	5,061,709	412	4.3	60,939	587,054	20,077,256	5,032,502	412.0
Sathorn	4.0	58,323	499,524	17,083,708	4,814,016	375	4.1	58,281	499,169	17,071,579	4,813,010	375.5
Lardprao	3.6	52,176	292,257	9,995,179	4,306,670	274	3.7	52,996	296,848	10,152,185	4,376,513	274.1
Bangrak	4.0	57,487	431,136	14,744,854	4,745,000	339	3.9	56,355	422,649	14,454,600	4,653,927	339.1
Phayathai	3.7	53,064	507,587	17,359,460	4,379,976	410	3.8	54,163	518,097	17,718,922	4,472,914	409.7
Huaykwang	4.1	58,661	482,854	16,513,616	4,841,976	364	3.8	53,896	443,629	15,172,124	4,450,866	364.1
Prakanong	3.6	52,180	271,417	9,282,471	4,307,018	260	3.6	51,476	267,753	9,157,162	4,251,006	260.5
Sapansoong	2.4	34,145	228,195	7,804,281	2,818,361	311	2.4	33,963	226,978	7,762,635	2,804,727	311.1
Pom Prap Sattru Phai	2.3	32,569	149,377	5,108,686	2,688,264	239	2.2	31,771	145,719	4,983,605	2,623,759	239.4
Samphantawong	1.5	21,776	162,419	5,554,713	1,797,452	338	1.5	21,726	162,042	5,541,837	1,794,185	337.7
Total	**100.0**	1,445,359	9,604,803	328,484,263	119,301,393	310	100.0	1,427,352	9,483,024	324,319,428	117,874,178	309.8

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2010 AND 2011

Year / District	2010						2011						
	Ratio of MSWc	MSWc (ton/year)	Energy				Ratio of MSWc	MSWc (ton/year)	Energy				
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)
Bangkapi	7.3	102,315	546,222	18,680,797	8,455,730	265.2	7.3	103,590	553,031	18,913,643	8,555,983	27,469,626	265.2
Klongtoey	7.2	101,396	664,843	22,737,625	8,379,831	306.9	7.3	103,491	678,578	23,207,378	8,547,817	31,755,195	306.8
Dindang	6.0	83,473	528,745	18,083,090	6,898,548	299.3	5.9	84,144	532,997	18,228,514	6,949,848	25,178,363	299.2
Wattana	5.8	80,695	462,074	15,802,930	6,668,975	278.5	6.0	84,791	485,528	16,605,067	7,003,274	23,608,341	278.4
Prawet	5.6	78,607	452,671	15,481,350	6,496,427	279.6	5.5	78,277	450,768	15,416,265	6,465,229	21,881,494	279.5
Pathumwan	5.5	76,844	445,823	15,247,150	6,350,693	281.1	5.6	79,753	462,699	15,824,321	6,587,134	22,411,455	281.0
Ladkrabung	5.1	71,627	437,557	14,964,459	5,919,514	291.6	5.2	74,134	452,875	15,488,326	6,123,061	21,611,386	291.5
Phranakorn	5.0	70,272	562,482	19,236,898	5,807,542	356.4	4.9	69,543	556,652	19,037,504	5,743,893	24,781,396	356.3
Wangthonglang	4.8	67,960	543,128	18,574,987	5,616,527	356.0	5.0	71,219	569,170	19,465,617	5,882,292	25,347,909	355.9
Suanluang	5.0	70,352	365,348	12,494,910	5,814,174	260.3	4.8	68,324	354,819	12,134,812	5,643,220	17,778,032	260.2
Bangna	4.8	66,861	327,920	11,214,867	5,525,673	250.4	4.9	69,292	339,844	11,622,676	5,723,164	17,345,840	250.3
Ratchatewi	4.3	59,714	446,012	15,253,624	4,934,995	338.1	4.5	63,508	474,349	16,222,734	5,245,377	21,468,111	338.0
