1. INTRODUCTION

1.1 Landfilll in Malaysia.

Landfilling is the oldest, most common and preferable disposal activity considering the social or economic aspects in developing countries, despite it being the least preferable in waste management hierarchy. Landfill as a final disposal is very important in waste management hierarchy because there are no technologies available to avoid the entire unwanted residue from the waste sector and no endowment for zero waste (Fauziah & Agamuthu 2012). The closure of the first sanitary landfill in Selangor ; Air Hitam Sanitary Landfill in Puchong, Selangor on 31st December 2006 was filled to the brim just after 15 years. Jeram landfill is expected to be closed in 2018, although it was planned to be in operation till 2023. Selangor state government is forced to cut short the lifespan of the Jeram Sanitary Landfill (JSL) to 11 years from the estimated 16. Without land use change, per capita emissions of each Malaysian was reported to be 5.7 tonnes of $C0_2$ eq in 2005 making the nation the 67th largest per capita generator of GHG emissions. As of 2000, the total amount of CH_4 emission from waste sector was estimated at 0.026 million Gg CO_2 eq where Malaysian Landfills' Global Warming Potential (GWP) from 1168.6 Gg CH_4 emission was 21. Lack of recycling and composting activities in the Malaysian waste management system resulted with a daily generation of approximately 2.7×10^6 L of CH_4 (Agamuthu & Fauziah 2010).

1.2 Landfill Functionality : Sink vs Reservoir

Public view landfills as a dumping site for garbage. Little is known that these buried wastes accumulate inside the landfill body not only experience gradual but also significant changes over time in terms of physical and chemical parameter. This makes landfill as a main artificial sink for chemical elements. Landfill accumulates and stores C and N- containing chemical compounds. The word 'sink' and 'reservoir' are often used over the years by researchers. Sinks function similar as reservoir in anthropogenic environment considering residence time of a particular material. Reservoirs and sinks may also be entities that are difficult to assess with great accuracy (e.g., an ocean) or small, easily quantifiable ones (e.g., warehouse and landfill). The term landfill implies to a generic final repository for anthropogenic material, which, in addition to actual landfills, would also include terrestrial sediments, ocean sediments, and seawater, among others. In terminology of element cycling, landfill is regarded as an accumulative reservoir, and the system is open (Klee & Graedel 2004). Based on functionality per say, sinks are reservoir in some way. While elements in reservoir can be harvested when necessary, sinks just keep the stock. Natural sinks are typically larger than artificial sinks (Brunner, 2011). Landfill for either sanitary or hazardous waste, is one of the main artificial sink in the academic research. A proper sink may be defined as a device ensuring that an input is stored safely and that the output to the environment is released passively, not to harm the surroundings e.g. a lake, the sea, groundwater, soils and sediments, or the atmosphere. Yet, an improper sink is a device that leak the stored hazardous material and elements at higher concentrations or quantities to the environment. It also demonstrates that many sinks are intermediate and not “final sinks” which are able to hold substances for geological timeframe (Baccini & Brunner, 2012). “Intermediate” here refers to space (limited or no boundaries) and time (temporary or permanent). There are few perfect final sinks on a global scale. The best researched sinks are probably those meant for safe disposal of nuclear waste. The better ones are salt mines, very old mountains, old and deep mine shafts, and sometimes even the deep seabed is mentioned (Brunner, 2011). Most other sinks like sanitary or secure landfills, ash and slag depots can only be regarded as temporary sinks, if well constructed, not overloaded, and leachate well taken care of may be effective until the leaching is fading away after many years but never exceeding the acceptable limit (Brunner, 2011).

1.3 Waste and Material Flow

One of the primary benefits of applying MFA to what is largely a waste management problem is the ability to see the entire system of material flow upstream and downstream of waste management according to categories (Fischer-Kowalski & Hüttler,1999). Waste flow follows materials as they enter the system (for example a city) through import or ; circulate or become additions to existing building stock (such as when building materials are placed into houses where they stay for long periods of time); are recycled in the city; or leave the system through disposal or export. Waste flow are related to economic-wide MFA. (Eurostat,2013). In order to visualize the waste management system in more detail, a material flow diagram was created that describes the types of waste. Stabilization was achieved by the degradation of the deposited waste through decomposition which affect the quality and quantity of landfilled waste output. The waste flow start from the waste stream and flows to entire system.

