LITERATURE REVIEW

2.0 Municipal Solid Waste Generations Trends

2.0.1 Global Trends

What A Waste Report (2012) by The World Bank provides consolidated data on MSW generation, collection, composition, and disposal by country and by region. Despite its importance, reliable MSW information at global level is not typically available. As suggested in the report there is enough MSW information to estimate global amounts and trends. Waste generation rate in developed countries were reported to be much higher than the developing, transitory and under-developed countries (Fauziah & Agamuthu, 2012). The generation of MSW in the developing nations ranging from 0.25 to 1.97 kg per capita per day (Agamuthu, 2001). While in more developed nations, the per capita generation of MSW ranged from 1.1 kg to 5.07 kg (Hoorwerg & Thomas, 1999). At present it was estimated that almost 1.3 billion tonnes of MSW are generated globally every year, or 1.2 kg/capita/day. Current global MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years (World Bank, 2012). However, global averages are broad estimates only as rates vary considerably by region, country, city and even within cities. Waste generation rates have been positively correlated to per capita energy consumption and GDP (Bogner *et al.*, 2008). Europe and the United States are the main producers of MSW globally (Lacoste & Chalmin, 2006).

Municipal Solid Waste (MSW) is generated in proportion with the economic productivity and the consumption rate of the population of the countries resources. Countries with higher incomes produce more waste per capita and their waste generally contains more packaging material and recyclable items. In low-income countries, commercial and industrial activity is limited therefore recycling activities are limited. Table 2.1 reflects the generation rates as compared to the economic level and the management cost in different countries. MSW generation has more relevant and visible impact to the environment. In most low income countries, land is available that is comparatively easier to operate open dumps as compared to developed countries where land cost is too high due to economic and residential demands. More advanced facilities are needed such as incineration, refuse-derived fuel, composting, material recovery facilities.

Table 2.1 : Global Perspective of Municipal Solid Waste Generation Rates and The Respective Management Costs (Cointreau, 2006).

	Units	Low Income	Middle Income	High Income
Mixed Urban Waste – Large City	kg/cap/day	0.50 to 0.75	0.55 to 1.10	0.75 to 2.20
Mixed Urban Waste – Medium City	kg/cap/day	0.35 to 0.65	0.45 to 0.75	0.65 to 1.50
Residential Waste Only	kg/cap/day	0.25 to 0.45	0.35 to 0.65	0.55 to 1.00
Average Income from GNP	USD/cap/yr	370	2,400	22,000
Collection Cost	USD/ton	10 to 30	30 to 70	70 to 120
Transfer Cost	USD/ton	3 to 8	5 to 15	15 to 20
Open Dumping Cost	USD/ton	0.5 to 2	1 to 3	5 to 10
Sanitary Landfill Cost	USD/ton	3 to 10	8 to 15	20 to 50
Tidal Land Reclamation Cost	USD/ton	3 to 15	10 to 40	30 to 100
Composting Cost	USD/ton	5 to 20	10 to 40	20 to 60
Incineration Cost	USD/ton	40 to 60	30 to 80	70 to 100
Total cost without Transfer	USD/ton	13 to 40	38 to 85	90 to 170
Total cost with Transfer	USD/ton	17 to 48	43 to 100	105 to 190
Cost as % of Income	%	0.7 to 2.6	0.5 to 1.3	0.2 to 0.5

* Income based on 1992 Gross National product data form the World Development Report (1994).

Table 2.2 reflects some of the generation rates, the country income and the composition of the MSW generated. In the lower income countries, generation rates are lower. Prosperity of urban residents is important in projecting MSW rates. For example, India and China have high urban waste generation rates per capita to economic status. The waste generation rates are disporpotional to economic status since poor rural populations in China and India are large (World Bank, 2012). This show that the socio economic status of a country has adverse effect on the generation rates and also the recycling rates. The total amount of waste generated per year in this region is 160 million tonnes, with per capita values ranging from 0.1 to 14 kg/capita/day, and an average of 1.1 kg/capita/day. World Bank (2012) reported that apart from the high per capita waste generation rates on islands in Africa, the largest per capita solid waste generation rates are also found in the islands of the Caribbean. In Middle East and North Africa, solid waste generation is 63 million tonnes per year (World Bank, 2012). Per capita waste generation is 0.16 to 5.7 kg per person per day with an average of 1.1 kg/capita/day (World Bank, 2012 & World Bank, 1999). The per capita values range from 1.1 to 3.7 kg per person per day with an average of 2.2 kg/capita/day (World Bank, 2012 & World Bank,1999). The higher the income level and rate of urbanization, the greater the amount of solid waste produced. The OECD countries generate 572 million tonnes of solid waste per year (OECD, 2008a). Apart from that, landfill CH_4 has been the largest source of global GHG emissions from the waste sector. The recovery and utilization of landfill CH_4 as a source of renewable energy was first commercialized in 1975 and is now being implemented at over 1150 plants worldwide with emission reductions of more than 105 $MtCO_2$-eq/yr (Willumsen, 2003; Bogner & Matthews, 2003).

Table 2.2 : Waste Generation Projections for 2025 Region by Income from reliable sources (World Development Indicators 2005;IEA Annual Energy Outlook, 2005;United Nations World Urbanization Prospects, 2007).

Region	**Current Available Data**			**Projections for 2025**			
	Total Urban Population (millions)	**Urban Waste Generation**		**Projected Population**		**Projected Urban Waste**	
		Per capita (kg/capita/day)	**Total (tons/day)**	**Total Population (millions)**	**Urban Population (millions)**	**Per capita (kg/capita/day)**	**Total (tons/day)**
Lower Income	**343**	**0.6**	**204,802**	**1,637**	**676**	**0.86**	**584,272**
Lower Middle Income	**1,293**	**0.78**	**1,012,321**	**4,010**	**2,080**	**1.3**	**2,618,804**
Upper Middle Income	**572**	**1.16**	**665,586**	**888**	**619**	**1.6**	**987,039**
High Income	**774**	**2.13**	**1,649,547**	**1,112**	**912**	**2.1**	**1,879,590**
Total	**2,982**	**1.19**	**3,532,256**	**7,647**	**4,287**	**1.4**	**6,069,705**

Further detail on how MSW disposal varies according to country income level is shown in Table 2.3. Developing countries are far more likely to have open and managed dumps and some may have a mix of all three types, with sanitary landfills in large cities, managed dumps in larger townships, and open dumps in rural and some urban sites (EPA, 2006a).

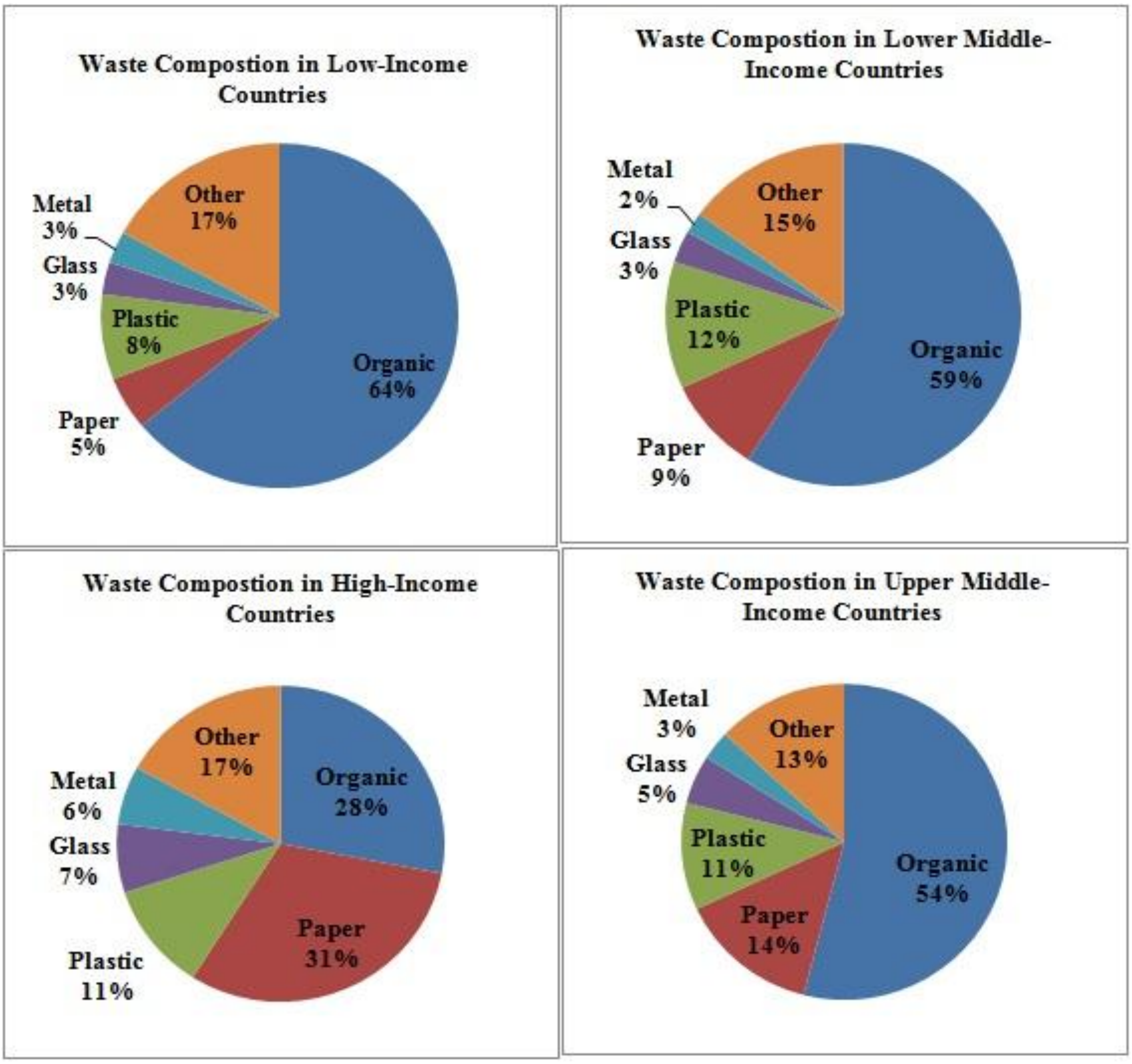
Table 2.3: MSW Disposal by Income (million tonnes) in low-income and upper middle-income countries (World Bank, 2012).

High Income		Upper Middle Income	
Dumps	0.05	Dumps	44
Landfills	250	Landfills	80
Compost	66	Compost	1.3
Recycled	129	Recycled	1.9
Incineration	122	Incineration	0.18
Other	21	Other	8.4
Low Income		Lower Middle Income	
Dumps	0.47	Dumps	27*
Landfills	2.2	Landfills	6.1
Compost	0.05	Compost	1.2
Recycled	0.02	Recycled	2.9
Incineration	0.05	Incineration	0.12
Other	0.97	Other	18

* The value is relatively high due to inclusion of China

2.0.2 Regional Trends.

World Bank (1999) predicted that by 2025 the daily MSW generation rate in Asia would be 1.8 million tonnes per day. These estimates are still accurate. At present, the daily generation rate in South Asia and East Asia and the Pacific combined is approximately 1 million tonnes per day (World Bank, 2012). Asia continent, like the rest of the world, continues to have a majority of organics and paper in its waste stream. Growth in waste quantities is the fastest in Asia (World Bank, 2012). The annual waste generation in East Asia and the Pacific Region is approximately 270 million tonnes per year (World Bank, 2012). This quantity is mainly influenced by waste generation in China, which makes up 70% of the regional total (World Bank, 2012). Per capita waste generation ranges from 0.44 to 4.3 kg per person per day for the region, with an average of 0.95 kg/capita/day (Hoornweg *et.al,* 2005). In South Asia, approximately 70 million tonnes of waste is generated per year, with per capita values ranging from 0.12 to 5.1 kg per person per day and an average of 0.45 kg/capita/day (World Bank, 2012). MSW composition by region is shown in Figure 2.1. The East Asia and the Pacific Region has the highest fraction of organic waste (62%) compared to OECD countries, which have the least (27%) (OECD, 2008a). As mentioned earlier, high income level and rate of urbanization significantly affect the amount of solid waste produced. Costs of landfilling have risen as disposal sites are exhausted and stricter environmental regulations are imposed. Countries like Japan and Australia classify their landfills according to the presence of hazardous waste, and implement leachate and gas control measures (International Energy Agency, 2009). In the long term, however, the costs related to impact of an unmanaged waste site on the health of the public and the environment may be much greater than the cost of closure. The goal should be to make waste disposal as controlled and as sanitary as possible (International Energy Agency, 2009) .