Yannawa	4.2	58,942	567,811	19,419,122	4,871,177	412.1	4.1	58,079	559,502	19,134,975	4,797,017	23,931,992	412.1
Sathorn	4.2	58,162	498,144	17,036,534	4,806,722	375.6	4.0	56,674	485,406	16,600,893	4,680,996	21,281,889	375.5
Lardprao	3.9	54,489	305,211	10,438,216	4,503,184	274.2	4.0	57,439	321,738	11,003,432	4,744,174	15,747,606	274.2
Bangrak	3.9	54,424	408,168	13,959,352	4,497,834	339.1	3.9	55,685	417,626	14,282,822	4,599,294	18,882,116	339.1
Phayathai	3.9	54,133	517,811	17,709,137	4,473,788	409.8	3.8	54,336	519,753	17,775,550	4,487,868	22,263,418	409.7
Huaykwang	3.8	53,873	443,439	15,165,604	4,452,281	364.2	3.8	54,535	448,891	15,352,061	4,504,313	19,856,374	364.1
Prakanong	3.5	49,643	258,219	8,831,086	4,102,699	260.5	3.5	49,483	257,387	8,802,628	4,087,022	12,889,650	260.5
Sapansoong	2.4	34,004	227,251	7,771,990	2,810,207	311.2	2.3	32,786	219,111	7,493,609	2,707,922	10,201,531	311.2
Pom Prap Sattru Phai	2.3	32,208	147,720	5,052,026	2,661,771	239.5	2.2	31,841	146,040	4,994,555	2,629,910	7,624,465	239.5
Samphantawong	1.5	21,310	158,936	5,435,625	1,761,115	337.7	1.5	21,242	158,435	5,418,471	1,754,502	7,172,973	337.7
Total	100.0	1,401,301	9,315,537	318,591,378	115,809,407	310.0	100.0	1,422,168	9,445,200	323,025,853	117,463,311	440,489,164	309.7

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER ON NUCH TS IN 2012 AND 2013

Year / District	2012							2013						
	Ratio of MSWc	MSWc (ton/year)	Energy					Ratio of MSWc	MSWc (ton/year)	Energy				
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)
Bangkapi	7.5	116,852	596,146	20,388,209	5,835,269	26,223,477	224.4	7.3	121,222	618,438	21,150,582	6,259,542	27,410,124	226.1
Klongtoey	7.2	113,367	859,758	29,403,725	5,661,223	35,064,948	309.3	7.5	124,200	941,910	32,213,330	6,413,306	38,626,637	311.0
Dindang	5.9	92,598	562,672	19,243,390	4,624,091	23,867,482	257.8	6.0	99,180	602,666	20,611,185	5,121,371	25,732,556	259.5
Wattana	6.2	96,420	517,531	17,699,543	4,814,957	22,514,500	233.5	6.3	104,435	560,549	19,170,775	5,392,727	24,563,503	235.2
Prawet	5.4	84,074	467,393	15,984,855	4,198,421	20,183,276	240.1	5.7	95,208	529,291	18,101,754	4,916,277	23,018,031	241.8
Pathumwan	6.1	96,095	462,699	15,824,321	4,798,688	20,623,008	214.6	6.3	104,254	501,987	17,167,967	5,383,376	22,551,343	216.3
Ladkrabung	5.2	81,752	453,522	15,510,464	4,082,460	19,592,924	239.7	5.3	88,903	493,195	16,867,273	4,590,717	21,457,990	241.4
Phranakorn	4.5	69,831	571,151	19,533,355	3,487,159	23,020,513	329.7	4.3	71,713	586,544	20,059,819	3,703,056	23,762,876	331.4
Wangthonglang	5.0	78,975	599,438	20,500,773	3,943,779	24,444,552	309.5	5.0	82,653	627,355	21,455,526	4,267,956	25,723,481	311.2