1.4 Mass &Element Balances in Municipal Solid Waste Landfill.

A number of elements such as C, N, Ca, K and P are present in municipal solid wastes. These elements can generally be divided into organics and inorganics. Landfilled waste buried in a space over a period of time have distinct physical and chemical parameters. Landfill in material flow analysis (MFA) framework is a closed but dynamic system. External factor such as precipitation (example rainfall) and temperature (closely related to humidity) affect the quality and quantity of leachate production and landfill gas in the long run.Water for instance is the medium for the transfer of substrate and nutrients within the landfill. Transfer coefficients for different elements mainly into gas and leachate, also known as exports, contribute to mobilizable potential (Baccini, *et.al*, 1987). Transfer coefficient are defined for each output of a process and could be a constant or a variable. They are useful for sensitivity analysis of the investigated system and for scenario analysis. MFA or Substance Flow Anlysis (SFA) assessed the flows and stocks of materials within a system defined in space and time. They were performed by means of the mass-balance model Substance Analysis (STAn) which performs MFA according to the Austrian standard ÖNorm 2096 S (MFA – Application in Waste Management) (Cencic & Rechberger, 2008) . In STAN, the waste system or any other system of interest can be built to graphically display as Sankey diagrams by adding known mass flows, concentrations and transfer coefficients. Simulations are performed by STAN to reconcile uncertain data and/or to compute parameters (e.g by Monte Carlo Simulations). MFA system definition and system analysis is an entity that could be spatial (geographic-based, global, regional or national) and temporal (time-based). In any one system, each flow-through is associated with the origin towards end-process which need to be clearly identified. System boundaries define the temporal and spatial delimitation of system under investigation. The spatial system boundaries for this study includes the landfill body, landfill surface and processes or cycles within a tropical sanitary landfill loop. This system includes facilities for gas and leachate treatment. Material flow into a system are imports while those from the system are known as exports. The system boundaries does not include the collection and transportation of waste to and from landfill.The sensitivity analysis allows to quantify the effect of a defined parameter change (e.g. variation of 10%) on a variable (Baccini & Bader, 1996). This quantification provides insight into the most determining parameters for given variables. It therefore indicates where priorities should be placed when developing countermeasures. Since limited data availability and reliability has been identified as one barrier to a wider application of MFA for policy making, considerations regarding uncertainty are of utmost importance. There is very little information on how to deal with limited data availability and reliability when applying the method of material flow analysis. Hedbrant and Sörme (2001) suggest a method based on uncertainty intervals to cope with uncertain quantitative data. In modelling approach, the mathematical description of MFA systems allows to simulate the impact of changes in the system and can therefore be used as a tool to evaluate potential waste management systems.

1.5 Carbon and Nitrogen Mass Balance in Landfill.

The C and N mass balance is one good indicator to assess and evaluate the residual polluting potential during and aftercare period of a particular landfill (Cossu *et. al,* 2005). In this study, reference parameter for carbon is Total Organic Carbon (TOC) while nitrogen balance is Total Kjeldhal Nitrogen (TKN). The stoichiometric complete conversion of biodegradable solids to CH_4, CO_2, NH_3, H_2S was calculated based on the formula proposed by Buswell and Mueller (1952) and the composition of the initial waste. The oxygen content was derived from the average content found in the literature (Barlaz *et al*, 1989; Tchobanoglous and Kreith, 2002) (Eq.1):

$$C_{1.995}H_{3.58}O_{1.256}N_{0.115}S_{0.047} + 0.581H_2O \Rightarrow 1.08CH_4 + 0.92CO_2 + 0.115NH_3 + 0.047H_2S \quad \text{(Eq. 1)}$$

In theory, fraction of C and N are very important in carbon and nitrogen balance in a landfill. The degree of waste stabilisation is closely related to C and N dynamics in a landfill system.

1.6 Problem Statement and Objectives

Problems of data quality and availability cause difficulties for planners and decision makers in comprehending waste production information in order to formulate appropriate management strategies. MFA is a framework or tool to quantify material flow at substance level with limited data (Brunner & Rechberger, 2004). This study will eventually determine the potential and limitations of applying MFA for municipal waste management. Carbon is the main source of emission from landfill gas, however available data from Jeram Sanitary Landfill (JSL) are limited. Furthermore, MSW behaviour in a sanitary landfill conditions require a deeper understanding since landfilling is one of waste management options, and the influence of specific parameters such as precipitation, temperature, MSW generation patterns and loading, waste recycling practices and landfill gas generation will be covered in MFA framework. The performance of C and N during landfilling phase and post closure (aftercare) phase should be an important aspect since carbon and nitrogen are chemically-reactive compounds as compared to inorganics. The quantification of these emission in a flow analysis will determine the best option for MSW management. There are minimal waste diversion apart from direct landfilling in JSL (for example recycling or landfill gas collection) and therefore the carbon emission is released as outflow in a landfill system.

The objectives of research are:

1. To collate background information on JSL and determine the potential and limitation of applying MFA for municipal waste management.
2. To quantify C and N flows in sanitary landfill system by means of waste-input output analysis, mass balancing of C and N flow, C and N element flow.
3. To establish total Substance Flow Analysis (SFA) of C and N from a sanitary landfill in Selangor via detailed Life-cycle Inventories (LCIs) in a sanitary landfill system.