CHAPTER 4 RESULTS AND DISCUSSION

4.1 MSW Compositions

MSW samples were taken for 62 days. As per Eq. 3.1, total weight of MSW collected during that period was 233,080.03kg, equivalent to 3.77 tonnes per day (Table 4.1):

Total MSW in 62 days

= (85,870.02 + 67,590.02 + 79,619.99) kg

= 233,080.03kg

Total waste collected 1,376.05 tonnes/ year (Table 4.1):

Total waste collected yearly

= (80.30 + 105.85 + 660.65 + 40.15 + 113.15 + 375.95) tonnes

= 1,376.05 tonnes

Percentage of each waste category was calculated using Eq. 3.2. The main MSW compositions were food waste (48.01%) followed by inerts like rubber, plastic and metal (27.32%) and garden, yard and park waste (8.22%) (Table 4.1). These compositions are line with the MSW compositions in Malaysia which contains mainly food waste, approximately 45% (National Solid Waste Management Department, 2005) (Figure 2.2). Overall sample sizes are within normal distribution. The smaller the standard error is, the closer the sample statistic is to the actual waste volume statistic. For further study in the future, it is recommended to increase sample size (number of sampling days) to further reduce the standard error.

Table 4.1: MSW compositions of samples

Waste category	Weight in 62 days (kg)	Weight per day (tonnes)	SE	Weight per year (tonnes)	Percentage (%)
Wood and wood products	13,445.20	0.22	5.90%	80.30	5.84
Pulp, paper and cardboard (other than sludge)	17,864.82	0.29	5.00%	105.85	7.69
Food, food waste, beverages and tobacco (other than sludge)	112,106.36	1.81	3.75%	660.65	48.01
Textiles	6,538.97	0.11	4.06%	40.15	2.92
Garden, yard and park waste	19,470.09	0.31	4.40%	113.15	8.22
Inerts	63,654.59	1.03	3.28%	375.95	27.32
Total	**233,080.03**	**3.77**		**1,376.05**	**100.00**

Legend:
SE=standard error

(See Appendix 1 and 2)

There were 120 days from January 2010-April 2010. Hence, total MSW collected during that period was 452.40 tonnes:

Total MSW collected January2010-April 2010

= 3.77 tonnes/day x 120 days

= 452.40 tonnes

The project owner was granted a new contract in certain parts of Selayang since May 2010. Therefore, total collected MSW had increased since May 2010. However, samples were taken only until April 2011. Tickets of weighing bridge from May-June 2010 (58 days) were referred to derive the average daily MSW collected from May-December 2010 (Appendix 3). Total MSW collected in 58 days was 644.83 tonnes, equivalent to 11.12 tonnes of MSW per day.

Total MSW collected May 2010-June 2010 (58 days)

= (105.05+112.45+111.77+111.90+96.56+107.10) tonnes

= 644.83 tonnes

(See Appendix 3)

Daily MSW collected during May 2010-December 2010

= 644.83 tonnes/ 58 days

= 11.12 tonnes/ day

There were 245 days from May 2010-December 2010. Total MSW collected during that period was 2,724.40 tonnes:

Total MSW collected May 2010-December 2010

= 11.12 tonnes x 245 days

= 2,724.40 tonnes

Total MSW collected in 2010 was 3,176.80 tonnes. It is the sum of MWS collected from January-December 2010:

Total MSW collected in 2010

= (January 2010-April 2010) + (May 2010-December 2010)

= 452.40 + 2,724.40

= 3,176.80 tonnes

MSW in developing countries increased 2%-3% annually (Agamuthu, 2001). An assumption is made in estimating baseline emission: The amount of MSW collected in 2011 onwards is based on daily amount of MSW collected in May-December 2010 and a consistent increase rate of 2% annually without any changes in waste composition. Hence 4,059 tonnes of MSW was collected in 2011 and 42,769 tonnes will be collected in 10 years (Table 4.2):

Total MSW collected in 2011

= 11.12 tonnes per day x 365 days = 4,058.80 tonnes per year

Table 4.2: Total MSW collected during crediting period

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total MSW collected (tonnes)	3,177	4,059	4,140	4,223	4,307	4,393	4,481	4,571	4,662	4,756

(See Appendix 4)

However, the amount of MSW shall be monitored during crediting period to record any changes and this depends on the projects newly granted or terminated and changes in MSW compositions.

4.2 Estimation of Baseline Emissions

Baseline emissions were calculated as per Eq. 3.3. In Malaysia, currently there is no prevailing regulation to capture and/ or combust methane, thus $MD_{y,reg} = 0$. Furthermore, the project activity involves neither composting of manure nor co-composting of wastewater, hence $BE_{CH4,manure,y} = 0$ and $MEP_{y,ww} = 0$. Therefore Eq.3.3 becomes:

$$BE_y = BE_{CH4,SWDS,y}$$

First Oder Decay (FOD) was initially designed for landfill GHG emissions calculation (IPCC, 2006), however this model is now used by all methodologies that deal with solid waste (Cyrill et al., 2011). This model covers different parameters, such as climatic zone, landfill management practice and particular waste type with different decay rate and degradable organic carbon (DOC) content. CH_4 emissions in year *y* from a quantity of waste disposed in year *x* is proportional to $e^{-k(y-x)}$ where *k* is the decay rate of the waste type.

Inerts such as rubber, plastic and metal are inorganic components. Thus, these materials do not emit and methane. Estimated baseline emissions are 8,058.97 tCO_2e during the crediting period (10 years), as per Eq.3.4. Food waste falls under waste type which degrades rapidly (UNFCCC, 2010). As a result, food waste contributes the highest emission from the total baseline emissions, far ahead other types of waste category, ranging from 80% in the first year to 62% in the 10th year during crediting period. Total emissions from food waste in 10 years would be 5,516.90 tCO_2e. The second contributor is pulp, paper and cardboard (other than sludge) followed by garden, yard and park waste with emission 966.27 tCO_2e and 916.14 tCO_2e respectively (Table 4.3, Figure 4.1 and Appendix 5). Though garden, yard and park waste degrade faster than pulp, paper and cardboard (other than sludge) and exist in a higher composition, but due to its low fraction of DOC (by weight) (Table 4.8), the emission from garden, yard and park waste is lower than pulp, paper and cardboard (other than sludge).