Suanluang	5.0	77,954	377,506	12,910,711	3,892,804	16,803,515	215.6	5.0	83,642	405,053	13,852,796	4,319,050	18,171,846	217.3
Bangna	4.7	73,261	408,309	13,964,161	3,658,448	17,622,610	240.5	4.7	78,707	438,664	15,002,293	4,064,229	19,066,523	242.2
Ratchatewi	4.5	71,191	504,274	17,246,161	3,555,058	20,801,219	292.2	4.5	74,731	529,349	18,103,735	3,858,877	21,962,612	293.9
Yannawa	4.0	62,458	573,859	19,625,965	3,118,976	22,744,941	364.2	3.9	65,119	598,306	20,462,058	3,362,550	23,824,609	365.9
Sathorn	4.0	62,627	500,641	17,121,912	3,127,407	20,249,320	323.3	3.8	63,129	504,654	17,259,182	3,259,799	20,518,981	325.0
Lardprao	3.8	59,419	338,073	11,562,109	2,967,219	14,529,327	244.5	3.7	61,676	350,914	12,001,264	3,184,769	15,186,033	246.2
Bangrak	3.7	58,521	470,559	16,093,129	2,922,381	19,015,510	324.9	3.7	61,312	493,002	16,860,674	3,165,992	20,026,666	326.6
Phayathai	3.7	58,541	534,005	18,262,979	2,923,386	21,186,365	361.9	3.5	57,523	524,721	17,945,443	2,970,347	20,915,790	363.6
Huaykwang	4.2	66,494	367,535	12,569,697	3,320,533	15,890,230	239.0	4.4	72,636	401,482	13,730,690	3,750,712	17,481,402	240.7
Prakanong	3.4	53,540	265,895	9,093,616	2,673,628	11,767,243	219.8	3.4	56,753	281,854	9,639,394	2,930,573	12,569,966	221.5
Sapansoong	2.4	37,886	233,325	7,979,707	1,891,900	9,871,607	260.6	2.5	41,666	256,607	8,775,948	2,151,512	10,927,460	262.3
Pom Prap Sattru Phai	2.1	33,088	189,911	6,494,956	1,652,310	8,147,266	246.2	2.0	33,003	189,425	6,478,352	1,704,191	8,182,542	247.9
Samphantawong	1.4	21,945	166,099	5,680,580	1,095,861	6,776,441	308.8	1.3	21,653	163,890	5,605,043	1,118,099	6,723,142	310.5
Total	100.0	1,566,889	10,020,302	342,694,319	78,245,958	420,940,277	268.6	100.0	1,663,319	10,599,856	362,515,083	85,889,028	448,404,111	269.6

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER NONG KHAME AND SAI MAI TS IN 2008 AND 2009

Year / District	2008						2009					
	Ratio of MSWc	MSWc (ton/year)	Energy				Ratio of MSWc	MSWc (ton/year)	Energy			
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)
Bangkae	5.7	91,511	479,124	16,386,050	2,852,372	210.2	5.7	91,574	479,456	16,397,408	2,854,301	210.2
Bangkuntein	5.2	83,952	643,038	21,991,888	2,616,770	293.1	5.4	86,799	664,845	22,737,695	2,705,467	293.1
Chomthong	4.4	71,214	314,653	10,761,150	2,219,737	182.3	4.3	70,028	309,413	10,581,910	2,182,729	182.3
Bangbon	4.2	67,738	471,402	16,121,937	2,111,389	269.2	4.2	68,520	476,839	16,307,881	2,135,706	269.2
Bangkoknoi	4.1	65,655	404,111	13,820,608	2,046,451	241.7	4.2	67,187	413,540	14,143,082	2,094,165	241.7
Thonburi	3.9	62,814	784,913	26,844,040	1,957,882	458.5	3.8	61,793	772,160	26,407,859	1,926,037	458.5
