Penerbit Akademia Baru

Journal of Advanced Research in Engineering Knowledge

Journal homepage: www.akademiabaru.com/arek.html
ISSN: 2600-8440

Material Flow Analysis of Carbon in Palm Oil Mill and Oil Palm Plantation: Towards Low Carbon Industry

Open Access

Hariz Zain[1,*], Noor Zalina Mahmood[2], Wan Azani Mustafa[1]

[1] Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia
[2] Institute of Biological Sciences, Faculty of Science, University of Malaya, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 18 August 2017
Received in revised form 4 October 2017
Accepted 2 December 2017
Available online 18 December 2017

Keywords:
Material Flow Analysis (MFA), carbon, POME, carbon stocks

ABSTRACT

The improvement of imbalance global carbon cycle that cause global warming, the Malaysian Government committed to reduce its carbon dioxide emission intensity to 40% GDP per capita by 2020 as compared to 2005 levels. This research aims to obtain information on carbon stocks and carbon cycles in the selected oil palm industry and plantation in the year 2016 by Material Flow Analysis (MFA) and finally to expose mitigation measures for impacts of carbon in the environment. This research was begun with data collection, site visits and the application of MFA to calculate carbon stocks and losses in the system. Carbon stocks at the plantation, upstream mill, anaerobic digester and compost field for 2016 were 9,122,241.92 MT C/year, 1,364,899.82 MT C/year, – 170,294.17 MT C/year and – 259,402.22 MT C/year accordingly. To mitigate carbon losses within the palm oil metabolism system, empty fruit bunches (EFB) and palm oil mill effluent (POME) recycling were the best mitigation measures.

1. Introduction

Throughout its production chain, the oil palm industry is involved in various environmental matters. There has been a number of related studies which show positive environmental impacts by the subject industry such as contribution as good carbon-sinking source. On the other hand, some studies showed that the industry has potential negative environmental impacts such as deforestation and habitat loss. In either case, higher efficiency related to material and energy use are vital for better business performance (higher profit) with less environmental impacts.

In addition, carbon-related issues draws keen attention around the world nowadays. While carbon plays an important role to sustain the biosphere lives by supplying and conserving energy at tropic level, it is also considered to cause climate change. In the oil palm industry, there are various emission sources including palm oil plantation mill chimney, POME fermentation, disposing and

* *Corresponding author.*
E-mail address: harizhijaureen@gmail.com (Hariz Zain)

composting field, draining the peat-land for plantation, transportation and leachate from treatment plants.

Sustainable palm oil production is comprised of legal, economically viable, environmentally appropriate and socially beneficial management and operations. Flow-based material and carbon analysis approaches based on Material Flow Analysis (MFA) allow organization to meet its environmental responsibility and conservation of natural resources and biodiversity together with commitment to long-term economic and financial viability.

Based on the background and approach above, the objective and scope of this paper is to increase transparency of the Malaysian palm oil production processes during the palm-oil production process for further clarification of carbon flow, carbon cycle, and material flow. Further, based on the flow-based analysis, mitigation measures for carbon effects in the environment, and accurate cost calculation for material and carbon losses will be made to the extent possible.

The objectives of the current study are outlined as below:

1. To calculate on carbon stocks and emission in selected oil palm plantation, upstream mill, biogas anaerobic digester and composting site by MFA.
2. To determine mitigation measures for carbon effects in the environment.

1.1 Material Flow Analysis (MFA): History of Material Flow Analysis'

Material Flow Analysis started from the early era of human metabolism by Santorio's analysis of human metabolism in the early 1614 and it was evolved to become the metabolism of the cities by Abel Wolman in the late 1960's and finally modernized by Brunner as MFA in 2004. The table below explained about the evolution of MFA from 1600's until now.

Material Flow Analysis (MFA) is a systematic assessment of flows and stocks of materials within a system defined in space and time [1]. The study of material flow was firstly aroused by a physiologist when the study of human metabolism emerged. The father of human metabolism (Sontorio, 1561 – 1636) found that there was a lot of missing of input-output of human body system. An experiment was set up by Santorio in 1614 to investigate material metabolism of a person. Santorio's experiment could not confirm his hypothesis that an unknown fluidum leaves the body at night, but more than half of the input mass leaves the body by an unknown pathway[2]. Brunner concluded that it is still impossible to assess accurate anthropogenic systems without knowing the material flows and stocks.

