

## **CHAPTER III**

### **METHODOLOGY**

The nature of this research is entirely a descriptive and explanatory type supplemented with some basic calculations for carbon (GHGs) emissions and reductions from all activities and various alternatives of treatment and management of waste stream. The problem of solid waste generation and its consequences are the imperative issue of concern at present. Waste, particularly solid waste, has been identified as one of the sectors responsible for carbon (GHGs) emission especially from land filling. Various options for municipal solid waste management are emerging so that it can minimize the volume of solid waste to be disposed off at landfill sites as well as reduce the carbon emission particularly methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>) by applying appropriate technologies or mechanism that can minimize resource use by saving energy and reuse/recycling of recyclable materials.

In order to address the objectives stated previously, the methodology of this research can be set up and divided into five parts: 1) Selection of study area 2) Data collection and establishment of database system, 3) Coefficients of carbon equivalence per unit quantity of solid waste based on the carbon balanced model, 4) Evaluation of carbon equivalence and 5) Formulation of carbon-balanced equations for solid waste management, as the details follow.

### **3.1 Selection of Study Area**

#### **3.1.1 Classification of Municipalities**

Thailand is divided into 75 provinces (changwat), and one Metropolitan municipality the capital Bangkok Metropolis (Krung Thep Maha Nakhon). Each province is divided into districts as of 2006; there are 877 districts (amphoe) and 50 districts of Bangkok (khet). Each district is divided into tambon (or sub-districts). The tambons are further subdivided into villages (muban). In Bangkok, the districts are called khet, and their subdivisions kwaeng, which are roughly equivalent to the

tambon (communes or sub-districts) in the provinces.

Additionally to these subdivisions except Bangkok, there are also cities and towns, which take over some of responsibilities of the districts and communes on the area covered by the municipality. There are three different levels of municipalities:

- City Municipality, as called thesaban nakhon (city) : More than 50,000 citizens, population density higher than 3,000 per km<sup>2</sup>
- District Municipality, as called thesaban mueang (Town): More than 10,000 citizens, population density higher than 3,000 per km<sup>2</sup> or a provincial capital
- Sub District Municipality, as called thesaban tambon (village): More than 5,000 citizens, population density higher 1,500 per km<sup>2</sup>

### 3.1.2 Site Selection of Municipalities

The site selection of the municipalities in this research were carried out based on two main criteria:

- 1) Level of Municipalities which the number of each size are

City Municipality	23
District Municipality	126
Sub District Municipality	1,033
Total	1,182

- 2) Municipalities located in 4 parts of Thailand.

According to the above criteria, 4 Municipalities chosen are as follow:

- Nonthaburi City Municipality
- Khon Kean City Municipality
- Phitsanuloke City Municipality
- Phuket City Municipality

## 3.2 Data Collection and Establishment of Database System

The data used in this study were both from primary and secondary sources. To evaluate the existing data, the preliminary survey of input material and energy consumption on solid waste management was carried out. Primary data for this research will be collected, not only for database but also validating the findings

derived from secondary data. In the collection of primary data, three different methods have been employed, as follows:

### **3.2.1 Field Survey**

All the selected municipalities were visited in order to observe the existing situation and the solid waste management, including separation, compaction, composting, recycling, incineration and disposal techniques applied. The general composition and the flow of waste volume were also observed.

### **3.2.2 Secondary Data**

Reliable secondary data were gathered from interviewing and survey. They were conducted only for the selected key informants, particularly the senior staffs at Municipalities, Pollution Control Department, staffs/members of transfer stations, landfill sites, and academic institutions, national and international organizations, which are partly or fully involved in various solid waste management activities. The survey was mostly focused on the main aspects: 1) general aspects of solid waste management services, 2) implementation of alternative treatment and management approach. The main purpose of survey was to gather the information on how and at what stage were these aspects of solid waste management at that moment, resources used, their effectiveness and benefits in the activities based on the CBM. The data information obtained from this survey was to evaluate the carbon balances of existing condition in each municipalities. The carbon-balanced model can be used to predict future consequences and effectiveness as well as for the calculation to make future projection of the amount of carbon in the form of carbon dioxide and methane to be mitigated.