Nongkaem	3.5	55,573	389,113	13,307,654	1,732,208	270.6	3.6	57,572	403,103	13,786,133	1,794,460	270.6
Phasicharoen	3.5	56,191	233,030	7,969,610	1,751,446	173.0	3.5	56,041	232,408	7,948,358	1,746,747	173.0
Bangplad	3.3	52,518	449,030	15,356,815	1,636,982	323.6	3.2	52,111	445,549	15,237,776	1,624,265	323.6
Ratburanah	2.8	44,559	308,471	10,549,699	1,388,903	267.9	2.7	42,986	297,582	10,177,300	1,339,853	267.9
Tungkru	2.6	41,313	92,680	3,169,667	1,287,718	107.9	2.6	41,205	92,438	3,161,364	1,284,323	107.9
Talingchan	2.5	39,556	204,309	6,987,380	1,232,951	207.8	2.5	40,243	207,856	7,108,659	1,254,331	207.8
Taweewattana	1.9	30,777	364,160	12,454,257	959,307	435.8	2.0	31,463	372,276	12,731,856	980,673	435.8
Bangkok Yai	2.1	32,883	330,336	11,297,488	1,024,949	374.7	2.0	32,747	328,971	11,250,815	1,020,697	374.7
Bang Kho Laem	3.0	48,850	299,836	10,254,377	1,522,639	241.1	2.9	47,321	290,449	9,933,350	1,474,946	241.1
Klongsan	2.9	46,156	362,517	12,398,084	1,438,664	299.8	2.8	44,689	351,000	12,004,215	1,392,936	299.8
Chatuchak	7.3	116,654	193,173	6,606,517	3,636,091	87.8	7.5	120,313	199,231	6,813,715	3,750,065	87.8
Klongsamwa	2.5	40,146	366,516	12,534,833	1,251,328	343.4	2.6	41,318	365,944	12,515,294	1,287,859	334.1
Bangkane	5.3	84,222	313,291	10,714,565	2,625,193	158.4	5.2	84,091	309,762	10,593,858	2,621,057	157.1
Dusit	3.9	62,771	438,683	15,002,963	1,956,555	270.2	3.8	62,064	431,612	14,761,144	1,934,481	269.0
Minburi	3.9	61,758	133,094	4,551,824	1,924,980	104.9	3.8	60,763	136,896	4,681,853	1,893,922	108.2
Saimai	3.7	58,934	558,742	19,108,990	1,836,971	355.4	3.8	60,618	556,322	19,026,215	1,889,416	345.0
Bangsue	3.7	59,161	901,053	30,816,028	1,844,039	552.1	3.7	58,905	882,363	30,176,815	1,836,020	543.5
Donmuang	3.6	57,057	497,441	17,012,473	1,778,445	329.3	3.5	55,873	500,850	17,129,084	1,741,525	337.7
Buengkum	3.4	54,871	386,339	13,212,787	1,710,315	272.0	3.4	55,247	404,214	13,824,122	1,722,009	281.4
Laksi	3.1	50,085	198,469	6,787,649	1,561,127	166.7	3.2	52,402	204,070	6,979,207	1,633,330	164.4
Kannayao	2.2	35,187	237,100	8,108,820	1,096,778	261.6	2.2	36,180	244,026	8,345,688	1,127,712	261.8
Nongchok	2.0	31,345	246,066	8,415,452	977,009	299.7	2.0	33,010	259,142	8,862,644	1,028,909	299.6
Total	100.0	1,603,451	10,600,690	362,543,604	49,979,197	257.3	100.0	1,613,063	10,632,319	363,625,300	50,277,942	256.6

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER NONG KHAME AND SAI MAI TS IN 2010 AND 2011

Year / District	2010						2011						
	Ratio of MSWc	MSWc (ton/year)	Energy				Ratio of MSWc	MSWc (ton/year)	Energy				
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)
Bangkae	5.7	91,790	480,585	16,436,012	-11232089.07	56.7	5.8	94,323	493,846	16,889,535	-16101715.80	787819	8.4