In the year of 1930, there was an emergence of input-output economical methodology by Leontief so called Leontief's Economic Input-output Methodology [3,4]. Wassily W. Leontief focused on interdependent of anthropogenic production systems to investigate economic transactions between various sector of economy. Input-output methodology was developed and the input-output tables were created to produce systematic quantity of mutual interrelationships among various sectors of a complex economic system.

Then, the "outer" metabolism called "Metabolism of Cities" was created by Abel Wolman in 1965. According to Wolman, the consumption and production of goods will affect and establish per capita input and output flows for a hypothetical American City of 1 million inhabitants [5]. According to Brunner, the metabolism of cities was the point of urban turnover of energy and materials concerns with the effects of the large flows on resource depletion [1].

The metabolism of Hong Kong and Brussels were investigated in the beginning of 1970's. Newcombe and his group began their research on Hong Kong metabolism and came out with outcome that Asian city was experiencing a rapid transition period of high population growth and intense economic development due to its privileged position at the interface between Western trade and Eastern production and manufacturing [6]. Newcombe found that the material and energy used for Hong Kong infrastructure was about one order of magnitude smaller than in more highly developed cities.

Table 1
The Chronology of MFA History [1]

Year	MFA History Event	Founder	Findings
1614	Analysis of human metabolism	Santorio [2]	To assess accurate anthropogenic system, knowing material flows and stocks are essential.
1930	Economic input-output methodology	Leontief [3,4]	To find out the production emissions and wastes of a process by analyzing input and output of a system.
1965	Metabolism of a city	Abel Wolman [5]	There is a linkage between large amount of waste generated in a city from its inputs.
1970	The metabolism of Hong Kong	Newcombe *et al* [6]	Material and energy used for developing country were smaller than the one in the developed country,
1975	The metabolism of Brussels	Duvingnaeud and Denayeyer-De Smet [7]	Energy balanced concepts was established by balancing the total imports and exports of goods such as fuel, construction materials, food, water, wastes, sewage, emissions and etc.
1985	Material Balance : Hudson River Study	Ayres *et al* [8]	Hudson river long term effect was caused by the anthropogenic activities and land use changing process.
1989	Industrial metabolism	Ayres [9]	The establishment of environmental protection and resource management studies.
1991	Metabolism of anthroposphere	Baccini and Brunner [10]	The improvement of resource management system of a region.
1994	Stockholm metabolism	Bergback *et al* [11]	Identification of a very valuable copper reservoir and preventing the stocks from emit to avoid environmental degradation of the city.
2002	Material Flow Analysis	Brunner [1]	Methodology to reduce ecological footprint of a country.

In 1975, Brussels Metabolism was established. Duvingnaeud and Denayeyer-De Smet analysed the city of Brussels. The total imports and exports of goods such as fuel, construction materials, food, water, wastes, sewage, emissions and etc. in and out of the city were assessed and energy balanced entity was established [7]. Materials such as food and raw construction materials were not recycled after their use and were exported as waste. The necessity of changing the structures of cities in a way that improves the utilization of energy and materials, creates material cycles, and reduces losses to the environment was highlighted in Brussels metabolism [1].

At the end of 1960's, aroused of material balance study and the first study on heavy metal accumulation in a region was initiated. Hudson River study was the catchiest research among the biochemists in the early of 1980's [8]. Ayres *et al*. [9] analysed the sources pathways and sinks of major pollutants in the Hudson-Raritan basin for a period of 100 years from 1885 to 1985. This project was to explore the long-term effects of anthropogenic activities on Hudson River. Changes in the environment were caused by the alteration in population, land use and regulation of the country. On 1989, Ayres expanded his study from single substances to more comprehensive systems, looking at the entire "industrial metabolism" using MFA methodology to study complex material flows and cycles in industrial system. “Industrial metabolism” was aimed to improve the technological systems, by inducing long-term planning based on resource conservation and environmental protection, and by producing less waste and recycling more materials.