## **3.3 Coefficients of Carbon Equivalence**

Coefficients of carbon equivalence were calculated using the concept of Carbon Balanced Model (CBM) previously described in Chapter II.

### **3.3.1 Organic Carbon**

The coefficients of carbon equivalence from resources containing carbon components were calculated by dividing molecular weight of the resource with the atomic weight of Carbon (12), as shown in Table 3.1.

**Table 3.1** Coefficients of carbon equivalence from organic carbon

Resource	Formula	Coefficients of carbon equivalence (kg C per kg resource)	Colorific value (MJ/kg)
Diesel at density 0.85	$C_{12}H_{23}$	0.94*	-
Gasoline	$C_8H_{17}$	0.85	-
LPG (PTT, 2010)		0.74	-
- 70% propane	$C_3H_8$	0.57	-
- 30% butane	$C_4H_{10}$	0.16	-
Fuel wood	$C_6H_{10}O_5$	0.44	-
Polyethylene**	$C_2H_4$	0.875	47.74
Polyethylene**			
Terephthalate (PET)**	$C_{10}H_8O_4$	0.624	24.23
Polystyrene**	$C_8H_8$	0.92	43.65
Polyvinylchloride**	$C_2H_4O$	0.55	23.31

\* Lal, R., 2004.

\*\* Richard, N. et al., 2000.

### 3.3.2 Fossil Based Fertilizers.

The coefficients of carbon equivalence from fertilizers. with the fossil based manufacturing were calculated by dividing energy requirement in process of resource production with the thermodynamic proportion of 43.3 MJ/kgC. For fertilizer, the coefficient was from added value of transport from the factory abroad to plantation in Thailand, which was 0.0385 kg C per kg fertilizer (Papong S. et al, 2008). The coefficients of fossil based fertilizers were shown in Table 3.2.

### 3.3.3 Electricity Generation

The carbon dioxide emission factor of Thailand's national electricity system in 2007 is 0.561 kg CO<sub>2</sub>/kWh with the ratio of C to CO<sub>2</sub> molecular weight of 0.27 (Hinchiranan S., 2009). Therefore, 0.153 kg CE/kWh was the coefficient used to determine the carbon equivalence from electricity consumption in this study.

**Table 3.2** Coefficients of carbon equivalence from fossil based fertilizers

Resource	Energy requirement (MJ/kg)	Coefficients of carbon equivalence (kg C per kg resource)	Reference
<b>Fertilizers</b>			
- Nitrogen (N)	60	1.38	Hatiril (2006)
- Phosphorus (P <sub>2</sub> O <sub>5</sub> )	12	0.28	Ozkan (2004)
- Potassium (K <sub>2</sub> O)	6.70	0.15	Gulistan (2007)

### 3.4 Evaluation of Carbon Equivalence

Carbon equivalence in this study was categorized into three groups, namely, carbon emission, fixation, and reduction.

#### 3.4.1 Carbon Emission

From the weight of resource usage, the following equation was used to calculate the carbon emission.

$$\frac{C_{em}}{Unit} = C_{coeff} \times \frac{W}{Unit} \quad (3.1)$$

Where:

$C_{em}$  is carbon emission (kg C).

$C_{coeff}$  is coefficients of carbon equivalence (kgC/ kg of resource).

Unit is mass of Solid Waste (Tons).

W is resource or energy input (kg).

#### 3.4.2 Carbon Fixation

Carbon fixation of mass of solid waste and composition or carbon transfer in the system was calculated from the carbon storage in the landfill.