Bangkuntein	5.5	89,416	684,889	23,423,203	-10941620.67	139.6	5.7	93,474	715,968	24,486,113	-15956792.49	8529321	91.2
Chomthong	4.3	69,569	307,381	10,512,438	-8512921.44	28.7	4.3	70,150	309,952	10,600,359	-11975292.91	-1374934	-19.6
Bangbon	4.3	69,019	480,311	16,426,623	-8445623.04	115.6	4.2	68,332	475,529	16,263,108	-11664800.77	4598307	67.3
Bangkoknoi	4.1	66,224	407,614	13,940,414	-8103675.91	88.1	4.1	67,759	417,062	14,263,518	-11567071.64	2696446	39.8
Thonburi	3.7	60,528	756,353	25,867,277	-7406646.72	305.0	3.6	59,361	741,773	25,368,624	-10133470.40	15235153	256.7
Nongkaem	3.6	57,993	406,057	13,887,145	-7096493.08	117.1	3.7	59,893	419,355	14,341,944	-10224197.05	4117747	68.8
Phasicharoen	3.4	55,426	229,859	7,861,178	-6782341.70	19.5	3.3	54,597	226,419	7,743,525	-9320112.57	-1576587	-28.9
Bangplad	3.2	51,816	443,026	15,151,483	-6340595.38	170.0	3.2	52,117	445,598	15,239,469	-8896826.25	6342642	121.7
Ratburanah	2.7	42,954	297,358	10,169,636	-5256170.57	114.4	2.6	43,143	298,669	10,214,463	-7364953.03	2849510	66.0
Tungkru	2.6	41,696	93,540	3,199,068	-5102261.75	-45.6	2.6	42,173	94,609	3,235,637	-7199286.88	-3963650	-94.0
Talingchan	2.5	40,608	209,744	7,173,256	-4969128.47	54.3	2.5	41,395	213,810	7,312,301	-7066564.14	245737	5.9
Taweewattana	2.0	32,444	383,886	13,128,911	-3970095.31	282.3	2.0	33,510	396,495	13,560,120	-5720396.58	7839723	234.0
Bangkok Yai	2.0	32,246	323,935	11,078,570	-3945810.27	221.2	2.0	31,991	321,379	10,991,163	-5461180.27	5529982	172.9
Bang Kho Laem	2.9	46,485	285,320	9,757,951	-5688247.42	87.5	2.8	45,741	280,756	9,601,842	-7808449.58	1793393	39.2
Klongsan	2.7	44,242	347,483	11,883,908	-5413725.94	146.2	2.7	44,232	347,406	11,881,286	-7550762.82	4330524	97.9
Chatuchak	7.6	122,823	203,388	6,955,875	-15029557.01	-65.7	7.5	123,319	204,209	6,983,950	-21051640.03	-14067690	-114.1
Klongsamwa	2.7	44,411	371,348	12,700,106	-5434502.71	163.6	2.8	46,407	377,166	12,899,061	-7922003.42	4977057	107.2
Bangkane	5.3	85,333	308,706	10,557,734	-10441967.65	1.4	5.3	86,670	320,793	10,971,124	-14795289.26	-3824165	-44.1
Dusit	3.8	61,852	429,380	14,684,813	-7568685.63	115.1	3.9	64,274	438,507	14,996,955	-10972137.53	4024818	62.6
Minburi	3.7	60,448	129,839	4,440,488	-7396903.82	-48.9	3.8	61,733	137,069	4,687,748	-10538408.94	-5850661	-94.8
Saimai	3.6	57,493	549,626	18,797,221	-7035256.76	204.6	3.7	60,694	545,618	18,660,124	-10361052.66	8299072	136.7
Bangsue	3.6	58,196	881,085	30,133,111	-7121282.27	395.4	3.5	57,771	905,559	30,970,106	-9862101.32	21108005	365.4
Donmuang	3.5	55,792	499,663	17,088,465	-6827157.53	183.9	3.5	57,342	499,974	17,099,115	-9788790.39	7310325	127.5