Table 4.3: Emissions of each waste category

Year	Emissions of each waste category (tCO_2e)					Total (tCO_2e)
	A	B	C	D	E	
2010	6.92	16.89	192.12	3.86	20.73	240.52
2011	15.44	36.98	356.64	8.46	43.04	460.56
2012	23.83	56.13	469.34	12.83	62.27	624.40
2013	32.10	74.35	545.95	16.97	78.80	748.17
2014	40.25	91.77	598.06	20.95	93.05	844.08
2015	48.28	108.15	635.26	24.67	105.29	921.65
2016	56.18	123.91	659.65	28.26	115.84	983.84
2017	63.96	138.78	676.23	31.63	124.92	1,035.52
2018	71.61	152.94	687.51	36.39	132.73	1,081.18
2019	79.16	166.37	696.14	37.91	139.47	1,119.05
Total	**437.73**	**966.27**	**5,516.90**	**221.93**	**916.14**	**8,058.97**

Legend:
A = Wood and wood products
B = Pulp, paper and cardboard (other than sludge)
C = Food, food waste, beverages, tobacco (other than sludge)
D = Textiles
E = Garden, yard and park waste

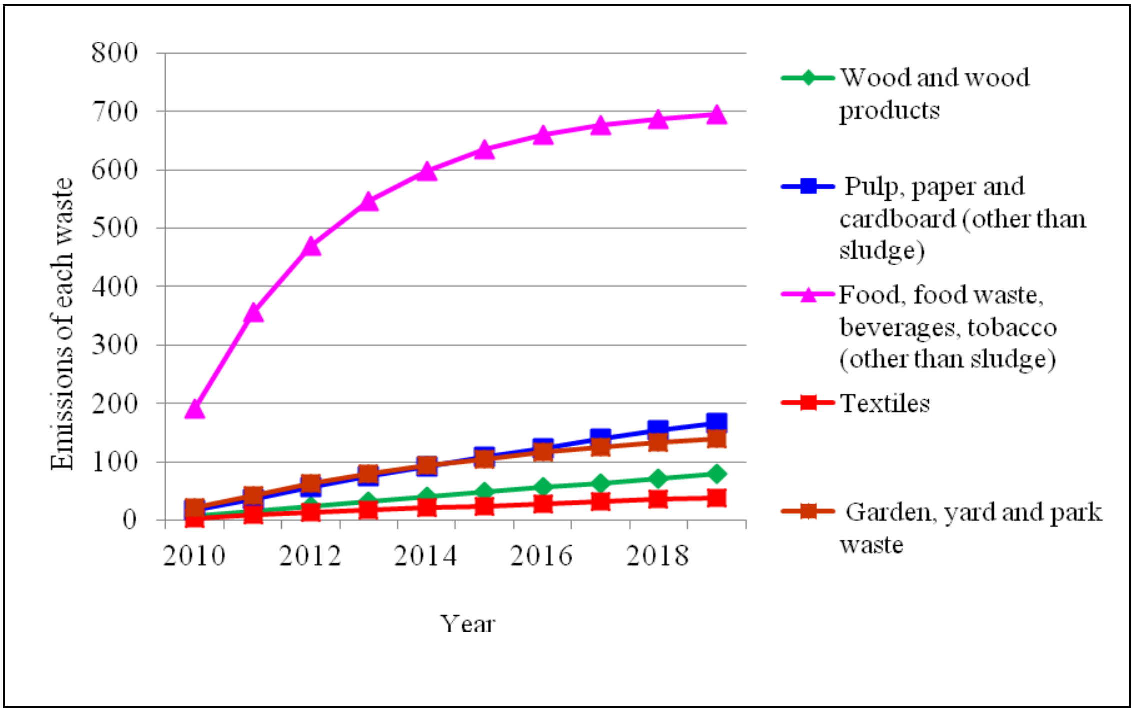

Figure 4.1: Emissions of each waste category

Baseline emissions are the total emissions of all types of waste category in every year throughout the crediting period. The trend is increasing as the quantity of MSW collected increased 2% annually. Baseline emissions in 2010 were 240.52 tCO_2 and total baseline emissions will reach 8,058.97 tCO_2 at the end of the crediting period (Table 4.4).

Table 4.4: Baseline emissions

Year	Baseline emissions (tCO_2)
2010	240.52
2011	460.56
2012	624.40
2013	748.17
2014	844.08
2015	921.65
2016	983.84
2017	1,035.52
2018	1,081.18
2019	1,119.05
Total	**8,058.97**

Emission per tonne of wet waste was calculated by dividing baseline emissions with total MSW collected in respective year. The emission per tonne of wet waste was estimated and it increased from 0.10 tCO_2e to 0.32 tCO_2e from 2010-2019 (Table 4.5). Study by Barton et al. (2008) showed that sanitary landfill with gas collection and flaring emits 0.19 tCO_2e per tonne of wet waste. At Bukit Tagar Sanitary Landfill, 55% of CH_4 is captured and flared. Hence, the result falls within the range.

Table 4.5: Emission per tonne wet waste (baseline)

Year	Total organic waste collected (tonnes)	Baseline emissions (tCO_2e)	Emission per tonne of wet waste (tCO_2e)
2010	2,309	240.52	0.10
2011	2,950	460.56	0.16
2012	3,009	624.4	0.21
2013	3,069	748.17	0.24
2014	3,131	844.08	0.27
2015	3,193	921.65	0.29
2016	3,257	983.84	0.30
2017	3,322	1,035.52	0.31
2018	3,389	1,081.18	0.32
2019	3,456	1,119.05	0.32

Details of each parameter in Eq. 3.4 are adopted from “Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)”. Fraction of methane captured at the Bukit Tagar Sanitary Landfill and flared, combusted or used in another manner (f) were from the operator of Bukit Tagar Sanitary Landfill - KUB-Berjaya Enviro Sdn Bhd. In 2010, 55% of methane was flared. This parameter shall be monitored annually for any changes. GWP_{CH4} of 21 shall be applied for the first commitment period of the Kyoto Protocol, 2008-2012. A default value of 0.5 for fraction of methane in the landfill gas (F) is recommended by IPCC. Under anaerobic conditions in the SWDS, some degradable organic carbon does not degrade and become residue, some degrades slowly.

Bukit Tagar Sanitary Landfill is a sanitary landfill with appropriate cover materials, which are clay soil with very low permeability and topped with high-density polyethylene (HDPE) membrane used daily. Hence, oxidation factor (OX) = 0.1 (Table 4.6).

Table 4.6: Oxidation Factor (OX) for SWDS

Type of Site	OX Default Value
Managed SWDS that are covered with oxidising material such as soil or compost	**0.1**
Other type of SWDS	0

Adopted from: Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)

Specific waste deposition areas are available at Bukit Tagar Sanitary Landfill. There are 17 cells which would last for 40 years and about 6 to 10 sub-cells per cell. Currently, Phase 1 cell is in operation. It is a fully aerobic managed solid waste disposal site which prohibits scavenging activities. Fires are prevented by applying daily covers to minimize oxygen from infiltrating into cells to aid in combustion with methane gas. No smoking is permitted at the landfill cell and many "No smoking" signs have been installed throughout the entire cell areas. Workers caught smoking are sacked with immediate effect. Soil cover is applied daily after mechanical compacting using landfill compactor CAT 826C and leveling of the waste by using D6 bulldozers. Hence, methane correction factor **(**MCF) = 1.0 (Table 4.7).