#### 3.4.3 Carbon Reduction

Carbon reduction ( $C_{re}$ ) was calculated from the recovery and recycling of waste or discarded materials generated from the MSWM . The equation used to calculate the carbon reduction is shown below.

$$\frac{C_{re}}{Unit} = C_{coeff} \times \frac{W}{Unit} \quad (3.2)$$

Where:

- $C_{re}$  is carbon reduction (kg C).  
 $C_{coeff}$  is coefficients of carbon equivalence (kgC/ kg of resource).  
 Unit is weigh or volume of energy or resources use or solid waste .  
 $W$  is input energy or resources use or solid waste (kg).

### 3.5 Formulation of Carbon-balanced Equations for Solid Waste Management

The total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO<sub>2</sub>) and converse to carbon by multiply with C/CO<sub>2</sub> conversion factor (12/44)

$$\text{Net CE} = \sum C_{ec} + \sum C_{lf} + \sum C_r + \sum C_{inc} + \sum C_{mbt} \quad (3.3)$$

Where:

CE = Carbon balance of the system MTCE/Year

$\sum C_{ec}$  is Total carbon equivalent from energy consumption in collection, transfer and transportation of the system. MTCE/ Year

Which calculated from total Energy (Diesel, Gasoline, NGV and Others) consumption in collection (unit/year) x Carbon Equivalent of each energy use (MTCE/unit of Energy) MTCE/ Year

$\sum C_{lf}$  is Total carbon equivalent from landfilling

Which calculated from  $\sum C_{elf} - \sum C_m - \sum C_s$

$\sum C_{elf}$  is Total Energy (Diesel, Gasoline, NGV, Electricity and Others) consumption in landfill (unit/year) x Carbon Equivalent of energy use (MTCE/unit of Energy) MTCE/ Year

- $\sum C_m$  is Carbon from methane production from biodegradable from solid waste in landfill site MTCE/year  
 = Total mass of biodegradable solid waste composition x CH<sub>4</sub> production rate from landfill for each composition of solid waste (Food waste, paper, some type of plastic, wood and yard waste) x Carbon/Methane conversion factor (12/16)
- $\sum C_s$  is Total carbon fixation in the landfill that are store in the landfill. MTCE/year  
 = Total mass for each of solid waste composition from the landfilled that are not fully decompose by anaerobic bacteria x The final storage factor of carbon for the biodegradable solid waste components MTCE of CO<sub>2</sub>E/Wet Short Ton x C/CO<sub>2</sub> conversion factor (12/44)
- $\sum C_r$  is Total carbon reduction from recyclable material MTCE/year  
 Which calculated from total mass of each recyclable material x Emissions factor for Recycling (MTCO<sub>2</sub>E/Short Ton of Material Recovered) x C/CO<sub>2</sub> conversion factor (12/44)
- $\sum C_{inc}$  is Total carbon equivalent from incineration  
 Which calculated from  $\sum C_{inc} = \sum C_{ec} + \sum C_{elec} + \sum C_{cf}$
- $\sum C_{elec}$  is Total carbon equivalent from Electricity production, use and sale  
 = Net Electricity x CE conversion factor (1 kWh = 0.153 kgCE)
- $\sum C_{cf}$  is Total carbon emission from fossil  
 = Mass of Plastic x CO<sub>2</sub> Emission factor from incineration kg/kg waste plastic x C/CO<sub>2</sub> conversion factor (12/44)
- $\sum C_{mbt}$  is Total carbon equivalent from Mechanical Biological Treatment (MBT)  
 Which calculated from  $\sum C_{mbt} = \sum C_{ec} + \sum C_{elec} + \sum C_s$
- $\sum C_{elec}$  is Total carbon equivalent from Electricity production, use and sale  
 = Net Electricity x CE conversion factor (1 kWh = 0.153 kgCE)

### 3.6 Quantification of Carbon Equivalence

Results from the data analyses will be used to simulate the carbon-balanced model of MSWM in order to calculate of carbon equivalences occurring in the system.

#### 3.6.1 Solid waste generation

Solid waste generation in the municipalities is based on the economic development, density of population, size of the urban habitation and consumption rate of commercial goods. The per capita generation of solid waste in 4 municipalities was given in Table 3.3 which indicates a range of 0.97 to 1.29 kg/day.