Buengkum	3.4	55,116	409,373	14,000,558	-6744410.25	131.7	3.4	55,150	413,644	14,146,618	-9414666.52	4731952	85.8
Laksi	3.3	53,071	200,164	6,845,600	-6494134.65	6.6	3.3	53,624	201,769	6,900,507	-9154169.88	-2253662	-42.0
Kannayao	2.2	35,488	262,294	8,970,448	-4342535.17	130.4	2.2	35,772	274,077	9,373,439	-6106652.74	3266786	91.3
Nongchok	2.0	32,609	255,994	8,754,989	-3990329.98	146.1	2.0	32,304	253,594	8,672,925	-5514538.74	3158386	97.8
Total	100	1,615,088	10,638,201	363,826,480	-197634170.16	102.9	100.0	1,637,251	10,770,605	368,354,681	-279493324.63	88,861,356	54.3

ENERGY CONSUMPTION ESTIMATION OF DISTRICTS UNDER NONG KHAME AND SAI MAI TS IN 2012 AND 2013

Year / District	2012							2013						
	Ratio of MSWc	MSWc (ton/year)	Energy					Ratio of MSWc	MSWc (ton/year)	Energy				
			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)			EC_{CS}(l)	EC_{CS}(MJ)	EC (MJ)	EC_{total} (MJ)	EI (MJ/ton)
Bangkae	5.5	96,729	493,846	16,889,535	-10564875.69	6324659	65.4	5.5	96,732	493,861	16,890,039	-7499750.95	9390289	97.1
Bangkuntein	5.6	97,183	758,724	25,948,377	-10614483.15	15333894	157.8	5.9	103,187	805,599	27,551,502	-8000247.09	19551254	189.5
Chomthong	4.0	70,075	310,593	10,622,269	-7653703.27	2968566	42.4	4.2	74,178	328,779	11,244,256	-5751147.52	5493108	74.1
Bangbon	4.0	69,958	527,238	18,031,553	-7640980.02	10390573	148.5	4.3	74,944	564,812	19,316,555	-5810521.24	13506034	180.2
Bangkoknoi	4.1	72,305	437,310	14,955,988	-7897322.56	7058666	97.6	3.9	68,517	414,396	14,172,334	-5312214.59	8860119	129.3
Thonburi	3.4	59,871	669,386	22,893,000	-6539184.07	16353816	273.2	3.4	59,428	664,434	22,723,643	-4607531.15	18116111	304.8
Nongkaem	3.6	62,457	436,960	14,944,017	-6821667.77	8122349	130.0	3.6	62,470	437,052	14,947,163	-4843412.61	10103750	161.7
Phasicharoen	3.2	55,929	233,818	7,996,588	-6108696.06	1887892	33.8	3.3	57,464	240,234	8,216,019	-4455276.86	3760742	65.4
Bangplad	3.1	54,575	495,873	16,958,862	-5960833.74	10998028	201.5	3.0	52,303	475,221	16,252,553	-4055098.12	12197455	233.2
Ratburanah	2.4	42,775	305,089	10,434,041	-4672008.51	5762033	134.7	2.4	42,708	304,608	10,417,596	-3249302.99	7168293	167.8
Tungkru	2.4	42,528	97,895	3,348,009	-4645000.14	-1296991	-30.5	2.6	45,447	104,613	3,577,777	-3523561.42	54215	1.2
Talingchan	2.5	43,540	226,089	7,732,258	-4755493.31	2976765	68.4	2.6	44,742	232,331	7,945,708	-3468896.19	4476812	100.1
Taweewattana	1.9	33,810	395,993	13,542,964	-3692790.03	9850174	291.3	2.0	35,149	411,672	14,079,187	-2725134.48	11354052	323.0
Bangkok Yai	1.9	32,698	333,025	11,389,444	-3571310.24	7818134	239.1	1.8	31,822	324,105	11,084,402	-2467213.88	8617188	270.8
Bang Kho Laem	2.7	47,787	287,474	9,831,608	-5219346.40	4612262	96.5	2.9	50,400	303,194	10,369,218	-3907572.49	6461646	128.2