Table 4.7: Methane Correction Factor (MCF) for SWDS

Type of Site	MCF Default Value
Anaerobic managed solid waste disposal sites • **These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i)cover material; (ii)mechanical compacting; or (iii)leveling of the waste.**	**1.0**
Semi-aerobic managed solid waste disposal sites • These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i)permeable cover material; (ii)leachate drainage system; (iii)regulating pondage; and (iv)gas ventilation system.	0.5
Unmanaged solid waste disposal sites – deep and/or with high water table • This comprises all SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.	0.8
Unmanaged shallow solid waste disposal site • This comprises all SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 metres.	0.4

Adopted from: Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)

After segregation, the organic materials will be piled as windrows as the first stage of composting. Hence, the values of wet waste were used for project activity (Table 4.8).

Table 4.8: Fraction of degradable organic carbon (by weight) in the waste type j

Waste type *j*	**DOC_j (% wet waste)**	DOC_j (% dry waste)
Wood and wood products	**43**	50
Pulp, paper and cardboard (other than sludge)	**40**	44
Food, food waste, beverages and tobacco (other than sludge)	**15**	38
Textiles	**24**	30
Garden, yard and park waste	**20**	49
Glass, plastic, metal, other inert waste	**0**	0

Adopted from: Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)

MAP/ PET is the ratio between the mean annual precipitation (MAP) and the potential evapotranspiration (PET). According to long term average values documented in the Environmental Impact Assessment (EIA) Report prepared in 2005, the landfill is located within tropical climate zone with an annual mean 24-hours temperature of approximately 27℃ and mean annual precipitation (MAP) of about 2700mm (UNFCCC, 2009c). This data is in parallel with the data recorded by meteorological station at Hospital Kuala Kubu Baru. The temperature ranged from 21.8℃ (mean daily minimum) to 33.3℃ (mean daily maximum) with rainfall of 2618.5mm per year year (Malaysia Meteorological Department, 2009a & b). Hence, decay rate of tropical weather (MAT>20℃) with high precipitation (MAP>1000mm) was chosen (Table 4.9).

Table 4.9: Decay rate for the waste type j

Waste type *j*		Boreal and Temperates (MAT ≤ 20°C) Dry (MAP/PET <1)	Boreal and Temperates (MAT ≤ 20°C) Wet (MAP/PET >1)	Tropical (MAT >20 ℃) Dry (MAP <1000mm)	Tropical (MAT >20 ℃) Wet (MAP >1000mm)
Slowly degrading	Wood, wood products and straw	0.02	0.03	0.025	**0.035**
	Pulp, paper, cardboard (other than sludge), textiles	0.04	0.06	0.045	**0.07**
Moderately degrading	Other (non-food) organic putrescible garden and park waste	0.05	0.1	0.065	**0.17**
Rapidly degrading	Food, food waste, sewage sludge, beverages and tobacco	0.06	0.185	0.085	**0.40**

Adopted from: Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)

The abovementioned default values except φ and GWP_{CH4} are subject to change. According to “Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)”, these values should be updated as per suggested in the most recently published IPCC Guidelines for Greenhouse Gas Inventories at the renewal of second and third crediting period. All the parameters mentioned above are summarised in Table 4.10.

Table 4.10: Parameters/data used to calculate baseline emissions

Variables	Parameters/Data	Unit	Value	Data Source
φ	Model correction factor to account for model uncertainties	-	0.9	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
f	Fraction of methane captured at the solid waste disposal site (SWDS) and flared, combusted or used in another manner	-	0.55	Operator of Bukit Tagar Sanitary Landfill (KUB-Berjaya Enviro Sdn Bhd)
GWP_{CH4}	Global Warming Potential of methane, valid for the relevant commitment period	tCO_2e/CH_4	21	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
OX	Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste	-	0.1 (Refer Table 4.7)	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
F	Fraction of methane at the SWDS gas (volume fraction)	-	0.5	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
DOC_f	Fraction of degradable organic carbon (DOC) that can decompose	-	0.5	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
MCF	Methane correction factor	-	1.0 (Refer Table 4.8)	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
$W_{j,x}$	Amount of organic waste type *j* prevented from disposal in the SWDS in the year *x* (tonnes)	tonnes	Refer Appendix 3	Calculated
DOC_j	Fraction of degradable organic carbon (by weight) in the waste type *j*	-	Refer Table 4.9	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value
k_j	Decay rate for the waste type *j*	-	Refer Table 4.10	IPCC 2006 Guidelines for Greenhouse Gas Inventories default value

4.3 Estimation of Project Emissions

4.3.1 Emissions from incremental transport distances, $PE_{y,transp}$

Transport emissions were calculated according to Eq. 3.6. Transport emissions for the project activity are divided into 2 sources:

a) Distances increase between the collection points of MSW and the composting plant compared to the baseline solid waste disposal site

b) Distance between composting site and the compost application sites

Regarding to incremental distances between the collection points of MSW and the composting plant as compared to the baseline solid waste disposal site, the distance between collection points (Selayang and Rawang) and solid waste disposal site (Bukit Tagar Sanitary Landfill) is approximately 53km and 40km respectively while the distance between Selayang and Rawang is approximately 20km (Figure 4.2). The composting plant is located in Rawang. The distance between MSW collection and composting plant is closer compared to Bukit Tagar Sanitary Landfill. Hence, there is no incremental in distance, $DAF_w = 0$. Therefore, emissions from incremental transport distances are solely contributed by compost transportation.

Regarding to distance between composting site and the compost application sites, the compost produced by the project activity is assumed to be applied within 50km from composting plant.