“Metabolism of the anthroposphere” was the extension of MFA and the goals were to develop methods to analyse, evaluate and control metabolic processes in man-made systems and to apply these methods to improve resource utilization and environmental protection on a regional level [10]. Then, evolved the study of metabolic processes using MFA by Bergback, on 1994, the pioneer of the study of Stockhom Metabolism which focused on the stock of materials and substances in private households and the corresponding infrastructure. This study manages to identify a very large reservoir of valuable substances such as copper and lead [1]. The finding was so important to prevent environmental pollution by the emission of stocks and to conserve the valuable substances hidden in the city. In 2002, MFA was invented to contribute a powerful methodology to measure the “ecological footprints” in regions and it was concluded that regions in affluent societies use a very large “hinterland” for their supply and disposal and there was a need to compare and ultimately reduce the ecological footprints of regions [1].

2. Methodology

The entire palm oil mill operated in Malaysia and even Asia has a more or less similar production process. Their main activity is to do the processing of fresh fruit bunches (FFB) into Crude Palm Oil (CPO) and Palm Kernel. In this study, the selected mill was undergoing a detail study on the whole operation process from raw material aspect until the disposal aspects.

2.1 Research Design

The research design for this study is non-experimental design because the oil palm plantation, palm oil mill and composting site are not randomly chosen. Interviews were conducted to the related stakeholders involved in this research. The research design for this research is non-experimental design because there is no control and therefore no experiment either in site or in laboratory exist in this study. Thus, data collection is the most crucial in this study methodology.

2.1.1 Study Sites

This study has been conducted in selected oil palm plantation regions in Peninsula Malaysia. The selected site is FELDA Maokil, which is located in Johor state of Malaysia.

2.1.2 Methodology Framework

Stage 1: Plantation

Plantation: To calculate carbon stock inside the oil palm trees, the Diameter Breadth Height (DBH) measurement were collected. The standard DBH value is 1.3 meter. The DBH and Heights of the trees were taken for each tree age profiles and the calculation of carbon stocks and carbon flow were applied [12]. Carbon flows and stocks were determined by using MFA approach.

For plantation, carbon stock is collected by completing the equation of “(Diameter of tree in DBH) 2 x Height of the tree”. Thus, data collection for plantation is based on the direct measurement of the oil palm trees diameter by ages and heights. Then, the calculation of carbon stocks and carbon sequestration in year 2016 was calculated using a specific methodology. The most important data for plantation is the production of Fresh Fruit Bunches (FFB) because FFB is the only carbon source that enter the next subsystem which is upstream mill.

Stage 2: Upstream Mill

Upstream Mill: To calculate carbon flow, Carbon losses and Carbon output from the upstream milling activity were calculated and analyzed by using MFA approach.

Upstream mill is the main “carbon converter” in the oil palm “carbon Metabolism” system. It converted carbon from FFB to become emission, POME, heat, CPO, kernel oil, kernel and EFB. The data needed were: the production of Crude Palm Oil (CPO), kernel, shell and other by-products of the mill, including the input of FFB with water and electricity consumption for the year 2016. Mill process flow should be identified to trace the exact carbon flow within the upstream mill boundary

Stage 3: Anaerobic Digester Biogas at Wastewater Treatment Plant

Wastewater treatment plant (Anaerobic Digester): To calculate carbon flow, emission and stocks, the formula of Biogas CDM project in palm oil wastewater treatment plant was referred and the data were obtained from the mill itself [13]. The formula to calculate carbon stocks in anaerobic digester is as follow;

$$BE_{\text{"2016"}} = \{ BE_{\text{"ww.treatment.2016"}} + BE_{\text{"ww.discharge.2016 "}} + BE_{\text{"sludge.final.2016 "}} \}$$

where; $BE_{\text{"2016"}}$ is Baseline emission for the year 2016, $BE_{\text{"ww.treatment.2016"}}$ is methane emission from baseline wastewater treatment systems which is anaerobic, $BE_{\text{"ww.discharge.2016 "}}$ is methane emission on account of inefficiencies in the baseline wastewater treatment system and with the presence of biodegradable organic carbon in untreated POME and finally $BE_{\text{"sludge.final.2016”}}$ is methane emission from the decay of final sludge generated by baseline treatment system which is compost sludge.