**Table 3.3** Comparison of solid waste generation from the municipalities studied

Municipality	Pop.	House Holds	Area sq.km	Pop.Density Pop/sq.km.	SW Tons/year	SW tons/day	SW kg/cap/day
Nonthaburi	264,485	107,451	38.9	6799.10	96,610.40	264.81±7.49	1.00±0.05
Khon Kaen	118,203	53,498	46	2569.63	55,795.37	152.86 ± 6.97	1.28±0.06
Phitsanulok	77,340	32,459	18.26	4099.01	27,509.48	78.9±3.62	0.97±0.05
Phuket	76,276	20,877	12	6356.33	35,792.77	98.10±4.02	1.29±0.06

#### 3.6.2 Waste composition and variations

There are many factors contributing to different patterns of waste composition, such as geographical location, season, income, household structure, pattern of living, pattern of commodity buying, behavior of consumption, attitude of living, and regulation. The composition of the waste generated in the four chosen municipalities, given in Table 3.4. Generally, the biodegradable portion is mainly due to food waste, typical of the developing countries. The composition dictates the technology needed for waste processing prior to disposal. In most municipalities, landfilling would be the most appropriate technology for such waste. Incineration

would not be a suitable option due to the extreme moisture content and accordingly a low calorific value, thereby making it too low for a self-sustaining incineration.

**Table 3.4** Solid waste composition (PCD, 2003)

Solid Waste Composition (% by Weight)	Municipality			
	Nonthaburi	Khon Kaen	Phitsanulok	Phuket
Food Waste	63.55	73.66	68.59	65.64
Paper	4.86	7.17	2.53	6.56
Plastic	14.92	14.29	20.59	19.28
Glass	10.21	2.05	1.61	4.09
Metal	1.12	0.62	1.45	0.35
Rubber/Leather	0.32	0.34	0.29	0.03
Cloth	2.07	0.71	1.51	0.64
Yard	0.84	0.30	0.89	-
others	2.11	0.86	2.54	3.41
%	100.00	100.00	100.00	100.00

### 3.7 Collection and Transport

A typical MSW collection and transportation system consists of (1) household waste containers, (2) waste collecting equipped trucks, (3) workers. In big cities, however, a transfer station may be needed due to the large amount of waste and the long distance to the MSW facilities. A transfer station consists of temporary MSW storage, transfer point, vehicles and equipment for MSW transfer.

### 3.8 Resource Recovery and Recycling

In Thailand, recovery of recyclable materials – mainly paper, plastics, glass and metals – is normally undertaken by private sector workers. Information indicated that more than 38% of MSW were potentially recyclable materials. The main work of recycling in Thailand is the sorting and collecting of reusable materials from wastes. The two existing systems in Thailand are (i) collecting and sorting works done by hands at the collecting points, (ii) collecting and sorting works done by scavengers at the disposal facilities. It can be seen that these two methods are not only

ineffective but also unhealthy. The data of recycling was not available because the recycling activities occurred before collection and weighting of solid waste. In this study used data from record and survey in each municipalities.

The data collection of waste recycling in Nonthaburi Municipality was conducted by surveying 38 recycle shops for ten days. The recyclable material consist of mixed paper, mixed plastic, mixed glass and mixed metal and then use the average per day of recyclable materials as a recycle factors. The data of waste recycling in Khon Kaen Municipality collected from secondary data which record in 2008<sup>1</sup>. In Phitsanulok Municipality every waste collecting trucks sold the recyclable materials to Ploypanich recycle shops before went to transfer station. The data was collected from this shop for seven days which consist of mixed paper, mixed plastic, mixed glass and mixed metal then use the average of recyclable materials as a recycle factor. The sorting plant at Phuket Municipality stopped operation since 2002 because of economic problem. The secondary data came from the record of Phuket Municipality. The data of recyclable material was shown in Table 3.5