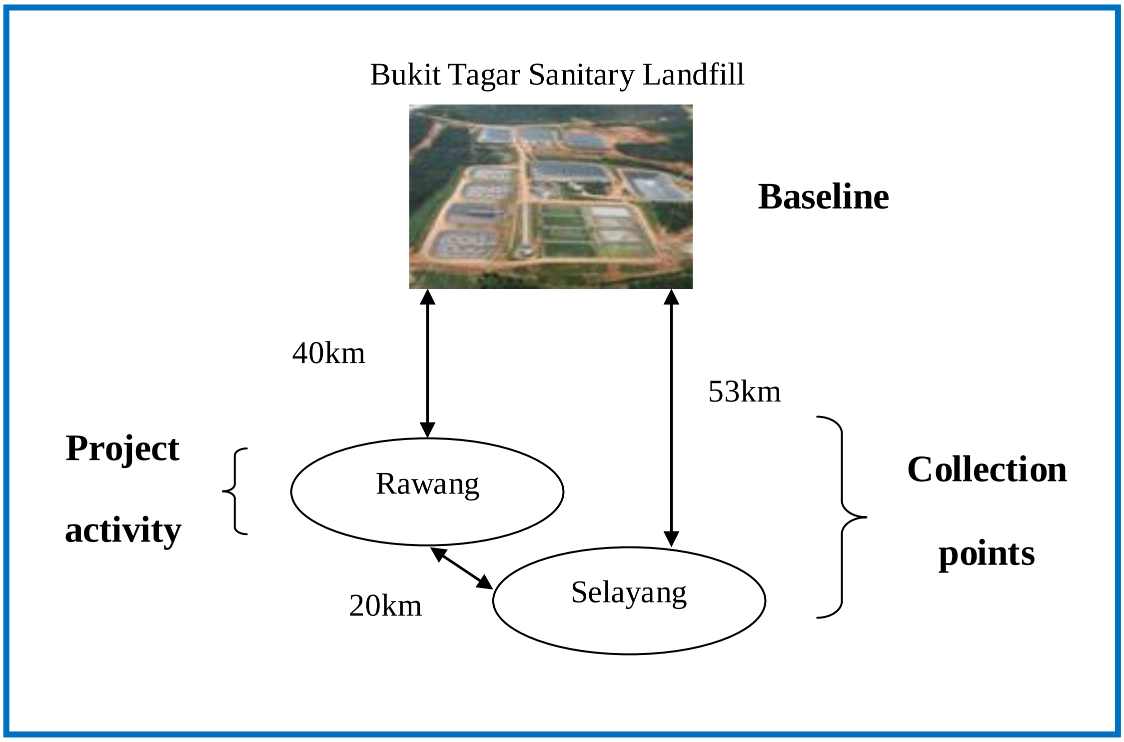

Figure 4.2: Distance between baseline, collection points and project activity

Project emission from transportation was calculated based on the following assumptions:

1. Only wood waste, food waste and garden waste are composted while paper, textiles and inert are sent for recycling. Volume reduction is 50% after composting. Hence, quantity of waste composted is estimated to be 1,972 tonnes in 2010 and 986 tonnes of compost will be produced. The quantity shows an increasing trend as the total collected MSW increase at an annual rate of 2%. During 10 crediting years, 26,547 tonnes of waste will be composted, producing 13,276 tonnes of compost (Table 4.11, Table 4.12 and Appendix 4).

Table 4.11: Quantity of MSW composted

Year	Wood and wood product (tonnes)	Food, food waste, beverages, and tobacco (other than sludge) (tonnes)	Garden, yard and park waste (tonnes)	Quantity of waste composted, Q_y (tonnes)
2010	186	1,525	261	1,972
2011	237	1,949	334	2,520
2012	242	1,988	340	2,570
2013	247	2,027	347	2,621
2014	252	2,068	354	2,674
2015	257	2,109	361	2,727
2016	262	2,151	368	2,781
2017	267	2,194	376	2,837
2018	272	2,238	383	2,893
2019	278	2,283	391	2,952
Total				**26,547**

Table 4.12: Quantity of compost produced

Year	Quantity of waste composted, Q_y (tonnes)	Weight reduction	Quantity of compost i produced, $Q_{y, treatment,i}$ (tonnes)
2010	1,972	50%	986
2011	2,520	50%	1,260
2012	2,570	50%	1,285
2013	2,621	50%	1,311
2014	2,674	50%	1,337
2015	2,727	50%	1,364
2016	2,781	50%	1,391
2017	2,837	50%	1,419
2018	2,893	50%	1,447
2019	2,952	50%	1,476
Total	**26,547**		**13,276**

2. Average truck capacity used for compost distribution is 10 tonnes trucks. The compost produced by the project activity will be used within 50 km from the composting plant. Hence, estimated distance travelled by each truck for compost distribution, $DAF_{treatment,i}$ is within the 50 km radius from the composting plant. Total

distance travelled by each truck is assumed to be 100 km maximum.

$$CT_{y, treatment,i} = 10$$

$$DAF_{treatment,i} = 100$$

3. Based on IPCC default value, 1 litre diesel consumption contributes 2.7 $kgCO_2$ emission and estimated that a 10 tonnes truck can travel approximately 3 km using 1 liter diesel. Thus,

$$EF_{CO2} = 2.7\ kgCO_2/\text{litre diesel} / 3\ \text{km/litre diesel}$$

$$= 0.90\ kgCO_2/km$$

$$= 0.0009\ tCO_2/km$$

As there is no incremental transportation of MSW, $DAF_w = 0$. Therefore, the only project emissions from transportation are from transportation of compost. 8.87 tCO_2 was emitted in 2010 and increase year by year throughout the crediting period as in parallel with the increased quantity of compost being produced. Total emissions from transportation are 119.48 tCO_2 for 10 crediting years (Table 4.13).

$$\mathbf{PE_{y,\ transp}\ (in\ 2010) = (Q_{y,\ treatment,i} / CT_{y,\ treatment,i}) * DAF_{treatment,\mathit{i}} * EF_{CO2}}$$

$$= (986/ 10) * 100 * 0.0009$$

$$= 8.87\ tCO_2$$

Table 4.13: Emissions from transportation

Year	$Q_{y, treatment,i}$	$CT_{y, treatment,i}$	$DAF_{treatment,i}$	EF_{CO2}	$PE_{y, transp}$ (tCO_2e)
2010	986	10	100	0.0009	8.87
2011	1,260	10	100	0.0009	11.34
2012	1,285	10	100	0.0009	11.57
2013	1,311	10	100	0.0009	11.80
2014	1,337	10	100	0.0009	12.03
2015	1,364	10	100	0.0009	12.28
2016	1,391	10	100	0.0009	12.52
2017	1,419	10	100	0.0009	12.77
2018	1,447	10	100	0.0009	13.02
2019	1,476	10	100	0.0009	13.28
Total					**119.48**

Parameters used in Eq. 3.6 to determine emission from transportation are summarised in Table 4.14.