This subsystem received carbon in POME flow as the output of upstream mill. The essential data needed are POME loading into the mixing pond for the whole year 2016, COD concentration of POME, electricity generation for the whole year, COD reading of POME after the treatment and POME loading to the plantation and composting site.

Stage 4: Composting Field

Composting Field: CDM formula and MFA approach were applied to calculate carbon stock, flow and emission. It is the final subsystem of carbon flow before carbon completed its cycle and return back to the plantation. The data of POME loading, Empty Fruit Bunches (EFB) inputs and the application of inoculants application frequency were essential to be captured. The output data from this subsystem such as compost production and waste generation were also collected [14]. The formula to calculate carbon stocks in composting site is as follow;

$$CER_{\text{"2016"}} = CER_{\text{"Composting.2016"}} - (CER_{\text{"Transportation/meachinery2016"}} + CER_{\text{"leachate.2016"}})$$

where; $CER_{\text{"2016"}}$ is the net amount of reduction of carbon dioxide after the eliminating of carbon dioxide emission in leachate and machinery, $CER_{\text{"Composting .2016"}}$ is the positive reduction of carbon dioxide from the composting site, $CER_{\text{"Transportation/mechunery2016"}}$ is the reduction of carbon dioxide emission from transportation and machinery and finally $CER_{\text{"leachate.2016"}}$ is the reduction of carbon dioxide in leachate that come across the composting site.

2.2 MFA System Analysis

Figure 1 (overall system) shows the whole system under this study, as a "Framework Model". The analysis will be simplified with numbering each process and good, in order to make reorganization towards each flows become easy to count. Table 2 exhibits the (8) Flows and (4) subsystems in this study which it definition for each term is explained in the "Framework model" as followed.

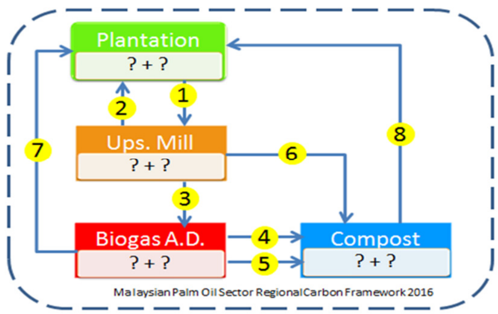

Fig. 1. System analysis of carbon balance in Malaysian palm oil industry in the year 2016

Table 2
The numeration of flow used in MFA Model

No.	Substance (carbon carrier)
1	Fresh Fruit Bunches
2	Shredded EFB, EFB ash
3	POME to anaerobic digester
4	POME to compost
5	Sludge to compost
6	EFB to compost
7	POME to plantation (for land application)
8	Compost to plantation

3. Results

After knowing the total input and output in the subsystems, based on Figure 2a, 2b, 2c and 2d, that there were accumulation of carbon stocks inside the plantation and upstream mill while there were carbon emissions from anaerobic digester and composting site of the system. Carbon balance analysis in each subsystem shows that the carbon stock in the plantation is 9,122,241.92 MT C/year, while in the upstream mill its carbon stock is 1,364,899.82 MT C/year. Anaerobic digester and composting sites show negative carbon stocks which means that carbon emission was come out from the subsystems. Carbon emission from the anaerobic digester is – 170,294.17 MT C/year while in the composting site is – 259,402.22 MT C/year.

4. Discussion
4.1 Carbon Stocks and Cycles

Carbon stocks in every subsystems are the accumulation of carbon inside the system where the carbon output is less than carbon input means, there is some carbon "stock" accumulate inside the system before it come out from the system to become carbon output. The residence time of carbon in the subsystem depends on the material of carbon (solid, liquid or gaseous state). Once carbon material is built into the stock, it will not show up quickly in the output of the stock.