Figures 2.1 : MSW composition by economic level classification (World Bank, 2012).

Therefore, it is true that improper waste management had been identified as one of the three main sources of environmental degradation in Asian countries (World Bank, 2010). This include most municipalities in Malaysia where landfilling proceeses being practiced are not sustainable. The issue addressed are regarding landfill gas which contains greenhouse gases (GHG) in Malaysia that are passively released into the atmosphere and contribute significantly to global warming potential. The landfilling process include aspect of management and economic, especially its contribution to the climate change. Regional trends show CH_4 and N_2O can be produced and emitted during municipal and industrial wastewater collection and treatment, depending on transport, treatment and operating conditions (World Bank, 2010). The sludges can also microbially generate CH_4 and N_2O, which may be emitted without gas capture. It was reported that more than 7.6 million Gg CO_2 eq was generated in the Asian region in 1994 and within 10 years GHG emission has increased by 80% (Agamuthu &Fauziah, 2010). Approximately 18% of global anthropogenic CH_4 is sourced from landfill and wastewater, contributing 90% of the total emissions from waste segment (USEPA, 2006).

2.0.3 National Trends

Malaysia generates more than 30,000 tonnes of municipal solid waste (MSW) everyday disposing approximately 95% of the waste volume into 260 active landfill which only five of it has LFG facilities. 90% are non-sanitary landfills lacking landfill liner and gas pipes (National Solid Waste Management Department Malaysia, 2009). Landfill posed risks of environmental impacts due to the generation of leachate and gases which is not desirable. Solid waste management policies and regulations in Malaysia have evolved from informal policies and gradually developed through supplementary provision in legislation such as the Streets, Drainage and Building Act, 1974, the Local Government Act, 1976 and the Environmental Quality Act, 1974 into a National Strategic Plan for Solid Waste Management (NSP) in 2005, the Master Plan on National Waste Minimization (MWM) in 2006 and finally to a Solid Waste and Public Cleansing Management Act (SWMA) in 2007 (Fauziah & Agamuthu, 2012). The NSP includes a target of 17% waste reduction and recovery by 2020, which equates to around 2 million tonnes of solid waste each year (Fauziah & Agamuthu, 2012). It also aims to close all existing dumps by 2020, which is expected to have a positive effect by controlling leachate discharge and methane emissions (ISWA White Paper, 2009). Solid waste recycling rates are estimated to be about 3-5%; less than half the targeted recycling rate of 10% in 2009 (ISWA White Paper, 2009). This suggests that policies and regulations require time and specific targets to achieve results. Among the solid waste management policies and regulation, only the NSP has specified milestone targets for its solid waste management and performance as shown in Table 2.4. The NSP, MWM and SWMB have all provided the legal framework and strategic direction necessary to achieve sustainable waste management through reducing waste generation at source, minimising the amount of waste disposed of at landfills and maximising the efficiency of resource utilisation.

Table 2.4 shows specified milestone targets for its solid waste management and performance in Malaysia (ISWA White Paper, 2009).

Level of service	2002	2003-2009	2010-2014	2015-2020
Extended Collection System	75 %	80 %	85 %	90 %
Reduction and Recovery	3-4 %	10 %	15 %	17 %
Closure of dumpsites	112 dumpsites	50 %	70 %	100 %
Source Seperation (Urban Areas)	None	20 %	80 %	100 %

The closure of the first sanitary landfill in Selangor ; Air Hitam Sanitary Landfill, Puchong Selangor was on 31st December 2006. The landfill was filled to the brim just after 15 years.

Jeram sanitary landfill is expected to close in 2018, although it was planned to operate until 2023. Census from Ministry of Housing and Local Government through its action body, National Solid Waste Management Department Malaysia in 2012 has reported that there were 136 operating non- sanitary landfill sites, 30 unregistered dump site, another 114 end-of-life sites and only 8 sanitary landfills in the country. In 2012 (as shown in Table 2.5), there were a total of 165 operating MSW disposal sites in Malaysia with only 11 classified as Sanitary landfill (Fauziah & Agamuthu, 2012).

National Solid Waste Management Department Malaysia reported that there are 176 operating landfill sites, another 114 end-of-life sites and only 8 sanitary landfills in the country as shown in Table 2.5.

Table 2.5 : Total Number of operating landfill/dump sites, end-of-life sites and sanitary landfills according to Malaysian states as at 31st December 2012 (National Solid Waste Management Department Malaysia, 2012)

States	Operating landfill /dumpsites	End-of-life landfill	Sanitary landfill
Perlis	1	1	0
Kedah	8	7	0
Penang	2	1	0
Perak	17	12	0
Pahang	16	16	1
Selangor	8	14	3
Putrajaya	0	0	0
Kuala Lumpur	0	7	1
Negeri Sembilan	7	11	0
Malacca	2	5	0
Johor	14	23	1
Kelantan	13	6	0
Terengganu	8	12	0
Labuan	1	0	0
Sabah	19	2	0
Sarawak	49	14	3
Total	**165**	**131**	**9**

According to various studies, a total of 40-60 M tones of CH_4 is emitted from landfills and old waste deposits worldwide, accounting approximately 11-12% of the global anthropogenic CH_4 emissions (IPCC, 2007). Methane from landfills represents 12% of total global methane emissions (USEPA 2006b). Landfills are responsible for almost half of the methane emissions attributed to the municipal waste sector in 2010 (IPCC 2007). On the other hand, WWF Climate Solutions Model (2008) explore whether it is possible to meet the projected 2050 demand for global energy services while achieving significant reductions in global greenhouse gas emissions through carbon capture and storage technology. In 1994, Malaysia's emission of greenhouse gases (GHG) are 144 x 10^6 tonnes of CO_2 , the net emission was equivalent to 3.7 tonnes on per capita basis (Second National Communication to the UNFCCC, 2011). In 2005, without land use change, per capita emissions of each Malaysian was reported to be 5.7 tonnes of $C0_2$ -eq in the 11-year period (Second National Communication to the UNFCCC, 2011). This has put Malaysia as the 67th largest nation per capita generator of GHG emissions in the world (Agamuthu & Fauziah, 2012). The importance of proper solid waste management is crucial in better understanding the current solid waste practices at regional level (UNEP, 2005).

2.1 Historical background and development of Material Flow Analysis.

It has been claimed that Material Flow Analysis (MFA) principles identified way back by Greek philosophers as early as 2000 years ago (Brunner & Rechberger, 2004). The classic example of MFA application is in human metabolism by Santorio Santorio (1561-1636) by measuring human input and output (Leontief, 1936). He discovered that human output are very much less than input. Hypothesis made that external factor such as perspiration are not quantified and therefore affect the human metabolism study. In other research field, the applied MFA conceptual theory and knowledge are linked to the physical and monetary input- output analysis developed by Wassily Leontief in the late 1930`s (Bailey *et al.,* 2006). Leontief (1936) pioneered the application of this principle in the field of economics. He used input–output analysis (IOA) to elucidate economic problems at a national scale. The input–output tables on which the IOA are based were later connected with coefficients of environmental pollution to determine the environmental impact of changes in the economic system (Duchin & Steenge, 1999). However, the physical MFA methods in modern day today was first applied by Wolman in the late 1960`s (Wolman, 1965) as a result of the introduction of metabolism studies for cities. This studies has later been conducted in megacities such as Brussels and Hong Kong (Binder, 2007) and more recently, applied in the optimizing of the material flows in eco-industrial parks in Kalundborg, Denmark (Heeres *et al.,* 2004).

As a beginning, modern theory on Material Flow Analysis (MFA) or Substance Flow Analysis (SFA) was originally developed by Baccini & Brunner (1991). Bergback *et. al* (2001) studied material flow of several metals such as Cadmium and Chromium in Stockholm, Sweden. The flow of Cuprum in Europe was investigated by several studies through a lifecycle from extracting raw metal, through processing and manufacturing, to solid waste management or recycling (Graedal *et.al*.,2002; Spatari *et.al.,*2002; Bertram *et.al.,* 2002). Substance flow analysis focuses on individual substances. They are related to a specific pollutant that leads to resource scarcity. Heavy metals and nutrients (organics or inorganics) are among the most prime substances in research that correlate to resource scarcity. SFA has been applied to trace pollutants through watersheds and urban regions (Stigliani *et al.,* 1993; Lohm *et al.*,1994) and to describe the metabolism of specific chemicals at the national and international level (Kleijn *et al.,* 1997; Van der Voet *et al.,* 2000; Spatari *et al.,* 2002). These studies were accounting efforts that rely on static models, based on matrix equations similar to the IOA basics. Simulating or modelling the dynamic behavior of material or substance flows in human environment systems allows forecasting and therefore most useful in a context of explorations of the future or of scenario analysis (Baccini & Bader 1996).

A sensible waste planning and rational evaluations of future environmental problems is the availability of reasonable projections of material usage and waste generation (Andersen *et al.*,2006). Brunner & Rechberger (2004) used MFA to study the flow of resources used and being transformed as they flow through a region. MFA is proved to be a suitable instrument for early detection of environmental problems and development of appropriate measures in industrialized countries (Baccini & Bader, 1996). Early examples of application have been demonstrated resource management planning at city and regional level, waste management planning and the development of environmental management systems in enterprises (Baccini & Brunner,1991). MFA has already been integrated in urban areas of developing countries in the field of environmental sanitation (Binder, 1996; Belevi, 2002; Montangero *et al*., 2004; Huang *et al*., 2006).

Ayres (1978) emphasised that material and energy balance is the fundamental basis for MFA study. Material balances have been used to study the metabolism of cities, specifically the way cities mobilize, “use” and discard materials in 1960s (Wolman, 1965). Since then, MFA has been used to understand systems, such as densely populated regions (Brunner & Baccini, 1992) and industries (Ayres & Ayres, 1978) in many developed countries. In the 1990s, MFA theory expanded into two main activities. First is material flow cost accounting (MFCA), also known as economy-wide MFA, which focuses to picture a society’s overall material metabolism based on statistical data. Secondly is material or substance flow analysis (M/SFA), focusing on flows of individual materials or chemicals throughout all kinds of systems (Bringezu *et. al.*, 1997). Material flow accounting has become an established activity for many countries worldwide. European Union's Statistical Agency or Eurostat (2011) have published a methodological guide linking the MFA accounts with official statistics. The idea behind material flow accounting is to represent the economic system in physical rather than monetary terms. Physical in this sense refer to global trade flows, showing a difference in the material basis of consuming and producing countries (producer and consumer countries). The first material flow accounts on the national level have been presented at the beginning of the 1990s for Austria (Steurer, 1992) and Japan (Environment Agency Japan, 1992). Since then, MFA has been a rapidly growing field of scientific interest and major efforts have been undertaken to harmonise the diverse methodological approaches developed by numerous research teams. The Concerted Action shortly known as ConAccount is funded by the European Commission were involved to harmonise MFA methodologies at international level (Bringezu *et. al.,* 1997; Kleijn *et al.*, 1999). Another organisation, the World Resources Institute (WRI) has published assessment of material inputs of four industries and guidelines to define resource input indicators (Adriaanse *et. al.,* 1997), material outflows and also introduced emission indicators study (Matthews *et. al.*, 2000). In term of publications, EUROSTAT, an European Commission body issued a methodological guide on economy-wide material flow accounts (EW-MFA) and derived economic indicators (EUROSTAT 2001). They introduced a system of national material flow accounts and balances. It also provides a detailed classification of the different mineral, biomass and import materials as well as types of emissions to water and dissipative material flows.