□

**Table 3.5 Recyclable material in each municipalities**

Recyclable Material	Municipality (Tons recycle/year: Tons/day)			
	Nonthaburi	Khon Kaen	Phitsanulok	Phuket
Mixed Paper	661.78/ 1.81	154.82/0.42	187.44/0.512	168.58/0.46
Mixed Plastic	94.39/0.26	144.94/0.94	311.65/0.85	199.37/0.55
Mixed Glass	207.4/0.57	37.70/0.103	42.25/0.12	501.46/1.37
Mixed Metal	1,896.39/5.18	119.32/0.33	228.09/0.62	4.65/0.03

From Secondary data and survey in municipalities

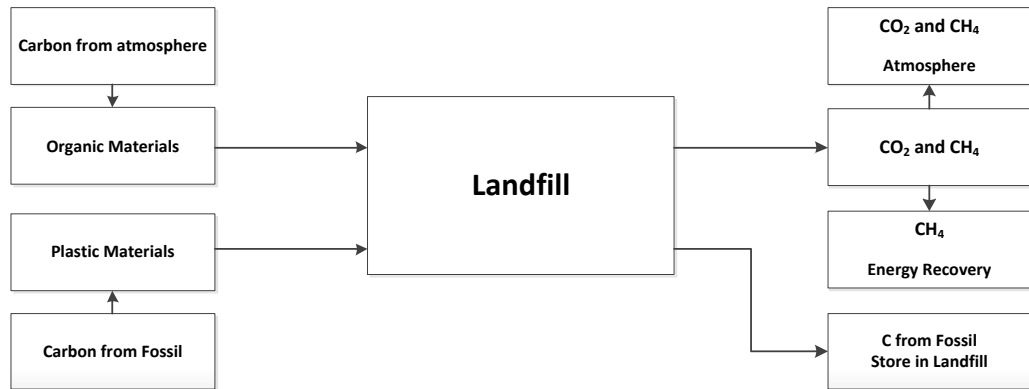
### 3.9 Processing and Disposal

#### 3.9.1 Carbon in Landfill

When food waste, paper and wood are landfilled, anaerobic bacteria degrade the materials, producing methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>). CH<sub>4</sub> and CO<sub>2</sub> is not counted as a carbon emission because it is considered as part of the natural carbon cycle of growth and decomposition under natural conditions (virtually all of

the biodegradable material would degrade to CO<sub>2</sub>, completing the photosynthesis/respiration cycle). If the methane brought to be used for electricity generation, then this amount of methane is considered as carbon reduction in carbon balance model. Because it reduce emission from electricity generated, using fossil energy.

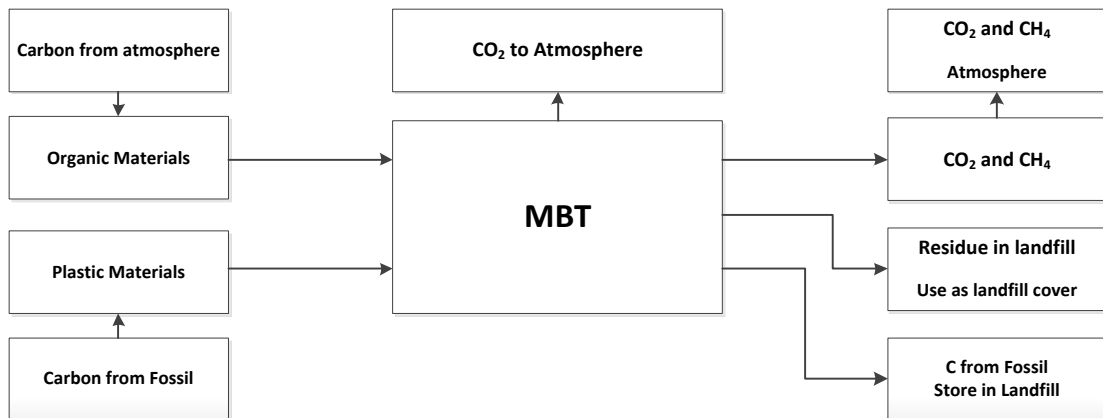
Some of the carbon in these materials (i.e., food scraps, yard trimmings, paper and wood) is stored in the landfill because these materials are not completely decomposed by anaerobic bacteria. Because this carbon storage would not normally occur, this is counted as an anthropogenic sink. However, carbon in plastics and rubber that remains in the landfill is not counted as stored carbon because it is of fossil origin. Fossil carbon (e.g., petroleum, coal) is already considered “stored” in its natural state; converting it to plastic or rubber and putting it in a landfill only moves the carbon from one storage site to another (EPA, 2010). The carbon flow in landfilling showed in Figure 3.1.