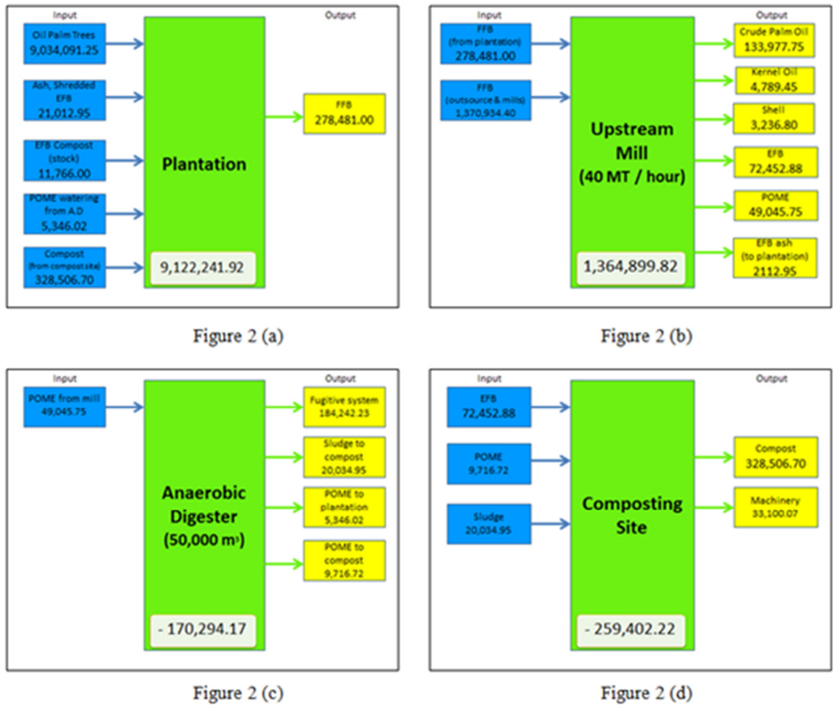

Fig. 2. Figure 2(a) shows carbon balance of the plantation. Figure 2(b) shows carbon balance of the upstream mill, Figure 2(c) shows carbon balance of the anaerobic digester and Figure 2(d) shows carbon balance of the composting site

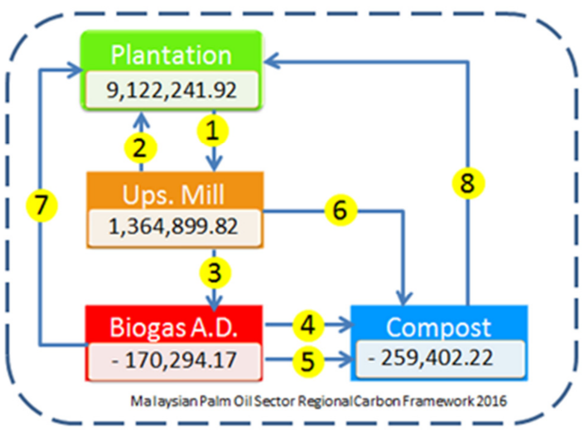

Fig. 3. Carbon cycle of Malaysian Oil Palm Industry and Plantation

Carbon cycle in this research referred to the carbon mobilization crossing the subsystems (plantation, upstream mill, anaerobic digester and composting field) within the system boundary. Starting with the ultimate carbon source which is the plantation, the foundation of carbon is totally from the oil palm trees and the plantation soil. Then, carbon source in the plantation is increased by the sequestration of carbon from the atmosphere by photosynthesis of the oil palm trees. Then, carbon from the plantation subsystem will flow as the output via Fresh Fruit Bunches (FFB) from the subsystem going out and entering the second subsystem called upstream mill.

Since FFB is the main raw material for the crude palm oil (CPO) production, it becomes the primary and fundamental input of upstream mill subsystem. Then FFB will be processed inside the upstream mill subsystem and produced CPO as the main product. Some carbon will flow out from the subsystem such as shredded and burnt EFB that transferred back to the plantation as mulching and soil conditioner in the plantation, palm oil mill effluent (POME) the wastewater from the production line transferred into the third subsystem so called biogas anaerobic digester and main solid waste, empty fruit bunches (EFB) into the last subsystem, composting site.