Table 4.14: Parameters used to calculate emissions from transportation

Parameter	Description	Unit	Value	Source
$Q_{y, treatment,i}$	Quantity of waste composted in the year	tonnes	varied	Calculated
$CT_{y, treatment,i}$	Average truck capacity for waste transportation	tonnes/ truck	10	Capacity based on capacity of trucks
$DAF_{treatment,i}$	Average incremental distance for waste transportation	km/ truck	100	Distance from project activity to landfill
EF_{CO2}	CO_2 emission factor from fuel use due to transportation	tCO_2/km	0.0009	2006 C

4.3.2 Emissions from power consumption, $PE_{y,power}$

Diesel and electricity are used by the project activity facilities for turning of compost piles, chopping of biomass for size reduction, unloading and loading, transportation of waste and compost. The consumption of both diesel and electricity will be monitored regularly. The emissions were calculated based on Eq. 3.7.

a) Emissions from diesel on-site consumption, $PE_{y,diesel\ on\text{-}site}$

Emissions from diesel consumption on-site are related to technical installations used on-site. The project activity uses diesel driven loader, turning machine, wood chipper and forklift in the composting process.

Feedstock of Kota Kinabalu Composting Plant is 109,500 tonnes/year and 300 tonnes/day (60% from 500 tonnes of total waste disposed) while the feedstock of the project activity is shown in Table 4.16. Quantity of MSW composted per day is 5.40 tonnes per day in 2010. This amount increases year by year as the MSW collected increased 2% annually. In 2019, quantity of MSW composted will reach approximately 8 tonnes per day (Table 4.15).

Table 4.15: Quantity of waste composted per day

Year	Quantity of MSW composted per year (tonnes)	Quantity of MSW composted per day (tonnes)
2010	1,972	5.40
2011	2,520	6.90
2012	2,570	7.04
2013	2,621	7.18
2014	2,674	7.33
2015	2,727	7.47
2016	2,781	7.62
2017	2,837	7.77
2018	2,893	7.93
2019	2,952	8.09
Total	**26,547**	**72.73**

Diesel consumption of Kota Kinabalu Composting Plant is used to derive the diesel consumption of the project activity with proportional adjustments (Table 4.16 and 4.17). $PE_{y,diesel\ on\text{-}site}$ is estimated from the following assumptions:

1. The project activity operates 6 days a week. It is closed every Sunday for maintenance. There are 52 weeks per year, hence, the composting plant operates 313 days per year. Due to insignificant changes in diesel consumption per hour, hence, quantity of waste composted is assumed consistent during crediting period, which is 8 tonnes per day (Table 4.15).

2. Skid face loader is used to transfer the sorted organic material to the windrows and transfer compost from windrows to final screening before being packaged. One skid face loader is used in this project activity. Diesel consumption is four litres per hour (Table 4.17).

3. Wood chipper is used to reduce size of wood into smaller pieces or wood dust before added into other organic materials such as food waste and garden waste. One wood chipper with diesel consumption six litres per hour is used (Table 4.17).

4. Turning machine is used to turn the windrows periodically. One turner with diesel consumption six litres per hour is used (Table 4.17).

5. Matured compost is transferred from windrows to packaging in 5-kg bags. The 5-kg packages will be placed on pallets and then stored for retail sale.

6. Diesel is also consumed by forklift to store 5-kg packages and upload them into trucks for distribution. However this equipment consumes lesser diesel and operates at lesser hours. The total diesel consumption per hour is one litre (Table 4.17).

7. Feedstock of the project activity is low. Thus, it does not require wheel loader.

At the project activity, highest diesel consumption is by the turning machine. It is used six minutes per day. With diesel consumption of 0.60 litres per day and operates 313 days per year, its total diesel consumption per year is 187.80 litres. Wood chipper and skid face loader use up same amount of diesel per year, which is 125.20 litres. The machine which consumes the least amount of diesel is forklift, which is 31.30 litres per year (Table 4.17).

Table 4.16: Diesel driven equipments used at the Kota Kinabalu Composting Plant

Type of equipment	Quantity	Litres per hour (each)	Operating hours per day	Total litres per day	Litres per year
Wheel loader	1	12	6	72	26,280
Wood chipper	1	6	4	24	8,760
Turning machine	1	6	6	36	13,140
Skid face loader	2	4	6	48	17,520
Forklift	5	1	6	30	10,950
Total					**76,650**

Adopted: Project outcome computation-fuel consumption (Green Technology Financing Scheme)

Table 4.17: Diesel driven equipments used at the project activity

Type of equipment	Quantity	Litres per hour	Operating hour per day	Total litres per day	Litres per year
Wood chipper	1	6	4 minutes	0.40	125.20
Turning machine	1	6	6 minutes	0.60	187.80
Skid face loader	1	4	6 minutes	0.40	125.20
Forklift	1	1	6 minutes	0.10	31.30
Total					**469.50**

The emissions were calculated based on Eq. 3.8, from the quantity of diesel used and specific CO_2 emission factor for diesel. Due to the assumption being made, 469.50 litres diesel is used per year, resulting in 1.27 tCO_2 of emissions annually, equivalent to 12.70 tCO_2 in 10 crediting years.

$$\mathbf{PE_{y,diesel\ on\text{-}site} = V_{y,diesel} * EF_{CO2}} \qquad \textbf{(Eq. 3.8)}$$

$$= 469.50 * 2.7\ kgCO_2/\text{litre diesel}$$

$$= 469.50 * 0.0027\ tCO_2/\text{litre diesel}$$

$$= 1.27\ tCO_2$$

Parameters used in Eq. 3.8 are summarised in Table 4.18.

Table 4.18: Parameters used to calculate emissions from diesel consumption on-site

Parameter	Description	Unit	Value	Source
$V_{y,diesel}$	Volume of diesel used	litres	469.50	Calculated
EF_{CO2}	Average truck capacity for waste transportation	tCO_2/litre diesel	0.0027	2006 IPCC

b) Emissions from electricity consumption, $PE_{y,electricity}$

Emissions from electricity used at the site were calculated based on Eq. 3.9. At Kota Kinabalu Composting Plant, out of all the facilities, only drum screen is operated using electricity taken from the grid. According to the project coordinator, the quantity of electricity consumed by the plant is minimum. Due to the huge difference in feedstock between the plant and the project activity, the electricity consumption of the project activity will be much lesser. Hence, the emissions from electricity consumption is negligible, $PE_{y,electricity} = 0$.

4.3.3 Emissions from physical leakage, $PE_{y,phy\ leakage}$

Emissions from physical leakages were calculated based on Eq. 3.10. Waste is not treated in any anaerobic digester in this project activity. Thus, project emission from physical leakages of anaerobic digester is not applicable for this project activity. Hence $PE_{y,\ phy\ leage} = 0$.

4.3.4 Emissions from composting, $PE_{y,compost}$

Emissions from composting process were calculated based on Eq. 3.11. According to Table 3.1, the composting process is aerobic. Hence, CH_4 emission is considered negligible. Furthermore, CO_2 emission is excluded as the emission is considered as biogenic. Hence, $PE_{y,compost} = 0$.