MFA assess flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways and the intermediate, and final sinks of a material. Because of the law of the conservation matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks and outputs and processes. This distinct characteristic of MFA makes the method suitable as a decision-support tool in resource management, waste management and environmental management (Brunner & Rechberger, 2004). MFA emphasised two distinct aspects namely goods and substances in order to achieve sustainable development goal. Goods is an economic unit to determine quantities while substances determine ecological and resource qualities (Brunner & Rechberger, 2004). MFA can provide holistic picture of resource use and loss in a geographic region in a specific year. All material/substance inflows, outflows and stocks are to be examined in their system pathways starting from waste generation, waste treatment until ultimate waste disposal or landfilling. It has become a useful tool for industrial ecology (IE) to analyze the metabolism of social systems, such as countries and regions. Fehringer *et.al* (2004) clearly defined and applied Substance Flow Analysis (SFA) to provide mass balance for the goods and substance flows and the processes of a system. MFA can be defined in time (temporal) and space (spatial/geographical) and taking into account the law of mass conservation and the changes of stocks. The system in question can be a single process or a link of several processes (Brunner & Rechberger, 2004). In environmental protection and resource management field, MFA studies the flow of resources used and transformed as they flow through a region, through a single process or via a combination of various processes (Brunner & Rechberger, 2004). It analyzes the flow of different materials through a defined space and within a certain time. In industrialized countries, MFA proved to be a suitable instrument for early recognition of environmental problems and development of solutions to these problems. For examples, flows and stocks of particular nutrients and metals at regional and global level (Brunner & Baccini,1992; Belevi, 2002). An economy-wide MFA approach shows the interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment dependent on a constant flow of materials and energy (Eurostat, 2013; Liu, *et. al*., 2009a; Weisz *et. al*.,2005). Raw materials, water and air are extracted from the natural system as inputs, transformed into products and finally transferred back into the natural system as outputs (e.g waste and emissions). To highlight the similarity to natural metabolic processes, the terms "industrial" (Ayres, 1989) or "societal" (Fischer-Kowalski, 1998a) metabolism have been introduced. Numerous studies in different research field has applied MFA theory. The method of material flow analysis was for the first time applied to study the metabolism or physiology of cities (Wolman, 1965). This study was followed by other studies in Brussels (Duvigneaud *et. al.*, 1975) (Figure 2.2) and Hong-Kong (Newcombe, 1978). Since then, MFA has been applied to understand systems such as densely populated regions in developed countries (Ayres, 1978; Brunner & Baccini 1992; Daxbeck *et. al*., 1997 & Henseler, 1995). MFA has also been applied to trace pollutants through watersheds or urban regions (Ayres & Simonis ,1992; Bergback *et. al*., 1994; Van der Voet *et. al*., 1994; Kleijn *et. al*., 1994 & Frosch *et. al.,* 1997) and in developing countries (Binder, 1996, Binder *et. al*., 1997, Erkman & Ramaswamy, 2003). National and international flows of copper and zinc were established (Van der Voet, 1994; Spatari *et. al*., 2003; Gordon *et. al*., 2003 & Graedel *et. al*., 2002).

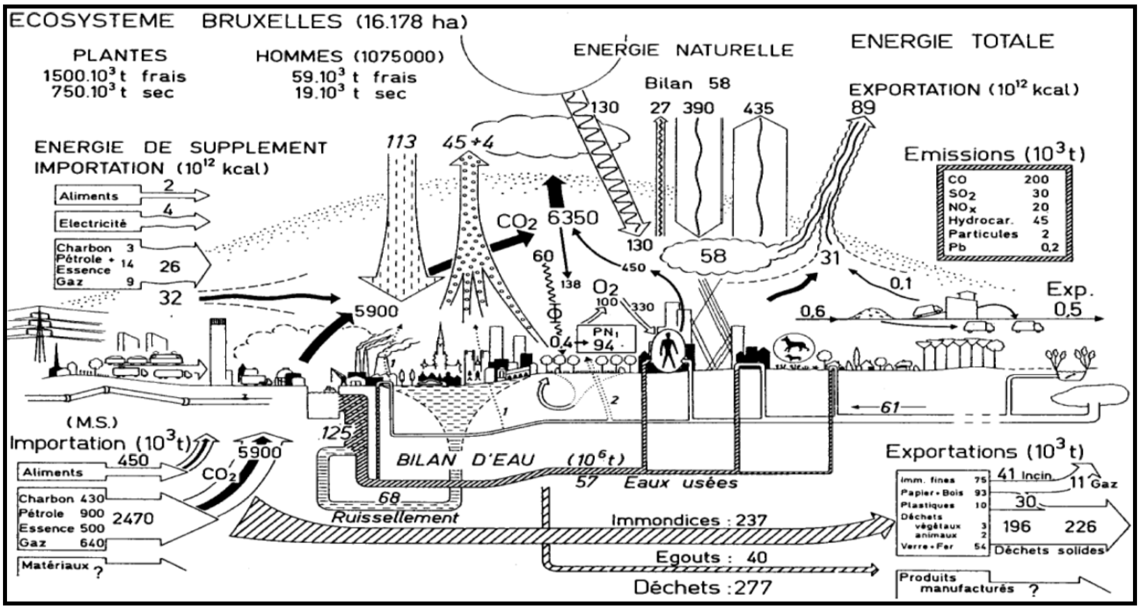


Figure 2.2 : Urban metabolism in Brussels, Belgium in the early 1970s. (Duvigneaud & Denaeyer-De S,1977).

Figure 2.3 combines many sorts of representation into an early example of a urban metabolism analysis. They are one of the earliest and most comprehensive studies by the ecologists Duvigneaud and Denaeyer-De Smet (1977). It includes quantification of urban biomass and even organic discharges from cats and dogs. It does incorporate Sankey-style flows and does consider flows and stocks in the system.

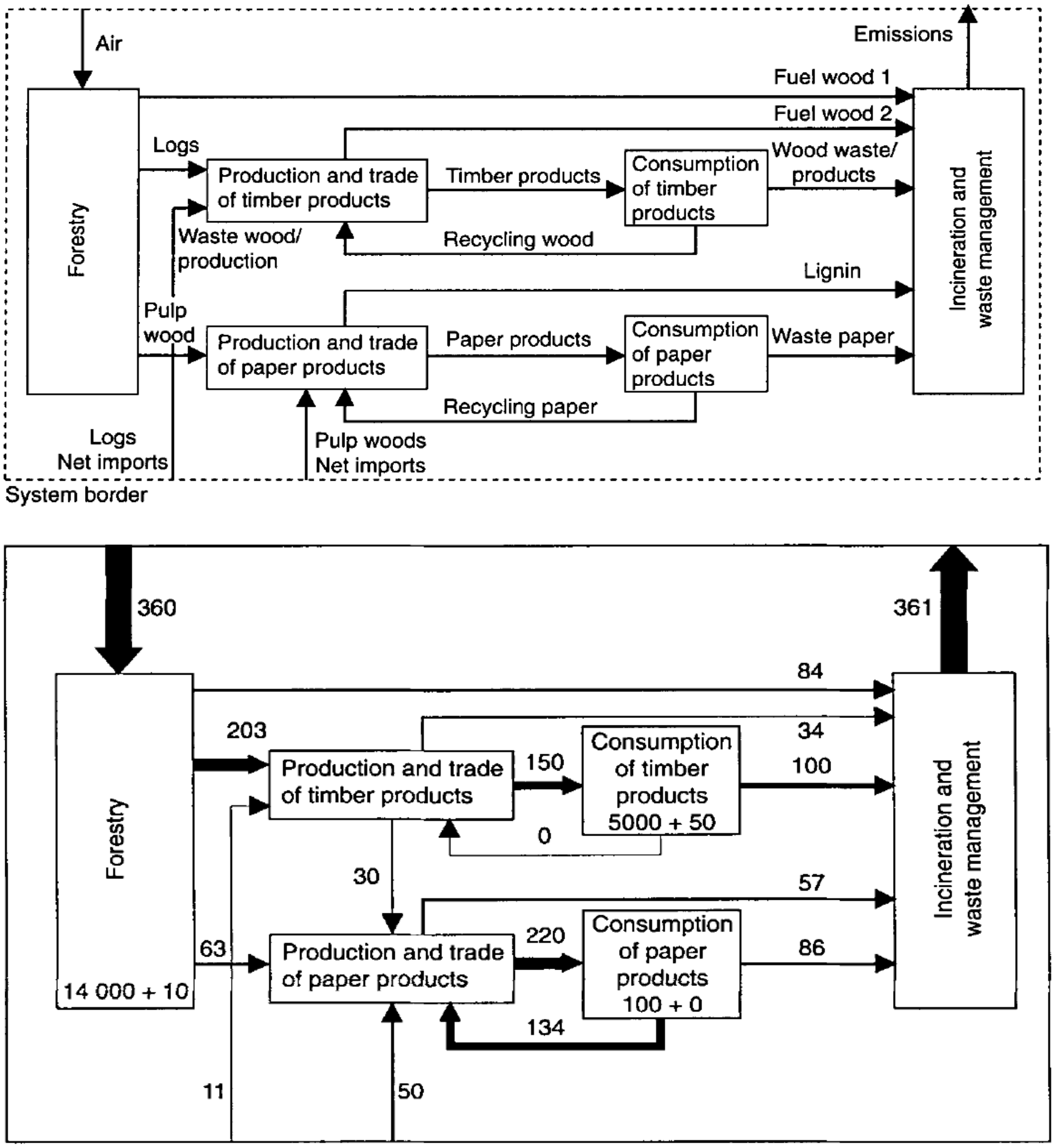


Figure 2.3: Example of an urban metabolism analysis in forest management (Duvigneaud & Denaeyer-De Smet,1977).