The next carbon pathway is the flow of carbon from upstream mill into anaerobic digester subsystem by POME. Carbon inside POME is very high concentrated since there is a vigorous decomposition activities occurred in POME by microorganisms. Thus, carbon content in POME can be considered very high and it is treated in the third subsystem so called biogas anaerobic digester. Anaerobic digester converted carbon from methane to become carbon dioxide by the production of electricity as the renewable energy from POME. Energy from anaerobic digester entering the upstream mill as electricity and some amount of carbon offset is achieved in this system. From this subsystem, carbon also will flow backward to the first subsystem, the plantation in POME as soil conditioner and water source of the oil palm trees. The low COD effluent flowed into the plantation by drainage and irrigation system as oil palm trees water and nutrient source and the high COD effluent were collected and channeled into the next subsystem named compost site subsystem.

Finally, the final subsystem is called compost site received POME and EFB as the main raw material to produce compost product for the utilization of plantation as the carbon and nutrient source for the oil palm trees growth. High COD of POME from anaerobic digester and ultimate EFB from upstream mill entering compost site subsystem and produced compost as the final carbon carrier that flow back to the first subsystem, plantation to complete the close cycle of carbon metabolism of oil palm plantation and industry in FELDA Maokil, Johor as the sample of Malaysian Oil Palm Carbon Metabolism.

4.2 Environmental Sustainability by Carbon Reduction

In this study, carbon cycle become the main issue of climate change. The released of GHG such as methane and carbon dioxide pass through the subsystem plantation, upstream mill, anaerobic digester and compost field gave cabon impacts to the environment. Thus, there were several carbon abatement mitigation measures suggested via this study.

In the plantation, during the planning stage, GHG such as methane and carbon dioxide were released by land and forest burning as the introduction to the new plantation land. Thus, carbon will be tremendously released into the atmosphere via forest burning and it caused extinction to the local faunal species after the burning. Half of carbon stock will be released outside the lithosphere (soil) and carbon resource inside the soil will be rapidly diminishing. To avoid the GHG release, this study suggest that the land and plantation developer avoid forest burning to open the new land and establish well-planned deforestation without burning.

This study also suggests that, there are no more deforestation for the new plantation. Agriculture developers can substitute other local agriculture commodity such as rubber estate, coca estate and many others to become oil palm plantation. Moreover, during the field establishment of the plantation, GHG emission of diesel burning via machineries and excavators can be avoided by substituting it into second generation of biodiesel from processed POME, recycling used cooking oil or olein.

Finally, carbon losses during harvesting period were leachate and agricultural waste. Leachate can be solved by channeling POME (as water source from anaerobic digester) with proper irrigation system. Agricultural waste can be reduced when the plantation workers utilized the fronds and palm leaves as soil conditioner by shredding them and apply them into the soil of the palm.

Second subsystem, upstream mill can be classified as carbon converter and the most condensed carbon stock. Carbon flown from the reception area and ended its flow as output as CPO, EFB to compost site and POME to the anaerobic digester system. In the upstream mill, there were excessive POME generated. This issues came from the excessive water generation during the sterilization process plus there were wastage during the cleaning process and finally water entered the effluent treatment plant (ETP) and caused excessive POME generated in 2016. Carbon that contains in POME were organic and very high nutrient and it might cause active biodegradation of microorganisms thus, the COD were very high. To reduce POME production, this study suggested the mill manager to recycle the water that yield from the sterilization process which were aqueous and used them to clean the mill. Sterilization process also can become more efficient by using a controlled system of energy (threshold) to avoid excessive burning thus, the energy will be wasted by the inefficient system. Rather than recycling sterilized water, this study suggested to optimize sterilization process and managing threshold energy limit to avoid energy wastage.

Second problem identified the energy consumption to dry the CPO. Pure CPO contains no water inside it. To dry the CPO, a lot of energy need to be consumed and this happened when there were inefficient sterilization, and inefficient pressing. The next energy wastage issues were at the boiler. Energy utilized to burn shells and fiber which were wet thus, more energy needed and the boiler worked very slow to produce electricity for the mill operation. So, to reduce energy wastage in boiler and to dry the CPO, mill operator must reduce the moisture contents of shells and CPO at the early stage of process. For the shells, the less moisture content available, the more calorific value the shell can be.