4.3.5 Emissions from runoff, $PE_{y,runoff}$

The emissions from runoff were calculated based on Eq. 3.12, using the following assumptions:

1. The composting plant is roofed and with concrete flooring. Thus the collected runoff is fully collected from the composting process. It was recycled into the composting process to add moisture onto the windrows.

2. During crediting period, the volume of runoff and the COD of runoff shall be monitored to account for any associated project emissions in rare cases. Hence, $PE_{y,runoff} = 0$.

4.3.6 Emissions from residual waste, $PE_{y,\ res\ waste}$

The compost was transported for distribution at the market. Thus it is unlikely that anaerobic storage or disposal in landfill will take place which may cause methane emissions from anaerobic decay of compost. Hence, $PE_{y,\ res\ waste} = 0$.

4.3.7 Total project emissions

Project emissions consist of emissions from transportation of compost for sale and soil application and diesel consumption during composting process. The formulas for project emissions can be summarised as below based on the explanations and assumptions presented earlier:

$$\mathbf{PE_y = PE_{y,\ transp} + PE_{power}}$$

The project emissions from transport and power consumption were calculated before added up to estimate the yearly project emissions:

$$\mathbf{PE_y = \Sigma PE_{y,monthly}}$$

Total project emissions are the sum of emissions from transport and diesel on-site consumption. Total project emission was 132.18 tCO_2e (Table 4.19). Emissions from transport take up 90% of total project emissions, while emissions from power consumption are insignificant, which was 12.70 tCO_2e .

Table 4.19: Project emissions

Year	$PE_{y,\ transp}$ (tCO_2e/year)	$PE_{y,diesel,on\text{-}site}$ (tCO_2e/year)	Total project emissions (tCO_2e)
2010	8.87	1.27	10.14
2011	11.34	1.27	12.61
2012	11.57	1.27	12.84
2013	11.80	1.27	13.07
2014	12.03	1.27	13.30
2015	12.28	1.27	13.55
2016	12.52	1.27	13.79
2017	12.77	1.27	14.04
2018	13.02	1.27	14.29
2019	13.28	1.27	14.55
Total	**119.48**	**12.70**	**132.18**

Emission per tonne of wet waste was estimated by dividing annual project emissions with respective quantity of waste sent for composting. The estimated emission was consistent at 0.0050 tCO_2e (Table 4.20). The emission is much lower compared to both theoretical estimates (0.284-0.323 tCO_2e per tonne of mixed waste) and practical estimates (0.183-0.932 tCO_2e per tonne of mixed waste) (Lou & Nair, 2009). The difference might be due to a few factors such as waste composition (such as organic fraction), composting technologies, use of gas cleaning (such as for enclosed systems) and the use of compost (Boldrin et al., 2009). The composting process is aerobic and the emissions are biogenic in origin, thus the emissions in this research are mainly operational emissions (Elena & Cristina, 2011).

Table 4.20: Project emission per tonne of wet waste

Year	Quantity of waste composted (tonnes)	Project emissions (tCO_2e)	Emission per tonne of wet waste (tCO_2e)
2010	1,972	10.14	0.0051
2011	2,520	12.61	0.0050
2012	2,570	12.84	0.0050
2013	2,621	13.07	0.0050
2014	2,674	13.30	0.0050
2015	2,727	13.55	0.0050
2016	2,781	13.79	0.0050
2017	2,837	14.04	0.0049
2018	2,893	14.29	0.0049
2019	2,952	14.55	0.0049

4.4 Estimation of Emissions Reduction

Emission reductions were calculated based on Eq. 3.13. Leakages happen when project technology or the equipment is transferred from another activity or if the existing equipment is transferred to another activity project. No leakages are anticipated from the project activity as all the equipments used in the project activity are brand new and bought for the purpose of the project activity. No equipments or treatment technology was transferred from another activity or existing equipment is transferred to another activity. Hence leakage = 0. Therefore, $\mathbf{ER_y = BE_y - PE_y}$.

Emissions reduction is the difference between baseline and project activity. By converting organic waste into compost, 7,926.79 tCO_2e will be able to be prevented from being emitted to the atmosphere during in 10 years, a tremendous reduction of 98% (Table 4.21). At the same time, the project activity also creates other environmental benefit by producing organic fertilizer (MSW compost). MSW compost is environmental friendly and can be used in organic plantation. However, the nutrients and heavy metal contents shall be studied further.

Table 4.21: Emissions reduction

Year	Estimation of baseline emissions (tCO_2e)	Estimation of project emissions (tCO_2e)	Estimation of leakage (tCO_2e)	Estimation of overall emissions reduction (tCO_2e)
2010	240.52	10.14	0	230.38
2011	460.56	12.61	0	447.95
2012	624.40	12.84	0	611.56
2013	748.17	13.07	0	735.10
2014	844.08	13.30	0	830.78
2015	921.65	13.55	0	908.10
2016	983.84	13.79	0	970.05
2017	1,035.52	14.04	0	1,021.48
2018	1,081.18	14.29	0	1,066.89
2019	1,119.05	14.55	0	1,104.50
Total	**8,058.97**	**132.18**	**0**	**7,926.79**

The emissions reduction per tonne of wet waste ranged from 0.12-0.37 tCO_2e (Table 4.22). This result falls within the results presented by Boldrin et al. (2009), -9.00 (net saving) to 0.300 (net load) tCO_2e per tonne of wet waste.

Table 4.22: Emissions reduction per tonne of wet waste

Year	Quantity of waste composted (tonnes)	Emissions reduction (tCO_2e)	Emissions reduction per tonne of wet waste (tCO_2e)
2010	1,972	230.38	0.12
2011	2,520	447.95	0.18
2012	2,570	611.56	0.24
2013	2,621	735.10	0.28
2014	2,674	830.78	0.31
2015	2,727	908.10	0.33
2016	2,781	970.05	0.35
2017	2,837	1,021.48	0.36
2018	2,893	1,066.89	0.37
2019	2,952	1,104.50	0.37

4.5 Project Financial Assessment in Regulated Market

4.5.1. Income

(a) Certified Emission Reductions (CERs) Sale

Income from CERs sale = 7,926.79 tCO_2e x US$13 per tonne

= US$103,048 (RM314,347)

Primary CER (pCER) refers to CER purchased directly from the party which makes the reduction (Annex I countries purchased from non-Annex I countries which host the

CDM projects) while secondary CER (sCER) is the CER traded in marketplace. CERs sale were calculated based on the following assumption:

1. CERs are sold as sCER at US$13 per tCO_2e (refer Table 2.9 - sCER).

The above assumptions shall be monitored during crediting period to record any changes of price in future carbon market. 7,926.79 tCO_2e emission reductions will be obtained from the project activity, generating income of US$103,048 (RM314,347).