**Figure 3.1** Organic and Fossil fuel flow in Landfilling  
(Modified from European Commission, 2005)

**3.9.2 Mechanical Biological Treatment (MBT)**

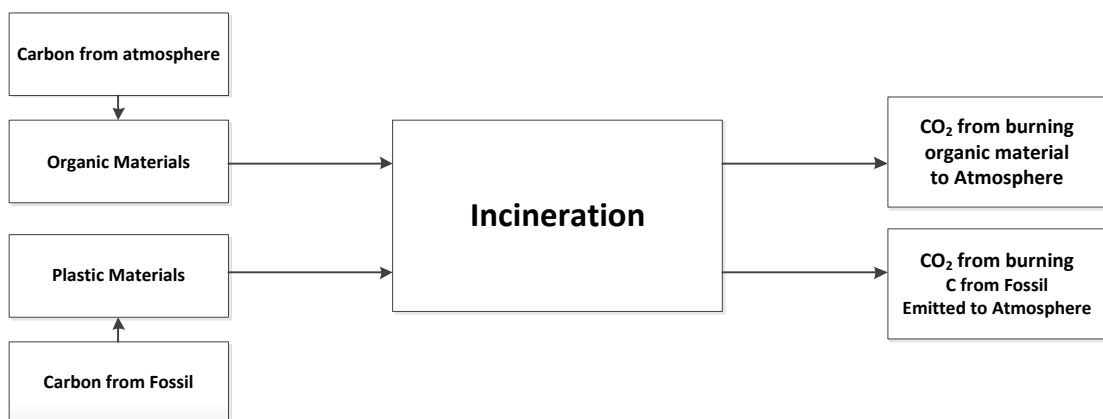
The Carbon flow in Mechanical Biological Treatment are the same reason as carbon in landfilling. The carbon flow in MBT is illustrated in Figure 3.2.



**Figure 3.2** Organic carbon and fossil fuel carbon flow with mechanical-biological treatment (MBT)  
(Modified from European Commission, 2005)

### 3.9.3 Incineration

Incineration is one of the methods for MSW management in Thailand. It is used in the huge municipality or tourist municipality area where sanitary landfill is not enough to receive the disposed MSW. Two type of carbon in incineration, CO<sub>2</sub> from organic carbon are not accounting to carbon emission, and CO<sub>2</sub> from fossil fuel carbon are accounting to carbon emission because increasing in the CO<sub>2</sub> concentration in the atmosphere. The carbon flow in incineration is illustrated in Figure 3.3.



**Figure 3.3** Organic carbon and fossil fuel carbon flow with incineration  
(Modified from European Commission, 2005)

### **3.10 Comparative Scenarios**

The comparative studies of base-line scenario and 10%, 25% and 35 % recycle of recyclable material scenario in each municipality were carried out to determine the net carbon emission from the MSWM. From the data analysis, the potential of carbon emission from the unit process came from collection, transfer station, transportation, landfilling and incineration in MSWM. The carbon reduction potential is recycling which is effective for carbon reduction in MSWM. So the recycling scenario setting was chosen to be the effective method for carbon reduction in municipal solid waste management.