Third subsystem, the anaerobic digester. Anaerobic digester become one of the green initiatives taken by the upstream mill to mitigate GHG emission from being released to the atmosphere and it is the best renewable energy application where energy were recovered from POME by methane biogassification process. Almost methane converted to become electricity energy via the system. Carbon losses only can be detected at the methane flare of the biogas system. A recommendation is at the sludge removal process. The sludge where sediment at the bottom of the anaerobic lagoon must be cleared more efficiently to avoid Carbon remaining in the lagoon finally the lagoon become the carbon stock without any flow. Appropriate system must be applied to make sure all the sludge with high COD and carbon contents removed out from the lagoon into the compost to ensure the compost product receive high carbon and nutrients from the sludge itself.

Fourth subsystem, and the final subsystem which is the compost site. The main problem of compost site were the released of heat and water vapor caused by the composting process especially at the composting thermophilic phase. The problem can be solved by maximizing the turning by excavator or manual labor and spraying POME excessively to reduce the heat inside the windrows. Maximizing the turning and POME spraying will mitigate methane production because the condition of the windrows become more aerobic caused by the complete aeration by the turning.

5. Conclusion

As the conclusion, oil palm plantation play roles as the best carbon stock in the system because it saves 9,122,241.92 MT carbon every year and upstream mill saves 1,364,899.82 MT carbon in a year. Anaerobic digester emits – 170,294.17 MT carbon in a year while composting site emits – 259,402.22 MT carbon in a year. In terms of carbon balance, the system still gain carbon rather than lost carbon from by the emission. The system becomes a good model in promoting low carbon and sustainable industry because carbon is fully recycled within the subsystems – plantation, upstream mill, anaerobic digester and composting field.

Acknowledgements
This work was supervised by Associate Prof. Dr. Noor Zalina Mahmood from Institute of Biological Sciences, University of Malaya and supported by FELDA.

References
[1] Brunner, Paul H., and Helmut Rechberger. "Practical handbook of material flow analysis." *The International Journal of Life Cycle Assessment* 9, no. 5 (2004): 337-338.
[2] Major, R.H. “Santorio Santorio,” Annual Medical History 10, 369 (1938).
[3] Leontief, W. The Structure of the American Economy, 1919-1929, Report International Arts and Sciences Press (now M.E. Sharpe), (White Plains, N.Y, 1977) p 1.
[4] Leontief, W. Input-Output Economics (Oxford University Press, New York, 1966) p 20.
[5] Wolman, Abel. "The metabolism of cities." *Scientific American*213, no. 3 (1965): 179-190.
[6] Newcombe, Ken, Jetse D. Kalma, and Alan R. Aston. "The metabolism of a city: the case of Hong Kong." *Ambio* (1978): 3-15.
[7] Duvigneaud, P., and Denayeyer-De Smet, S. in L’Ecosysteme Urbain Bruxellois, edited by P. Kestemont (Section Belge du Programme Biologique International, Brussels, 1975) pp 581-597.
[8] Ayres, Robert U., Leslie W. Ayres, James McCurley, Mitchell J. Small, Joel A. Tarr, and Rolande C. Widgery. "An historical reconstruction of major pollutant levels in the Hudson-Raritan basin 1800–1980." *Rockville, Md.: National Oceanic and Atmospheric Administration* (1988).
[9] Ayes, R. U. "Industrial metabolism technology and environment." (1989).
[10] Baccini, Peter, and Paul H. Brunner. *Metabolism of the Anthroposphere*. Springer-Verlag, 1991.
[11] Bergbäck, Bo, Kjell Johansson, and Ulf Mohlander. "Urban metal flows–a case study of Stockholm. Review and Conclusions." *Water, air and soil pollution: Focus* 1, no. 3-4 (2001): 3-24.
[12] Birdsey, Richard A. "Carbon storage and accumulation in United States forest ecosystems." (1992).
[13] United Nations Framework Convention on Climate Change. Project Design Document: Biogas and Electricity Generation from Anaerobic Lagoon Methane Recovery System (UNFCCC, Germany, 2006).
[14] United Nations Convention Framework Convention on Climate Change. Project Design Document: Avoidance of Methane Production from Biomass Decay Through Composting (UNFCCC, Germany, 2009).