(b) MSW Compost Sale

MSW compost sale were calculated based on the following assumption:

1. MSW compost sold at US$5 per tonne.

Market value and demand of MSW compost is lower than compost of agricultural waste. Price of MSW compost in Malaysian market ranged from US$5 to US$10 while compost of agricultural waste can sell at US$15 to US$35 (UNFCCC, 2008b). Pricing of MSW compost shall be monitored ex-post to account for any changes in future MSW compost market.

Income from MSW compost sale = 13,276 tonnes x US$5 per tonne

= US$66,380 (RM202,492)

In Table 4.12, the project activity produces 13,276 tonnes of MSW compost within 10 years. By assuming the MSW composts sold at US$5 per tonne, US$66,380

(RM202,492) will be generated from MSW compost sales.

(c) Total Income in 10 Years

Total income in 10 years = CERs sales + MSW compost sales

= US$103,048 + US$66,380

= US$169,428 (RM516,840)

The operation of the project activity relies mainly on the total income which is sourced from sale of CERs and MSW compost. By having 7,926.79 tCO2e of emission reductions and 13,276 tonnes of MSW compost in 10 years, total income US$169,428 (RM516,840) will be generated at the end of the crediting period.

4.5.2. Cost

(a) Initial Capital Investment, Operation and Maintenance Cost

The project activity receives approximately 8 tonnes of MSW daily while 500 tonnes of MSW is sent to Malaysia-Kota Kinabalu Composting Plant daily. US$6.4 million is required to set up Malaysia-Kota Kinabalu Composting Plant and its continuous operation and maintenance costs for 10 years (Table 4.23).

At Malaysia-Kota Kinabalu Composting Plant, 500 tonnes per day require costs of US$6.4 million (Table 4.23). Hence, at the project activity, 8 tonnes per day require:

= (8 tonnes x US$6.4 million) / 500 tonnes

= US$102,400

Hence, the cost required by the project activity was estimated similarly as US$102,400 after proportional adjustment. However, this cost shall be monitored during crediting period to record any changes.

Table 4.23: Costs of Malaysia-Kota Kinabalu Composting Plant

Costs	Amount (US$)	Frequency
Initial Capital Investment	2,049,696	On implementation
Operation & Maintenance costs (10 year project cycle)	4,373,378	Whole project cycle
Total	**6,423,073**	

Source: Project Design Document (PDD) Malaysia - Kota Kinabalu Composting Project, 2008

(b) Small-Scale CDM Registration Cost

In order to register as a small scale CDM project, there are numerous activities involved, such as Project Design Document (PDD) preparation, registration and validation. The estimated cost for the whole process is more than US$65,000 (Table 4.24). For this research purpose, the figure is rounded up to US$65,000, as a conservative figure. This cost shall be monitored during crediting period to record any changes.

Table 4.24: Estimated cost of Small-Scale CDM project

Activity of Small-Scale CDM project	Estimated cost (US$)
Project Design Document (PDD) preparation	20,000
Stakeholder consultation and host country approval	5,000
Validation	12,500
Registration	5,000
Transaction negotiation and contracting	10,000
Project monitoring (periodic)	varies
Initial verification	7,500
Periodic verification (cost per verification)	5,000
Approximate total	**>65,000**

Note: Actual cost will vary considerably depending on several factors
Source: Green Markets International, 2007

(c) Total Cost in 10 Years

Total cost in 10 years = Initial capital investment, operation and maintenance cost + small-scale CDM registration cost

= US$102,400 + US$65,000.00

= US$167,400 (RM510,654)

Cost tCO_2e = US$167,400/ 7,926.79 tCO_2e

= US$21 (RM64)

Total cost is the sum of initial capital investment, operation and maintenance cost and small scale CDM registration cost, which exceeds US$167,400. For this research purpose, this figure will be rounded up to US$167,400(RM510,654), whereas the cost per tonne CO_2e is US$21 (RM64).

4.5.3. Profit/ Loss

Profit is the difference between income being generated and cost incurred. Benefit cost ratio shows the feasibility of a proposed project by taking into account amount of money gained from the project over the set up cost.

Profit/ loss in 10 years	=	Income - Cost
	=	US$169,428 - US$167,400
	=	US$2,028 (RM6,186) (profit)

Benefit cost ratio	=	Profit / Cost
	=	US$2,028 / US$167,400
	=	0.012

Only US$2,028 (RM6,186) will be gained from the project activity, throughout a 10-year period. While benefit cost ratio is relatively low, only 0.012.

4.6 Project Financial Assessment in Voluntary Market

Besides regulated market where Annex I countries are obliged to reach the emissions reduction targets, voluntary market also exists. The carbon credits are purchased by corporate to fulfill their voluntary corporate GHG reduction targets, to reach a status of carbon neutral.

4.6.1. Income

(a) Carbon Credits Sale

Income from carbon credits sale = 7,926.79 tCO_2e x US$7 per tonnes

= US$55,487 (RM169,263)

Price of carbon credits in voluntary market is 50% lower than regulatory market. The factors that cause the difference is the high CDM registration cost and higher credibility of CER in CDM projects as an offset. Carbon credits sale were calculated based on the following assumption:

1. Carbon credits are sold at US$7 per tCO_2e (refer Table 2.9 – voluntary market).

The above assumptions shall be monitored ex-post to account for any changes of price in future carbon market. 7,926.79 tCO_2e emission reductions will be obtained from the project activity, generating income of US$55,487 (RM169,263).

(b) MSW Compost Sale

MSW compost market remains same regardless the type of market the carbon credits will be traded. Hence, MSW compost sale is same as part 4.5.1 (b).

(c) Total Income in 10 Years

Total income in 10 years = Carbon credits sales + MSW compost sales

= US$55,487 + US$66,380

= US$121,867 (RM371,755)

Total income is lower than part 4.5.3 as the price of carbon credits in voluntary market is much lower than regulated market. In regulatory market, income from sale of carbon credits consists of 61% of total income, while it is 46% in voluntary market. Total income US$121,867 (RM371,755) will be generated at the end of the crediting period.

4.6.2. Cost

(a) Initial Capital Investment, Operation and Maintenance Cost

Initial capital investment, operation and maintenance cost remains same regardless the type of market the carbon credits will be traded. Hence, the cost is same as part 4.5.2 (a).

(b) Small-Scale Voluntary Project Registration Cost

Besides that, the project activity also can go for voluntary carbon market instead of CDM project. Though the processes involved are same as CDM projects, but they can be done at much lower registration cost, which exceeds >US$25,000 (Table 4.25). For this research purpose, this figure is rounded up as US$25,000, as a conservative figure. The cost involved is 62% lower compared to CDM project as the registration cost is only US$25,000. This cost shall be monitored ex-post to account for any changes.