There have also been established national and international flows of non-ferrous metals for example copper and zinc (Spatari *et. al.,* 2003 & Graedel *et. al.,* 2002). These studies are based on dynamic modeling which is required for forecasting future flows and stocks. MFA objectives are first and foremost related to the early recognition of potentially harmful or beneficial accumulations and depletions in stocks, as well as prediction of future environmental loadings (SOCOPSE, 2009). Minimization of pollutant substance increase or accumulation can be achieved by setting priorities regarding systems design that promote environmental protection, resource conservation, or waste management options (Brunner & Rechberger, 2004). In the SOCOPSE (Source Control of Priority Substances in Europe) project, MFA are used to describe European sources, inflow and outflow in the environment for selected priority substances including mercury (Hg), cadmium (Cd), benzene and Polycyclic Aromatic Hydrocarbons (PAHs) (SOCOPSE, 2009). MFA system has been adapted in various industries for example in alumnium industry (Bertram *et. al.,* 2009), phosphorus flow in Japan with regard to iron and steel industry (Matsubae *et. al.,* 2009), flow of nitrogen and phosphorus in municipal waste in Finland (Laura *et. al*., 2004). The method was also applied to river water quality management in Europe, in a Swiss river catchment (Brunner *et. al.,* 1990); and on transnational scale for the Danube Basin (Somlyódy *et. al.,* 1997). They proved to be a valuable tool for the early recognition of environmental problems, and evaluation of solutions to these problems. Schaffner *et. al.,* (2006) also conducted a MFA study to assess river water quality problems and mitigation measures in the Tha Chin River Basin, Thailand. Belevi (2002), Huang *et. al.,* (2005) and Montangero *et. al.,* (2006) applied MFA to address urban environmental problems in developing countries in the context of urban waste and sanitation management in Ghana, Kunming and Vietnam respectively. Similar study was conducted by Huang *et. al.,* (2007) on the urban water system in Kunming City, China to evaluate the current efficiency of wastewater treatment. MFA is used to assess nutrient flow in septic tanks to improve public sanitation system in Hanoi Vietnam (Montangero *et. al.*, 2006 & Montangero & Belevi, 2008). It allows to simulate new environmental sanitation concepts, which can be evaluated by their nutrient load to the environment, nutrient saving or recovery for example through urban waste reuse in agriculture (Montangero & Belevi, 2007; Montangero *et. al.,* 2006). MFA is therefore a reliable method that could contribute to the development of new environmental sanitation concepts in developing countries (Binder, 1996; Belevi, 2002). This application had results in setting up monitoring concepts to early recognize of resource demand and environmental impacts and evaluate the effect of technical measures in mitigating these impacts (Binder *et. al*., 1997). Binder & Patzel (2001) applied MFA to describe carbon fluxes in organic wastes between the rural and the urban areas of the municipality of Tunja, Colombia and estimated the effect of waste reuse on soil organic matter. MFA was also applied in the city (urban and sub-urban area) of Kumasi, Ghana in order to estimate the volume of the nitrogen and phosphorous demand in agricultural sector (Belevi, 2002). Nutrient management starts by assesssing the nutrients' origin, followed by the existing mass flow pathways and exploration of alternatives to direct the nutrient streams in order to facilitate the use of nutrients in agriculture (Larsen & Boller, 2001). Brunner (2009) regarded MFA as strategic resource management for nutrients phosphorus, nitrogen and ferum. Evidently, MFA has been proven useful and suitable tool for river water quality management. Based on estimations, the approach provides an overview of pollution problems and their respective solutions in a river system, allowing to identify key sources and pathways of pollution, and to determine cost-effective mitigation priorities (Montangero *et. al.,* 2006). On smaller scale, the flows of materials and substance were studied in a windrow composting plant treating garden waste in Aarhus (Denmark) (Andersen *et. al.*, 2010). Graedel (2004) studies the metal flow and stock (chromium and copper) at regional level in USA, Japan and South Africa. Binder (2005) studied the element flows of urban and rural area in Switzerland. The MFA method were used to determine potentials and challenges for sustainable land management. Hiroshi (2008) develop a dynamic substance flow model of zinc in Japan based on past consumption and lifetime distribution that justify resource depletion in zinc stocks at national level. In Poland and Austria, plastic flow study has been conducted way back in 1997 (Bogucka & Brunner, 2007, Bogucka *et. al.*, 2008, Fehringer & Brunner, 1997, Rechberger, 2008). Analysis of waste electrical and elctronic equipment (WEEE) also been studied using both MFA and LCA in Switzerland (Morf 2008; Morf & Tremp 2005; Morf 2006). The MFA results were then accessible in database for concentration levels and uncertainty in WEEE for 2003 (Morf & Tremp, 2005). The outcome was a reliable data set that are constructed for regional level for Switzerland and other European countries. Danius (2002) identified data uncertainty in MFA as one barrier to a broader use of the method, particularly as a tool for policy decision. This issue is even more important in the context of developing countries where data availability and reliability is low, and resources for data collection are limited (availability of laboratory equipment, trained laboratory staff, financial and human resources). Montangero & Belevi (2006a) describes simple methods that can be used in the event of limited data to assess nutrient flows in common sanitation options in developing countries: septic tanks, pit latrines and urine diversion latrines. These methods will be used to develop and calibrate a broader model to assess water and nutrient flows within the environmental sanitation system of Hanoi, Vietnam. Seelsaen *et. al.*, (2007) did SFA on copper in stormwater runoff in Sydney Australia. Similar MFA study has also been conducted at regional level on agricultural phosphorus flow and its environmental impacts in China (Chen *et. al.*, 2008). Daniels (2002) used MFA approach as critical tools in the design and implementation of industrial ecology strategies for greater ecoefficiency.Another advantages is that MFA can be demonstrated to cover broad areas of economic activity and minimize environmental impacts of human activity. Wittmer (2005) attempt to model the water and material flows of nitrogen (N) and phosporus (P) of fresh aquaculture in Thailand using MFA. Rotter *et. al.,* (2004) used MFA to evaluate the possibilities of modifying the chemical characteristics of refuse-derived fuels (RDF) that are processed from residual household waste. Elfin (2006) integrate LCA and MFA approach to evaluate resource consumption and environmental impacts estimation in universities in the USA. The results enable campus decision makers to conceptualize the ecological footprint of the campus (Elfin, 2006). Kay (2002) conducted MFA on public logistics network to improve many features associated with public warehouses to the entire supply chain in the southeastern USA. In 2008, OECD (Organisation for Economic Co-operation and Development) published a series of 4 documents on Measuring Material Flows and Resource Productivity in which had been prepared based on extensive consultation process among the experts of the OECD member states and international consultants (OECD, 2008a; OECD, 2008b; OECD, 2008c; OECD, 2008d).

2.2 Progress in the study of Material Flow Analysis

A comprehensive definition of MFA provided by Organisation for Economic Cooperation and Development (OECD) are as follow:

"The study of physical flows of natural resources and materials into through and out of a given system (usually the economy). It is based on organised accounts method in physical units, and uses the principle of mass balance to analyse the relationships between material flows (including energy), human activities (including economic and trade developments) and environmental changes".

The mass of input to a process, industry or region balances the mass of outputs as products emissions and wastes plus any change in stock. When applied in a systematic manner this simple and straightforward concept of balancing resource use with outputs can provide a comprehensive methodology for analysing resource flow (Figure 2.4).

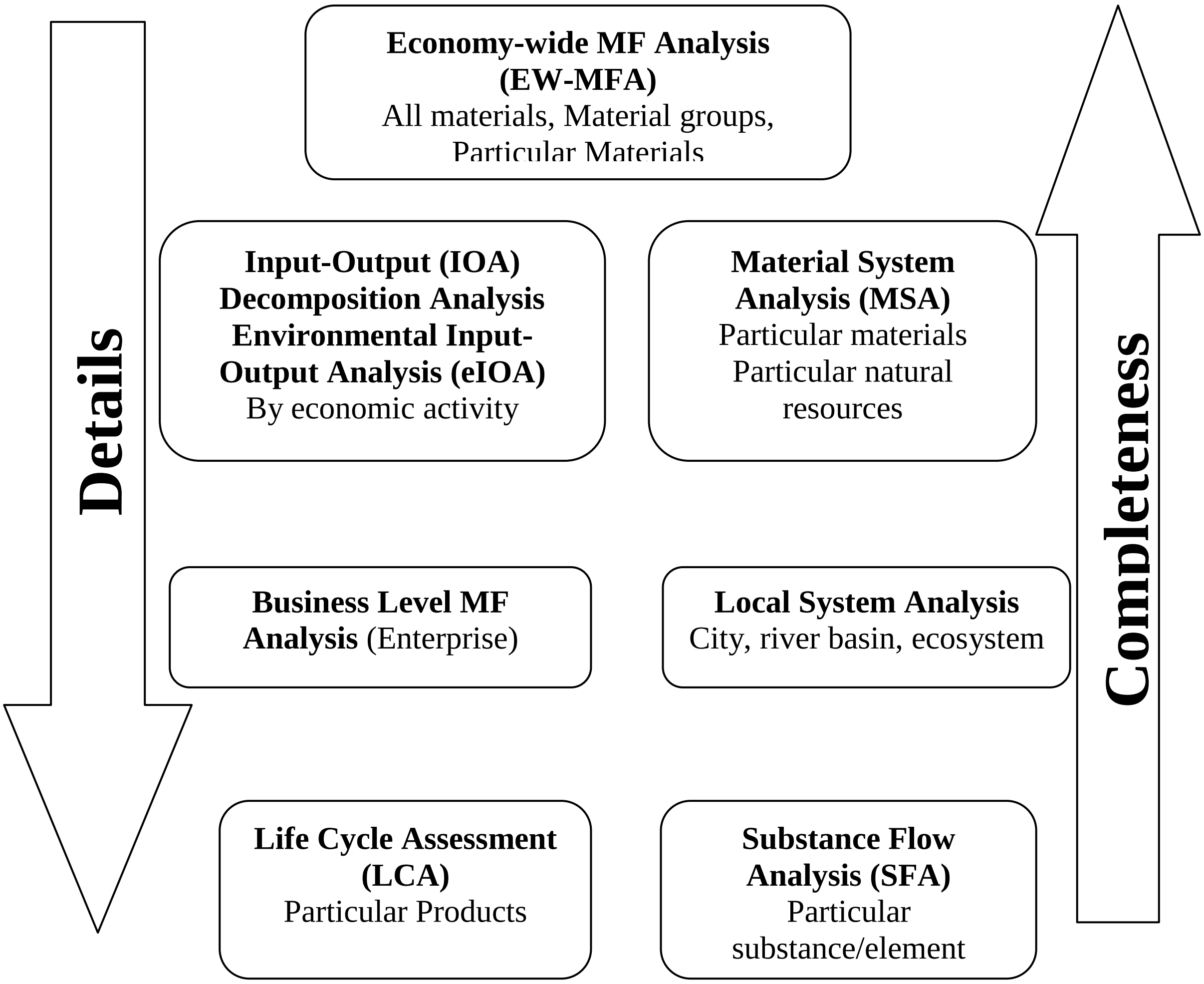


Figure 2.4 : A multi-purpose family of tools and overall architecture of MFA and related tools (OECD, 2008a).

MFA can be used to study the laws of material metabolism through the analysis of the relationship among material flows, resource consumption and socio-economic development (OECD, 2008b). The progress in MFA give are described at three levels as following：

1) National level (Table 2.6)
2) Regional level (Table 2.7)
3) Industrial level (Table 2.8)

The term MFA therefore designates a family of tools including a variety analytical approaches and measurement tools. These tools range in scope from economy-wide to substance or product-specific analysis and input-output analysis (OECD, 2008b; OECD, 2008c). Each type of analysis is associated with MFA accounts or other measurement tools, and can be used to derive various types of indicators. (OECD, 2008b). A material flow study can cover any set of materials at various scales and levels of detail and completeness. (OECD (2008b) emphasized on 3 key categories as follow :

1) All materials entering and leaving the national economy
2) The industry level, enterprise level and product level from product groups down to specific products
3) Certain materials and substances, from national down to the local level.

Recent MFA/SFA theoretical studies have provided a concept definition (Bringezu, 2003; Brunner and Ma, 2008), research framework, formulation of procedure and indicators (Lassen & Hansen, 2000; Udo de Haes *et. al.,* 1997), classification methods (Kleijn & Van Der Voet, 2001), model design (Bouman *et. al.,* 2000), and MFA software development (Cencic, 2006; Liu *et al.*, 2009).

Table 2.6 : Summary of MFA study at the national level.

Year	The Area of Study	Reference
1992-1993	Main material flow of Austria, Japan and Germany	Steurer, 1992; EAJ, 1992; Schutz & Bringezu, 1993
1997 - 2000	The respective material input and output of the United States of America (USA), Japan, Austria, Germany and The Netherlands	Adriaanse *et. al.* 1997; Mathews *et. al.* 2000
2000	Denmark	Gravgaard, 2000
2000	Finland, Sweden	Muukkonen, 2000; Isacsson & Jonsson 2000
2000	United Kingdom (UK)	Schandl & Schulz, 2000
2000	Poland	Schqtz & Welfens, 2000
2000-2001	China	Chen & Qiao, 2000; Chen & Qiao, 2001; Chen *et.al*, 2003 ; Liu *et.al.*, 2005; Wang *et. al.*, 2005; Li, 2004 Li, 2005; Xu & Zhang, 2005; Liu *et.al.*, 2009; Duan, 2009
2001	Italy	Marco *et. al* 2001
2003	Republic of Czech	Milan *et. al* 2003
2004	The overall comparative study of Direct Material input and material needs of 11 countries and regions including Finland, Germany, Italy, Netherlands, UK, Poland, EU-15, USA, Japan and China.	Bringezu *et. al*. 2004
2006	Portugal	Niza & Ferr˜ao, 2005
2006	Cross-country comparison and determinants of material consumption in the 15 European Union members, including Austria, Belgium, Luxembourg, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom	Weisz *et. al.*,2005
2007	Singapore	Schulz, 2007
2008	Comparison of the resource flows of Chile, Ecuador, Mexico & Peru	Russi *et. al.* 2008

Table 2.7 : Summary of MFA study at the regional level.

Nation	Year	Study Area	Method	Reference
Switzerland	1991	The city of St. Gallen	Classification and statistics of material consumption data	Tao, 2003
Spain	2002	The total material needs of the Basque region	A model based on EU Guideline	IHOBE, 2002
	2007	An industrial area in Catalonia	A framework based on EU Guidelines with some complementation	Sendra, 2007
Germany	2003	The environmental-economic system of Hamburg	EU Guidelines	Hammer *et. al.*, 2003
Canada	2003	The Greater Toronto Area in Canada	A framework based on urban metabolism	Sahely *et. al.*, 2003
Japan	2008	Aichi Prefecture	Input-output table	Tachibana *et.al.*, 2008
China	1986 1988	The city of Tangshan, The city of Dali	Classification and statistics of Materials	Cui *et. al.*, 1986; Du, 1988
	2001	Hong Kong	A framework based on urban metabolism	Warren-Rhodes, 2001
	2004-2009	The cities of Guiyang, Tianjin, Shanghai, Qingdao, Xiamen, Handan, The Provinces of Shanxi, Guangdong, Liaoning, and Jiangsu. The comparison of 19 main cities	Models built according to EU Guidelines with some necessary adjustments according to the actual situations	Xu *et. al.*, 2004;Liu *et. al.*, 2006; Huang & Zhu, 2007; Qian *et. al.*, 2009; Wei & Zhu, 2009; Lou, 2007; Zhang & Lei, 2006; Zhang *et. al.*, 2007; Xu *et. al.*, 2008; Zhang *et. al.*, 2009; Li *et. al.*, 2007
	2006	The city of Yima	A three-dimensional physical input-output table	Xu & Zhang, 2006
	2009	The city of Beijing	A physical input-output table	Zhang *et. al.*, 2009b

Table 2.8 : Summary of MFA study at the industrial level.