Klongsan	2.6	45,778	385,817	13,194,944	-4999906.64	8195037	179.0	2.6	46,421	391,238	13,380,346	-3599077.23	9781269	210.7
Chatuchak	7.5	130,269	228,647	7,819,712	-14228270.85	-6408559	-49.2	7.5	134,690	236,406	8,085,081	-10247487.52	-2162406	-16.1
Klongsamwa	3.0	53,176	399,273	13,655,151	-5807993.08	7847158	147.6	3.5	61,035	408,462	13,969,398	-4732143.09	9237255	151.3
Bangkane	5.2	90,888	324,830	11,109,184	-9926909.89	1182274	13.0	5.2	92,979	321,186	10,984,546	-7074029.77	3910516	42.1
Dusit	3.8	65,844	472,862	16,171,875	-7191633.77	8980242	136.4	3.6	65,106	498,737	17,056,819	-4953351.61	12103468	185.9
Minburi	3.7	65,441	162,572	5,559,963	-7147629.39	-1587666	-24.3	3.9	69,022	154,583	5,286,746	-5251354.33	35392	0.5
Saimai	4.1	71,075	595,999	20,383,176	-7762989.54	12620187	177.6	3.8	67,583	578,624	19,788,935	-5141823.85	14647112	216.7
Bangsue	3.5	60,295	995,189	34,035,460	-6585570.58	27449890	455.3	3.3	58,538	796,178	27,229,288	-4453645.24	22775643	389.1
Donmuang	4.4	76,465	539,085	18,436,692	-8351623.12	10085069	131.9	3.4	61,174	577,065	19,735,626	-4654222.87	15081404	246.5
Buengkum	3.7	64,238	438,303	14,989,972	-7016162.35	7973809	124.1	3.8	68,764	428,747	14,663,133	-5231655.98	9431477	137.2
Laksi	3.3	58,508	211,990	7,250,056	-6390363.87	859692	14.7	3.2	57,232	217,633	7,443,052	-4354348.53	3088704	54.0
Kannayao	2.6	45,761	339,365	11,606,293	-4998149.26	6608144	144.4	2.6	46,980	389,520	13,321,583	-3574296.51	9747286	207.5
Nongchok	2.1	36,938	266,334	9,108,637	-4034428.27	5074209	137.4	2.3	40,306	290,617	9,939,086	-3066526.23	6872560	170.5
Total	100.0	1,746,897	11,369,580	388,839,629	-190799325.59	198,040,303	113.4	100.0	1,769,317	11,393,906	389,671,592	-136010844.34	253,660,748	143.4

VITA

Ms. Saravanee Singtong was born on January 16th, 1986 in Bangkok Province, Thailand. She received Bachelor degree of Science in Environmental Resource Chemistry from King Mongkut of Institute Technology Lardkrabung, Thailand in 2007, and Master degree of Science in Environmental Management from Chulalongkorn University, Thailand in 2010. The research of Master degree was Effect of Ferrocene on solubilisation of Alkanes in Microemulsion System which published in Journal of Environmental research volume 12, 33: 41-55, 2011. For Doctoral degree, she received scholarships from Center of Excellence on Hazardous Substance Management (HSM) Chulalongkorn University and the 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund). On employment aspects, she worked in Environmental Resource Institute Chulalongkorn University as Researcher assistant in 2010-2011 and she has been employed by Thailand Research Fund since 2015.