Table 4.25: Estimated cost of small scale voluntary project

Activity of Small-Scale CDM project	Estimated cost (US$)
Project Design Document preparation	7,500
Stakeholder consultation and host country approval	2,500
Validation	5,000
Registration	NA
Transaction negotiation and contracting	5,000
Project monitoring (periodic)	Varies
Initial verification	2,500
Periodic verification (cost per verification)	2,500
Approximate total	**>25,000**

Note: Actual cost will vary considerably depending on several factors
Source: Green Markets International, 2007

(c) Total Cost in 10 Years

Total cost in 10 years = Initial capital investment, operation and maintenance cost + small-scale voluntary project registration cost

= US$102,400 + US$25,000

= US$127,400 (RM388,634)

Cost tCO_2e = US$127,400/ 7,926.79 tCO_2e

= US$16 (RM49)

Total cost is much lower compare to CDM project, the sum of initial capital investment, which exceeds US$127,400. For calculation purpose, this figure will be rounded up as US$127,400 (RM388,634), whereas the cost per tonne CO_2e is US$16 (RM49).

4.6.3. Profit/ Loss

Profit/ loss = Income – Cost

= US$121,867 - US$127,400

= -US$5,533 (RM16,878) (loss)

Benefit cost ratio = Profit / Cost

= -US$5,533 / US$127,400

= -0.043

A loss of US$5,533 (RM16,878) will be encountered if the project activity goes for voluntary market with benefit cost ratio of -0.043. Volume of feedstock is low and consequently capacities of composting machineries have not been fully utilized. Hence, higher feedstock volume may increase the feasibility by increasing the sales volume especially carbon credits as this portion is the main income stream. This may also help the second scenario to generate profit. However, practical calculations are required to determine the feasibility.

4.7 General Discussion

The concentration of CO_2 has increased from 315 ppm in 1958 to 385 ppm in June 2008 (Ecosystem Restoration Associates Inc, 2011). Top scientists say carbon emission must be reduced to zero by 2050, otherwise temperature will continue to rise. Mark (2008), the author of Six Degrees: Our Future on a Hotter Planet has presented the possible consequences if the average planet temperature is raised by one to six degrees Celsius (Caspar, 2007 ; The Guardian, 2007). One degree Celsius rise will destroy most coral reefs and many mountain glaciers will be melting. A three degree Celsius rise would put the Amazon rainforest and Greenland's ice sheet in devastation and desertification across the Midwestern United States and southern Africa. While most life on earth include humanity will not survive under a six degree Celsius increase (Mark, 2008).

Regarding to this, the CDM projects are helpful to reduce GHG emissions and create sustainable development in developing countries, at the same time to assist developed countries to reach their emission reduction obligation. This research focused on waste management, specifically composting under the Kyoto Protocol's CDM. Waste sector is one of the seven main sectors contributing to climate change (IPCC, 2007b). Thus, it becomes target of investors to reduce emissions (Fenhann, 2010). Emission mitigation technologies applied in waste sectors include landfill gas recovery and landfill CH_4 prevention through aeration or avoidance of landfilling such as composting (Cyrill et al., 2011). The number of landfill gas related CDM projects is much higher compared to composting CDM projects. In March 2010, out of 203 registered projects in waste sector, 154 was landfill gas projects while only 37 was composting projects (Fenhann, 2010). The latter was less favoured among investors due to its low cash flows in early stages generated (Cyrill et al., 2011). The first CDM composting projects was accepted in 2006, which is a composting project in Dhaka (UNFCCC, 2006b). However, not many have been registered after that. The worst is, out of the 37 projects, no carbon credits have been issued successfully (Fenhann, 2011).

Nevertheless, composting is a good waste management method in developing countries due to several factors such as high biodegradable content in waste, low labour cost, simple technology and cheap (Barton et al., 2008; Elango et al., 2009; Gonzenbach and Coad, 2007; Hofny-Collins, 2006). Furthermore, composting is able to generate more emission reductions (Barton et al., 2008). In Europe and Australia, composting is combined with mechanical biological treatment technologies (MTB) to stabilize the organic matter in the waste (Elena & Cristina, 2011). Besides developed countries, the MTB technologies have been implemented in developing countries such as Pudong, China (Hong et al., 2006). The benefits of compost is widely recognized, thus it is highly regulated in the OECD countries (UNEP, 2010).

However, Malaysia lags behind. Currently, there is no CDM MSW composting projects in the country. All the registered CDM composting projects are related to palm oil mill effluent (POME). Since MSW composting is uncommon in the country, thus, it requires more detailed feasibility study. In order to evaluate the feasibility of the project activity, income and costs involved must be identified. In this research, carbon credits generated are assumed to be traded in regulatory market and voluntary carbon market. The results of this research show that 8,058.97 tCO_2e will be released with the absence of the project activity. However, by setting up the composting plant, 7,926.79 tCO_2e will be prevented from being released into the atmosphere.

Despite the emissions reduction, a project can only be sustainable if it covered both environmental and economical aspects. The project feasibility shall be determined by studying the cash flow and net present value (NPV) (Couth & Trois, 2010). The cost to reduce one tonne of CO_2e in developing countries is cheaper than in developed countries (Lee et al., 2005). The carbon credit price was US$13 and US$7 tCO_2e in regulated market and voluntary market respectively. Thus, the cost to design, build, finance and operate shall be 50% less than the price (Couth & Trois, 2010). However, in this research, it is found that the cost per tonne CO_2e in both market types is not in the range, which is US$21 and US$16, respectively. The high cost is due to the low feedstock which cause the facilities are not fully utilized up to their maximum capacity.

Another determining factor is the global carbon market prospect. Due to uncertain market perceptions due to lack of post Kyoto regulatory clarity, the value of CDM dropped to its lowest record to US$1.5 billion since 2005, the first year of Kyoto Protocol (Carbon Finance Unit of the World Bank, 2011). On the other hand, voluntary market continues growing and in 2010, it increased 34% to 131.2 MtCO_2e transacted from 2009 to 2010 (Molly et al., 2011). Though voluntary market only take up a small portion from global carbon market, 0.3%, yet continual offsetting commitment among company in fulfilling their corporate social responsibility (CSR), economy recovery and market growth makes the market is predicted to be positive beyond 2011.

The outlook of global carbon market beyond 2012 is complex and uncertain. The possibility of a binding international agreement will be achieved in short term is low.

The absence of post Kyoto agreement and uncertainty in demand for carbon credits have halted the investors. However, the High-Level Advisory Group on Climate Change Financing under the UN Secretary-General has pointed a positive view, that with the help of market based instruments, countries are believed to be able to combating climate change provided the market in the countries could show regulatory confidence in the post-2012 era (Carbon Finance Unit of the World Bank, 2011).