Nation	Year	Study Area	Method	Reference
United States of America (USA)	2003-2007	Stocks and flows of copper, zinc, iron and steel, nickel, silver and other metals in different levels, Material flows of two Antarctica workstations.	Stocks and flows model (STAF) with consideration of the life cycles of each metal.	Graedel *et. al.*, 2004 ; Graedel *et.al*, 2005 ; Gordon, 2006; Müller, 2006; Drakonakis, 2007; Rostkowski *et. al.*, 2007; Van Beers & Graedel, 2003; Klee, 2005
	2007	Mercury in products in the USA	Substance Flow Analysis (SFA) model based on the life cycle.	Cain *et. al.*, 2007
	2007	Material flows of lead and cadmium	Physical input-output matrix.	Hawkins *et. al.*, 2007
	2008	The stocks and flows of cement in the USA	A dynamic substance flow model	Kapur, 2008
Japan	2002-2006	The appliance waste	The waste input-output model , Life-cycle cost analysis	Nakamura & Kondo, 2002; Kondo & Nakamura, 2004; Nakamura & Kondo, 2006
	2004	The wood resource	Several indicators of MFA	Hashimoto *et. al*, 2004
	2005,2009	Stainless steel	Dynamic material flow analysis	Igarashi *et. al*, 2005; Daigo *et. al.*, 2009
	2007	Base metals	Physical input-output tables	Nakamura *et. al.*, 2007
	2009	Copper and copper-based alloys	Dynamic material stocks and flows analysis	Daigo *et. al.*, 2009
The Netherlands	2000	Metal policies in the Netherlands	Combination of an applied general equilibrium model and a material flow model	Dellink & Kandelaars, 2000
	2000	The paper and wood flow in the Netherlands, The plastic flows in the Netherlands	The Statistical Research for Analyzing Material Streams (STREAMS)	Hekkert *et. al.*, 2000; Joosten *et. al.*, 2000
	2005	Household metabolism in European countries and cities.	A family metabolic model	Moll *et. al.*, 2005

Table 2.8 : Summary of MFA study at the industrial level (Cont'd)

Nation	Year	Study Area	Method	Reference
Switzerland	2004	Regional wood management in Appenzell Ausserrhoden	The integration of material flux analysis and agent analysis	Binder *et. al.*, 2004
	2004	The food production chain	Economically extended MFA	Kytzia *et. al.*, 2004
	2007	Material Flow Management	Social sciences modelling approaches coupled to MFA	Binder, 2007a; Binder, 2007b
United Kingdom	2000	The UK steel sector	A historical materials and energy flow analysis and scenario analysis	Michaelis & Jackson, 2000a; Michaelis & Jackson, 2000b
	2007	The supply chain for iron and steel in the UK	A time-dependent material flow analysis model	Geyer *et.al.*, 2007
	2008	The local household consumption in the UK	Local Area Resource Analysis Model	Druckman *et.al.*, 2008
Sweden	1995	Annual material flows of freight transportation in Sweden	A flow model of transport	Hunhammar, 1995
	2006	Food consumption and nutrient flows in the city of Linkoping	Identification and statistics of flows within the systems and emissions	Neset *et. al.*, 2006
India	2001	MFA in the remote tropical island of Trinket	A framework based on socio-economic metabolism	Singh *et.al.*, 2001
	2005	The waste electrical and electronic equipment (WEEE) in the city of Delhi	A process-based MFA	Porte *et. al.*, 2005
	2006	The plastics material flows	A framework based on life cycle	Mutha *et. al.*, (2006)
Finland	2001	The Finnish forest industry system	Material and energy flow model	Korhonen, 2001
	2007	The Finnish food fux	An extended input-output model	Risku-Norjaa & Mäenpääb, 2007
Austria	2003	Austrian family	Physical input-output tables	Tao, 2003
Australia	2007	Cadmium in Australia	A Substance Flow Analysis	Kwonpongsagoon, 2007

Table 2.8 : Summary of MFA study at the industrial level (Cont'd)

Nation	Year	Study Area	Method	Reference
Norway	2009	Wastewater pipeline networks of Oslo	Combined MFA-LCA	Venkatesh, 2009
China	1983	Iron, titanium, vanadium flows in the city of Dukou	A model based on the life cycles of each model	Chen *et. al.*, 1983
	2000-2009	Iron and steel industry, Lead industry, copper recycling, Mineral, Cement industry in Beijing, Automotive Industry, Phosporus metabolism system, Construction industry, Road transportation	Frameworks based on the EU Guidelines wth accordance to the material life cycles	Lu, 2002; Mao et.al., 2007; Yue & Lu, 2006; Zhang, 2005; Du & Cai, 2006; Cai *et. al*, 2006; Cai *et.al.*, 2008; Chen *et. al.*, 2005; Shi, 2006; Liu & Chen, 2006; Chen & Zhang, 2005; Wen *et. al.*, 2009; Wang *et.al.*, 2009
	2003	Taipei's urban construction	Identification of relevant materials and a frameworks indicators	Huang & Xu, 2003
	2004	Fossil fuels	Statistics of material needs	Xu & Zhang, 2004
	2006	Public projects	Material flow tracking model	Shen *et. al.*, 2006

2.3 Application of Material Flow Analysis in Municipal Solid Waste Management (MSW).

MFA is a suitable tool to support decisions regarding waste management because waste amounts and waste compositions are often not available. MFA allows calculating the amount and composition of waste. This was done via mass balance the process of waste generation or the process of waste treatment. Generally, MFA is used in waste management by modelling elemental compositions of wastes and evaluating material management or performance in recycling or composting or wastewater treatment facilities. A distinct input by Brunner (2012) & Moriguchi (2003) was that the main goal of modern waste management in 21st century is to establish clean cycles where resources are conserved (materials, energy and land). Therefore, a concept known as "sound-material society" can come into existence. Secondly, landfilling may act as a method to achieve final sinks where no material export in the long-term and mass conservation will take place after sanitary landfill closure (Brunner, 2012).

Jung *et. al.,* (2006) carried out a comprehensive study to identify the metal flow in a municipal solid waste (MSW) management system. In Austria, the recent SFA on lead, mercury and copper for example compares the flows and stocks of these heavy metals within the Austrian economy (Spatari *et. al.,* 2003). A special emphasis was put to simulate the heavy metal flows within the waste sector and within the recycling material flows. For Austria, time series of MFA database for the period 1960 to 2005 was prepared by Statistik Austria and published for the following 6 material groups namely biomass and biomass products, metal and concentrates (processed metals), non metallic minerals (primary and processed), fossil energy carriers (primary and processed) and waste imported for final treatment and disposal (Petrovic, 2007). MFA-related work is carried out by local waste management agencies in Zurich, Geneva, St. Gallen and Thurgau and research institutes such as the Swiss Federal Institute of Technology in Zurich and Lausanne (Binder, 1996).

Nicolas & Agata (2012) attempt to map out the waste management at an urban city Addis Ababa, Ethiopia where the research are more qualitative rather than quantitative (Figure 2.5). However, it is important to highlight the gist of the study of some known and unknown (or suspected) flow of materials in the process of urbanized city.

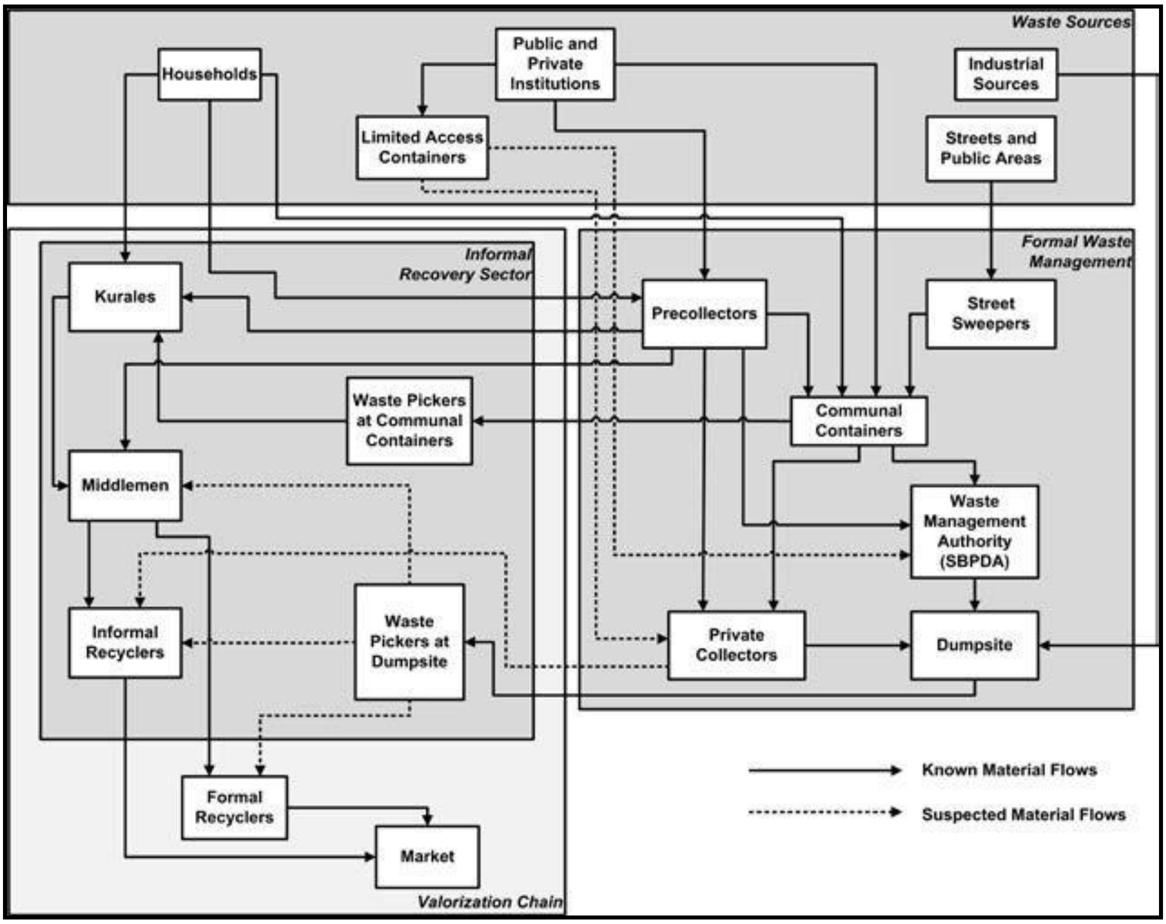


Figure 2.5: Waste management at an urban city Addis Ababa, Ethiopia. (Nicolas & Agata, 2012).

2.4 Landfill as a sink

During the course of history, many cities faced the problem of limiting sinks regarding their wastes (Brunner & Kral, 2010). A key person driving this metabolic view of cities was Abel Wolman who states in his famous publication in the "The Metabolism of Cities" :

“ … *the need for sinks, where materials can be disposed of in an appropriate way,i.e. without endangering the environment*” (Wolman, 1968)

During the 19th century, it became common knowledge that a healthy city needs a waste water collection and treatment system, and in the 20th century, such systems have been established in all cities of world rank. (Wolman, 1968) pointed out that, without having appropriate sinks, the environmental system could eventually become overloaded by the output of urban activities. Today, global human population has exceeded more than 10 million people, and a material turnover of more than 200 tonnes per capita and year, the question arises if such intense metabolic systems are limited by the availability of sinks in water, air, and soil (Brunner & Kral, 2010). The integral assessment of entire substance flows from a city over time from all emissions including from the use of materials, the accumulation and depletion of materials in water, air, and soil have to be taken into account.

Tarr (1996) has mentioned that the term “sink” is a vague concept despite some excellent literature on this issue even until today. Thus, definitions of the expressions “sink” and “final sink” must be improved in order to make it operational for environmental protection, for urban planning and for resource management. Man-made flows of several elements of the periodic table surpass geogenic flows (Klee and Graedel, 2004), indicating that anthropogenic activities interfere with natural processes on a large scale. It is necessary to investigate in as far as this interference leads to elevated concentrations in water air and soil. Brunner & Kral (2010) added an explanation that “sink” for a material flow from a city can be a conveyor belt such as water or air that transports materials out of the city boundaries. These material can undergo a transformation such as an incinerator that completely mineralizes organic substances, and it can also be a storage process such as a landfill where substances are disposed of. In contrast, Brunner & Kral (2010) made a hypothesis that a "final sink" denominates a place on the planet where a particular substance has a residence time of more than 10, 000 years. It may consist of an underground salt mine, an ocean sediment or a place on the globe where sedimentation processes prevail erosion processes. For organic substances, a "final sink" may also be a transformation or mineralization process.

Landfill is a dynamic system in which a different parameter influence the emissions from landfill body over time and during closure (Belevi & Baccini,1989; Heyer and Stegmann, 1997). Emissions will be getting lower at a constant rate since reactions in terms of physical and chemical processes still happened during after-care period (Laner, *et. al.*, 2010). Even during after-care period, there are no input into the landfill system. A landfill can be considered as Continuous Stirred Tank Reactor (CSTR) filled with waste (Cossu, 2004) (Figure 2.6).

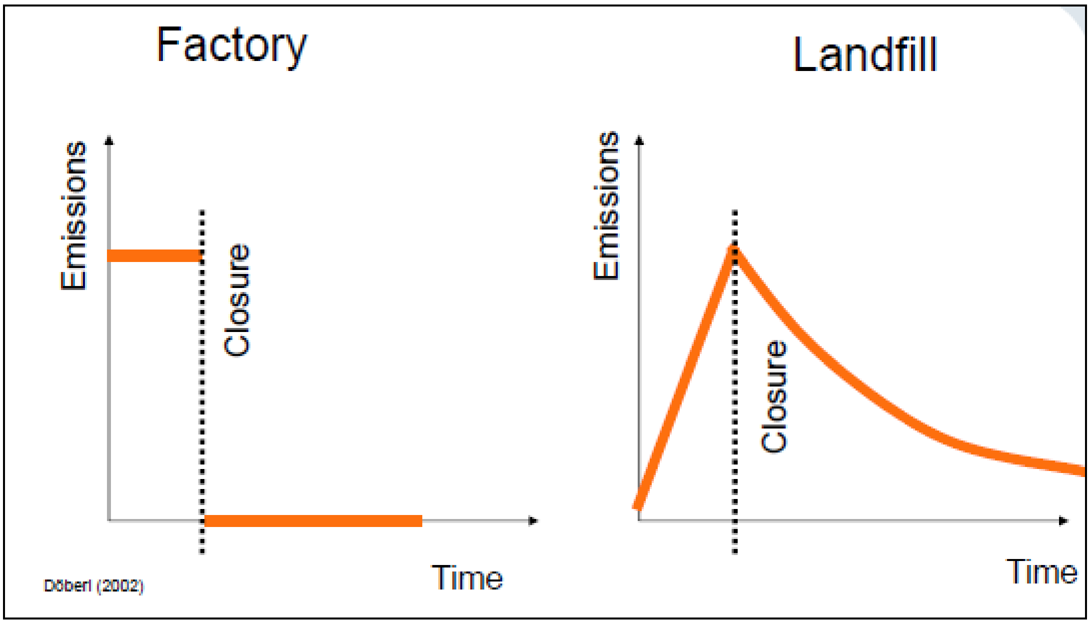


Figure 2.6 : Comparison of two systems (factory and landfill) versus time (Cossu, 2004).

Comparison between the sustainable landfill model (tolerable emission within 30 years) and a traditional landfill scenario in theory is shown in Figure 2.7. In this point of view, mass balance can be a suitable tool for studying long term emissions. It can be applied in small scale to different landfill models, then obtained results can be used in real-scale evaluations.

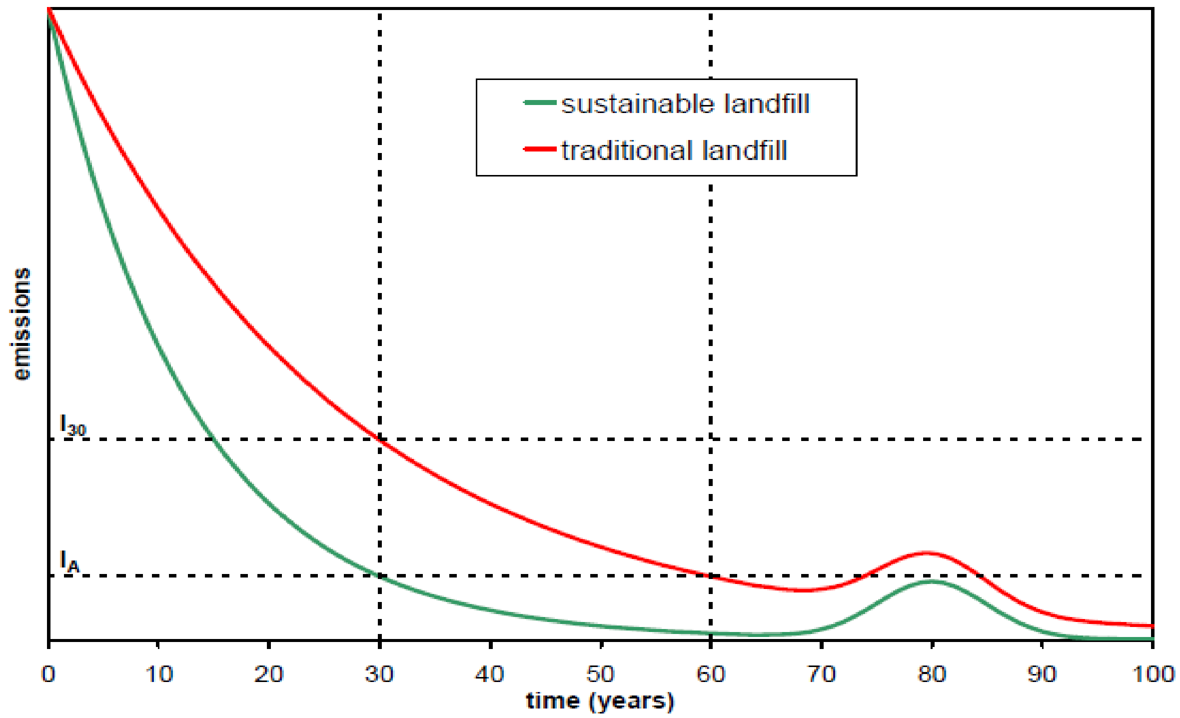


Figure 2.7 :Comparison between the sustainable landfill model (tolerable emission within 30 years) and a traditional landfill scenario (Cossu *et. al*, 2005).

Quantity and quality of emissions are determined by four main factors namely waste input (composition), amount of water infiltrated, physical-chemical conditions and water flow pattern (moisture distribution) (Cossu *et. al*, 2005; Cossu, 2004) .

Recycling is an appropriate strategy to minimize resource consumption and hence the need for sinks during resource extraction, production, consumption and waste disposal. However, a) the loss of substances during recycling cannot be completely prevented due to thermodynamic reasons, and b) most substances have to be disposed of in a final sink after the "last possible cycle". Hence, a modern society that is based on circular use of materials will need sinks.

2.5 Waste and Climate Change

Waste contains organic material, such as food, paper, wood, and garden trimmings. Once waste is deposited in a landfill, microbes begin to consume the carbon in organic material, which causes decomposition. Under the anaerobic conditions in landfills, the microbial communities contain methane-producing bacteria. As the microbes gradually decompose organic matter over time, methane (approximately 50%), carbon dioxide (approximately 50%), and other trace amounts of gaseous compounds (< 1%) are generated and form landfill gas (ISWA White Paper, 2009). In controlled sanitary landfills, the process of burying waste and regularly covering deposits with a low permeability material creates an internal environment that favours methane-producing bacteria. In any ecological system, optimum conditions of temperature, moisture, and nutrient source (i.e. organic waste) resulted in greater biochemical activity and also greater generation of landfill gas. GHG emissions from MSW have emerged as a major concern as post-consumer waste is estimated to account for almost 5% (1,460 Mt CO_2 eq) of total global greenhouse gas emissions (World Bank,2012). Methane from landfills represents 12% of total global methane emissions (EPA 2006b). Landfills are responsible for almost half of the methane emissions attributed to the municipal waste sector in 2010 (IPCC, 2007).

In terms of reporting landfill emissions, the Intergovernmental Panel on Climate Change (IPCC) has set an international convention to not report CO_2 released due to the landfill decomposition or incineration of biogenic sources of carbon (UNEP, 2010). For accounting methodologies, biogenic carbon is accounted for under the ‘land use / land use change and forestry’ (LULUCF) sector (IPCC, 2006). Therefore, where landfill is concerned, only methane emissions are reported, expressed as tonnes of CO_2 equivalent (1 tonne of methane is expressed as 25 tonnes of CO_2-eq). In practice, methane emissions from landfill are not accurately measured, but more of an estimation for reporting (IPCC, 2006) (Table 2.9)

Table 2.9: Global warming potential (GWP) for a given time horizon (Forster *et. al.*, 2007).

GHG	GWP 20 year (kg CO_2-e)	GWP (IPCC 2007) 100 year (kg CO_2-e)	GWP 500 year (kg CO_2-e)
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	72	25	7.6
Nitrous oxide N_2O	289	298	153

Numerous landfill studies has shown that gradual decay of the carbon stock in a landfill generates emissions even after landfill closure. This is because the chemical and biochemical reactions take time to progress and only a small amount of the carbon contained in waste is emitted in the year this waste is disposed (UNEP, 2010). None of the legislation implemented in Malaysia specifies a direct requirement for GHG emission reduction. The main goal of the waste management sector in Malaysia is to establish the basic aspects of solid waste management as opposed to tackling climate change (ISWA White Paper, 2009).

Malaysia's solid waste management policy and regulation are valuable instruments that can be considered relatively comprehensive and contain many elements found in other countries policy and regulations (ISWA White Paper, 2009). Waste policy is expected to have a positive impact on solid waste management and indirectly on climate change by providing the legal framework, strategic direction and implementation mechanism for sustainable waste management systems (UNEP, 2010). In a nutshell, GHG mitigation and climate change is so far not targeted directly in Malaysian waste management policy and regulation (ISWA White Paper,2009). Under Ministry of Natural Resources and Environment (NRE) Malaysia, "National Policy on Climate Change" served as a blueprint for future direction in handling climate change scenarios in Malaysia. The mitigation and adaptation plan to combat climate change encompass many prominent sectors apart from waste management sector (National Policy on Climate Change Malaysia, 2010). Policy Study on Climate Change funded under the 9th Malaysia Plan jointly implemented by the Conservation and Environmental Management Division (CEMD), NRE, Institute for Environment and Development (LESTARI) and National University Malaysia (UKM).

The waste industry occupies a unique position as a potential reducer of greenhouse gas (GHG) emissions. As industries and countries worldwide struggle to address their carbon footprint, waste sector activities represent an opportunity for carbon reduction which has yet to be fully exploited (ISWA, 2009). Between 1990 and 2003, total global GHG emissions from the waste sector declined 14–19% for the 36 industrialised countries and Economies in Transition (EIT) under the United Nations Framework Convention on Climate Change (UNFCCC) list (ISWA White Paper, 2009). This reduction was mainly due to increased landfill methane recovery. An overview of carbon flows through waste management systems addresses the issue of carbon storage versus carbon turnover for major waste management strategies including landfilling, incineration and composting (Figure 2.8). Landfills function as a relatively inefficient anaerobic digesters or reactors. Significant long-term carbon storage occurs in landfills, which is addressed in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

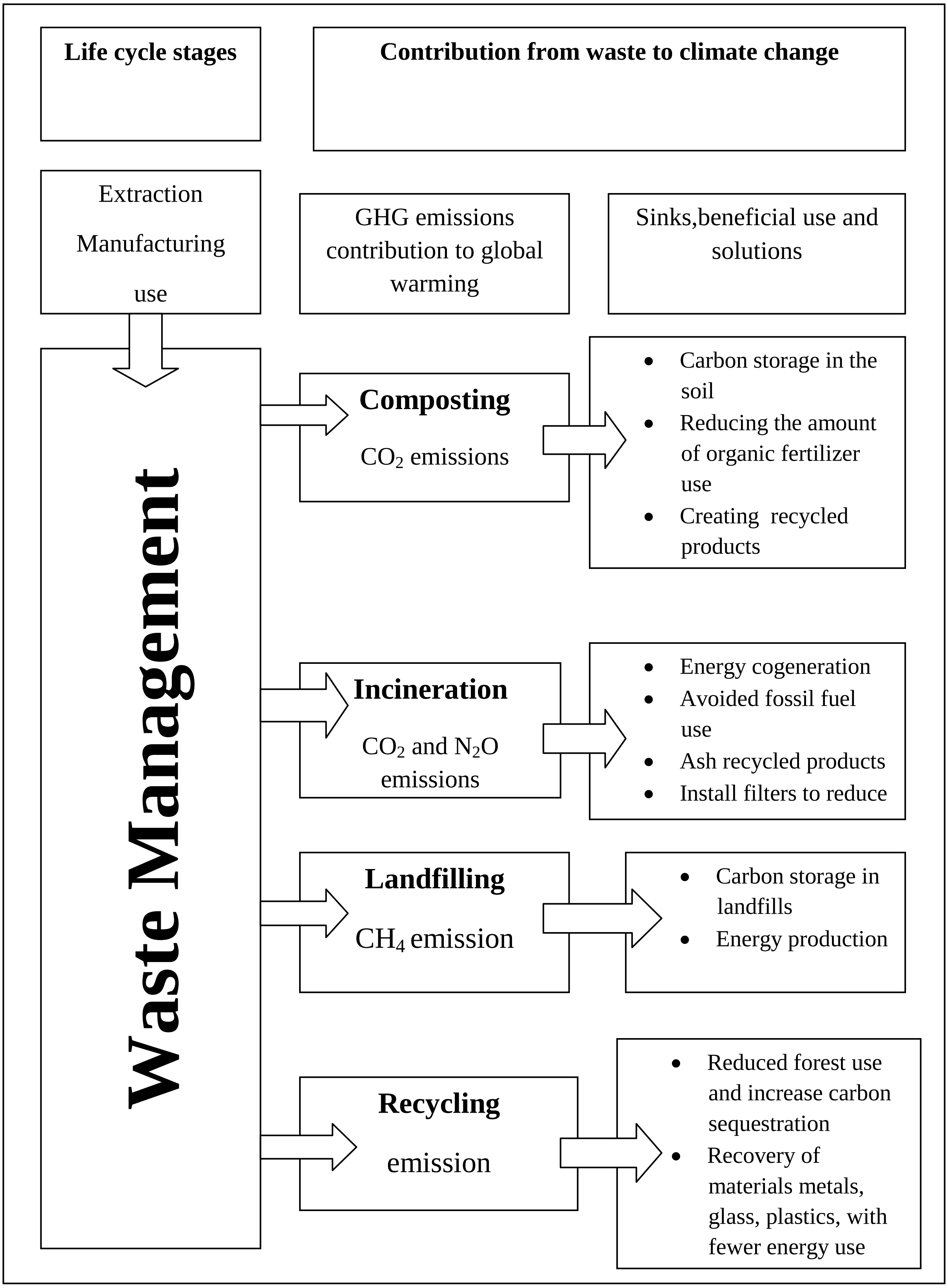


Figure 2.8 : Contribution from waste to climate change in a waste management field (Reproduced from UNEP, 2004).

2.6 Carbon Flows Through Waste Management System

2.6.1 Carbon Cycle Process in Sanitary Landfill

The CO_2 from biomass is not included in GHG inventories for waste (Huber-Humer, 2004; Zinati *et. al.*, 2001; Barlaz, 1998; Bramryd, 1997; Bogner, 1992). A process-oriented perspective on the major GHG emissions from the waste sector is provided in Figure 2.9. Landfill CH_4 is the major gaseous C emission from waste; there are also minor emissions of CO_2 from incinerated fossil carbon (plastics). The CO_2 emissions from biomass sources including the CO_2 in landfill gas, the CO_2 from composting and CO_2 from incineration of waste biomass are not taken into account in GHG inventories as these are covered by changes in biomass stocks in the land-use, land-use change and forestry sectors (IPCC, 2007) .

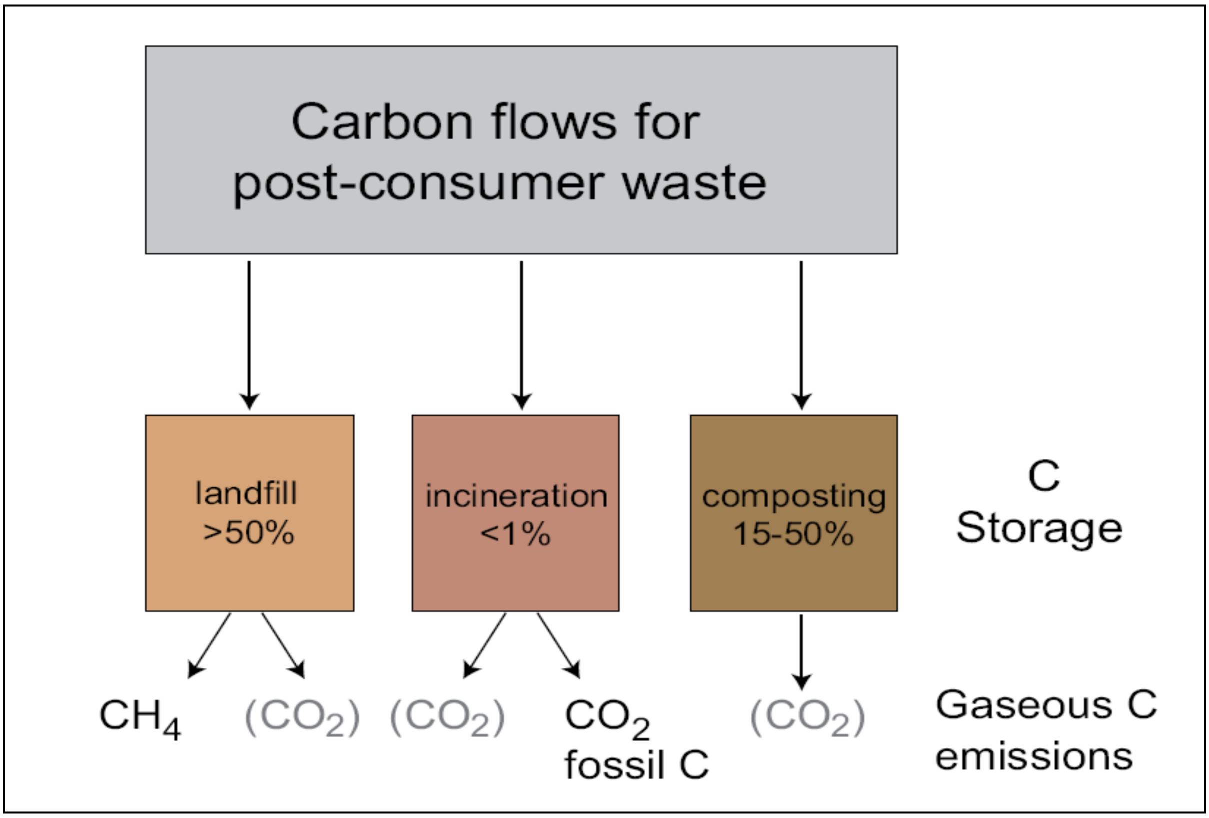


Figure 2.9 : Carbon flows through major waste management systems including C storage and gaseous C emissions (UNEP, 2010).

Simplified landfill CH_4 mass balance are based on the total CH_4 generated in landfilled waste including CH_4 emitted, recovered and oxidized (Figure 2.10). There are two longer-term CH_4 pathways namely lateral CH_4 mitigation and internal changes in CH_4 storage (Bogner & Spokas, 1993; Spokas *et. al.,* 2006). Methane can be stored in shallow sediments for several thousand years (Coleman, 1979) (Figure 2.10).

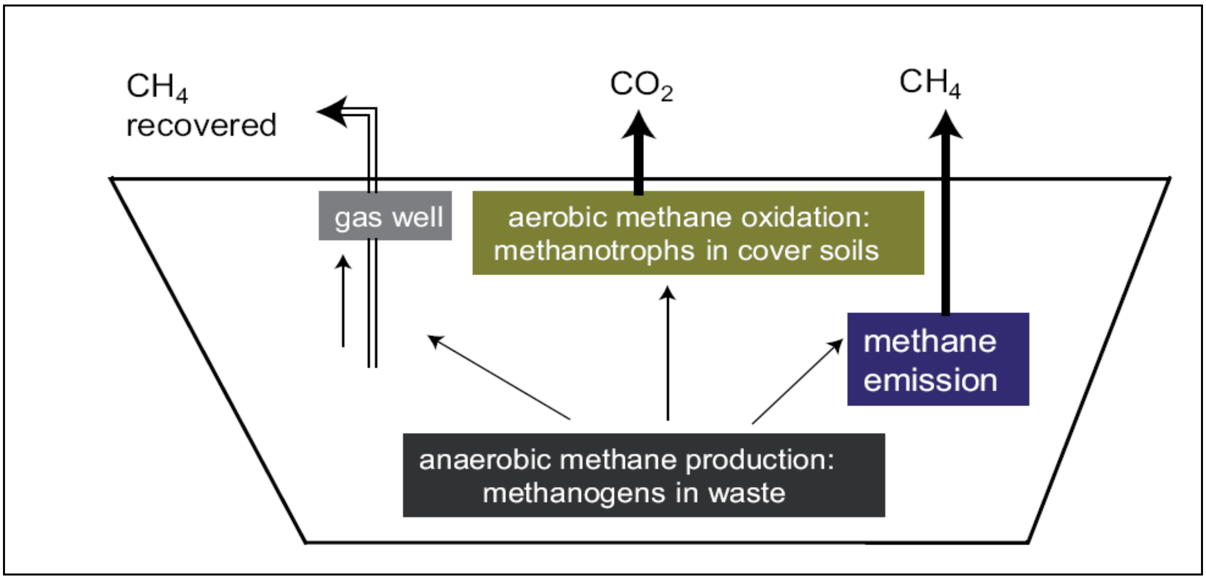


Figure 2.10 : Simplified landfill Methane mass balance showing pathways for GHG emissions from landfills and leachate systems (UNEP, 2010).

In the context of a landfill, CH_4 mass balance emissions are one of several possible pathways for the CH_4 production by anaerobic methanogenic microorganisms in landfills. Other pathways include recovery, oxidation by aerobic methanotrophic microorganisms in cover soils, and two longer-term pathways namely lateral migration and internal storage (Bogner and Spokas, 1993; Spokas *et al.*, 2006). With regard to emissions from wastewater transport and treatment, the CH_4 is microbially produced under strict anaerobic conditions as in landfills, while the N_2O is an intermediate product of microbial nitrogen cycling promoted by conditions of reduced aeration, high moisture and abundant nitrogen (Bogner *et al.*, 2007).

2.6.2 Global Grennhouse Gas Emission Trends

Table 2.10 compares estimated emissions and trends from two studies (USEPA, 2006 & Monni *et. al.*, 2006). The US EPA (2006) study collected data from national inventories and projections reported to the United Nations Framework Convention on Climate Change (UNFCCC) and supplemented data gaps with estimates and extrapolations based on IPCC default data and simple mass balance calculations using the 1996 IPCC Tier 1 methodology for landfill CH_4. Monni *et. al.* (2006) calculated a time series for landfill CH_4 using the first-order decay (FOD) methodology and default data in the 2006 IPCC Guidelines, taking into account the time lag in landfill emissions compared to year of disposal.

Table 2.10: Emissions estimates and projections on Global GHG emission trend.

Source	1990	1995	2000	2005	2010	2015	2020	2030	2050
Landfill CH_4[a]	760	770	730	750	760	790	820		
Landfill CH_4[b]	340	400	450	520	640	800	1000	1500	2900
Landfill CH_4 (average of a and b)	550	585	590	635	700	795	910		
Wastewater CH_4[a]	450	490	520	590	600	630	670		
Wastewater N_2O[a]	80	90	90	100	100	100	100		
Incineration CO_2[b]	40	40	50	50	60	60	60	70	80
Total GHG emissions	1120	1205	1250	1345	1460	1585	1740		

[a] Based on reported emissions from national inventories and national communications, and (for non-reporting countries) on 1996 inventory guidelines and extrapolations (USEPA, 2006).
[b] Based on 2006 inventory guidelines and BAU projection (Monni *et. al.*, 2006).Total includes landfill CH_4 (average), wastewater CH_4, wastewater N_2O and incineration CO_2.

Quantifying global trends requires annual national data on waste production and management practices. Estimates for many countries are uncertain because data are lacking, incosistent or incomplete. The IPCC Guidelines (2006) also provide methodologies for CO_2, CH_4 and N_2O emissions from open burning of waste and for CH_4 and N_2O emissions from composting and anearobic digestion of biowaste. Composting and other biological treatments emit very small quantities of GHGs but were also included (IPCC, 2006). Overall, the waste sector contributes less than 5% of global GHG emissions.

2.6.3 Methane as a Greenhouse Gas

Methane, the major component of natural gas, is also a potent greenhouse gas. It is 25 times more effective than CO2 at trapping heat on the atmosphere over a100-year time period (IPCC, 2007). Therefore, the global warming potential of methane in the IPCC's Fourth Assessment Report (2007) is 25 times over 100- years time period. Methane is a significant GHG after CO_2, accounting for 16% of global GHG emissions (Figure 2.11). The chemical lifetime of methane in the atmosphere is approximately 12 years (USEPA, 2006a). This relatively short atmospheric lifetime makes it an important gas for mitigating global warming in the near term. Several studies have assessed the importance of mitigating methane emissions early, due to the immediate climate impacts to the environment (Fisher, *et. al.*, 2007).

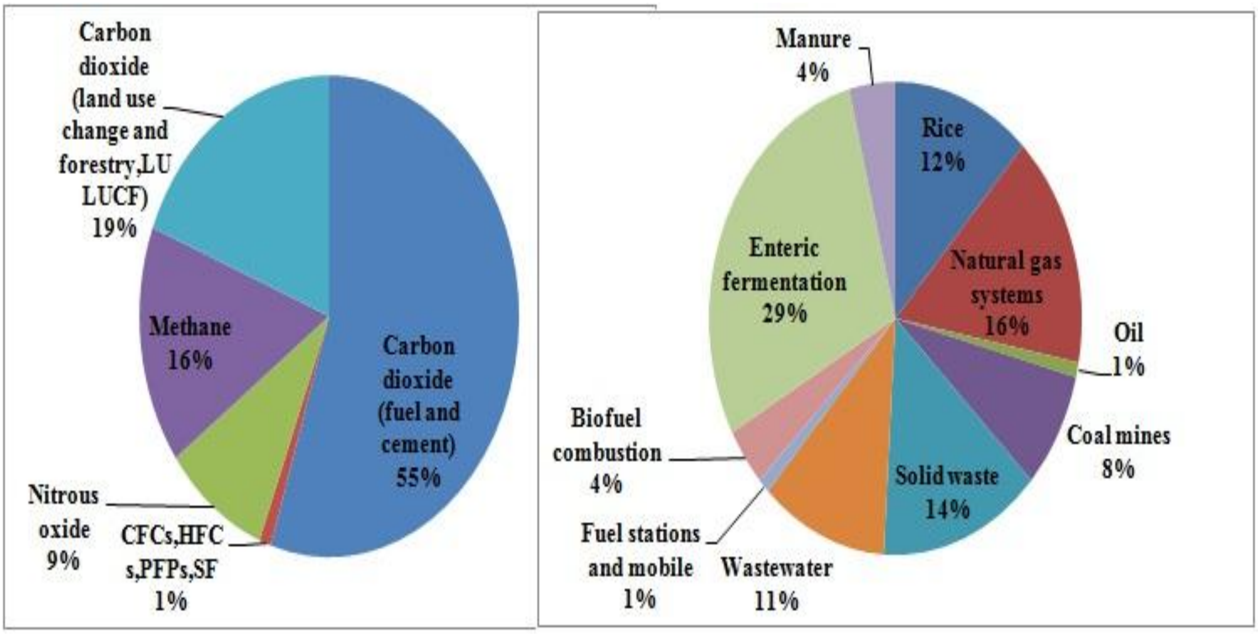


Figure 2.11**:** Global Greenhouse Gas Emissions In 2000 and Anthropogenic Methane Sources. (International Energy Agency/IEA, 2009) .

The United States, China, Russia, Mexico, Canada, and Southeast Asia are the main contributors of methane emissions from solid waste management (International Energy Agency/IEA, 2008). Methane emissions from landfills are expected to decrease in industrialised countries and increase in developing countries (International Energy Agency/IEA, 2008). Industrialised countries' emissions are expected to decline as the result of expanded recycling and composting programmes, increased regulatory requirements to capture and combust landfill gas (LFG), and improved LFG recovery technologies (International Energy Agency/IEA, 2008). Developing countries' LFG emissions are expected to increase due to expanding populations, combined with a trend away from open dumps to sanitary landfills with increased anaerobic conditions (International Energy Agency/IEA, 2008). Anthropogenic sources include fossil fuel production, agriculture (enteric fermentation in livestock, manure management, and rice cultivation), biomass burning, and waste management. Methane emissions from energyand waste activities comprised approximately 36% of the global anthropogenic methane emissions in 2000 (IPCC, 2001). Since the mid-1700s, global average atmospheric concentrations of methane have increased 150%, from approximately 700 to 1745 parts per billion by volume (ppbv) (IPCC, 2001). Although methane concentrations have continued to increase, the overall growth rate during the past decade has slowed, largely due to mitigation efforts in several nations, including the European Union, the United States, Canada, and Japan (USEPA, 2006). In the late 1970s, the growth rate was approximately 20 ppbv per year (IPCC, 2001). From 1990 to 1998, methane grew by up to 13 ppbv per year (IPCC, 2001). The rise from 2006 to 2007 is the highest annual increase observed since 1998, although it is unclear whether this represents the start of a new upward trend (World Meteorological Organisation/WMO, 2008). The cycling of methane, however, is complex and requires an understanding of its many sources and sinks. Malaysia is part of a large global community. It is important to note that Malaysia contributes only 0.7%

to global CO_2 emissions (UNDP Human Development Report, 2008). However, on an emissions intensity levels, calculated as a ratio of GHGs emissions to the country's GDP, Malaysia's emission intensity levels are above the global average in the energy sector as shown in Figure 2.12. Major efforts will be introduced to reduce emissions intensity, and as Malaysia moves towards a high income economy, emissions intensity is expected to decline. The Government has embarked on several programmes aimed at reducing emission of GHGs. During the 10th Malaysia Plan, the efforts will continue to focus on five areas (Second National Communication to the UNFCCC/NC2, 2011):

1. Creating stronger incentives for investments in renewable energy (RE);
2. Promoting energy efficiency to encourage productive use of energy;
3. Improving solid waste management;
4. Conserving forests; and
5. Reducing emissions to improve air quality.

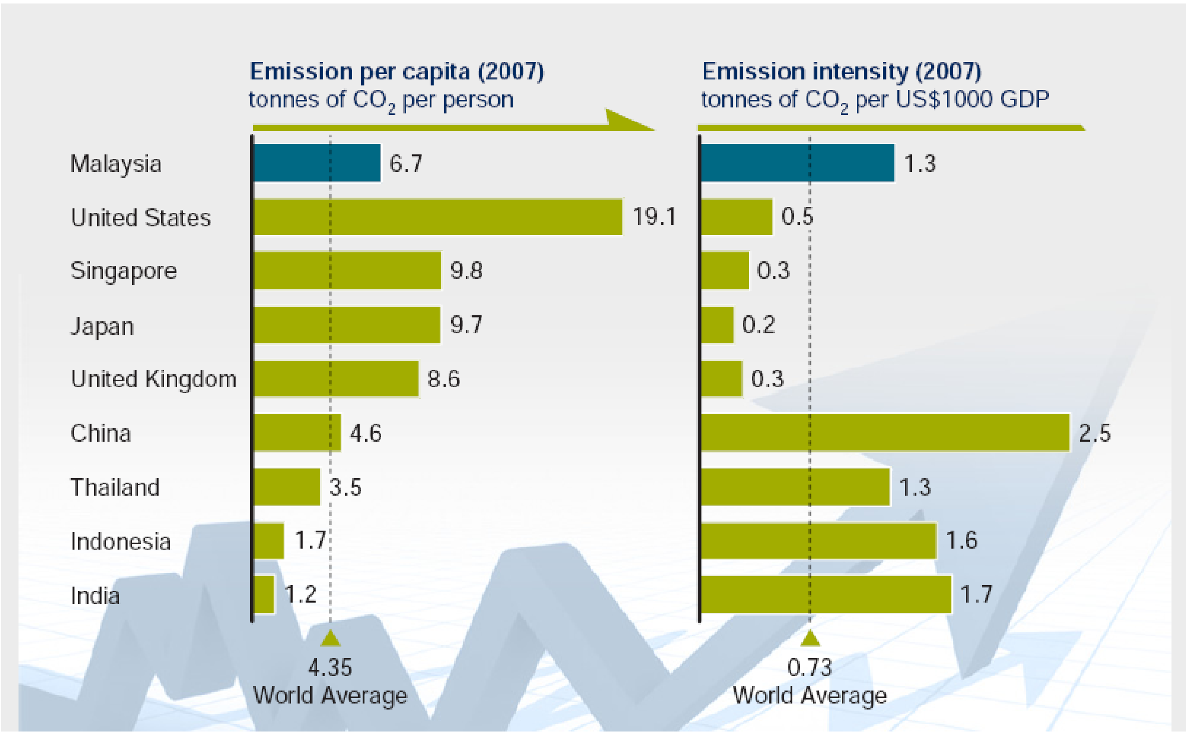


Figure 2.12 : Malaysian's emission intensity compared to global average for the waste sector in 2007 (Second National Communication to the UNFCCC/NC2, 2011).

The Malaysian government will continue efforts to enhance the efficiency and effectiveness of solid waste management, which will also lead to the reduction of GHGs emission (Ministry of Housing and Local Government Malaysia & Japan International Cooperation Agency/JICA, 2006). Among measures that will be undertaken include the building of material recovery facilities and thermal treatment plants, as well as, recycling of non-organic waste. The segregation of organic material from waste can be turned into compost or used for other purposes. This in turn will reduce the volume of waste disposed at landfills, thus reducing the emission of methane. A holistic management of solid waste through sanitary landfills will help recover the methane produced from the waste and use it to generate energy..

2.7.1 Nitrogen Removal and Transformation Process in Landfill

The nitrogen cycle in an open environment such as landfill is a complex process due to heterogeneous nature of solid waste. Because the waste is heterogeneous, portions of the landfill may contain different amounts of nutrients, temperatures, moisture levels, and different oxidation-reduction potential. Nitrogen removal in leachate treatment can be achieved using biological physicochemical processes. For this reason for leachate treatments are recommended to be multiple stage systems that include biological and physicochemical processes (Albers & Krückeberg, 1992 & Leitzke, 1996). Environmental conditions (rainfall and temperature) greatly affect the transformation and removal of nitrogen (Federico, 2013). Therefore, within one landfill cell, there may be many nitrogen transformation processes occurring simultaneously or sequentially (Berge & Reinhart, 2005). Landfill system design is rigid with respect to parameters such as waste composition and age. Waste components cannot be controlled and vary from one landfill to another similarly with waste age that varies from location to location within a landfill boundary (Berge & Reinhart, 2005).

2.7.1 Ammonia-nitrogen removal in leachate and gas.

Ammonia-nitrogen removal methods often include complex sequences of physical, chemical, and/or biological processes, including chemical precipitation, nanofiltration, air stripping, and biological nitrification/denitrification via various reactor configurations for example rotating biological filters, suspended and attached growth reactors (Berge & Reinhart, 2005). In activated sludge, nitrogen removal from leachate can be achieved by biosynthesis, ammonia stripping and denitrification (Robinson & Maris *et. al.,* 1992; Marttinen *et. al.,* 2002; Abufayed & Schroeder, 1986) (Figure 2.13).

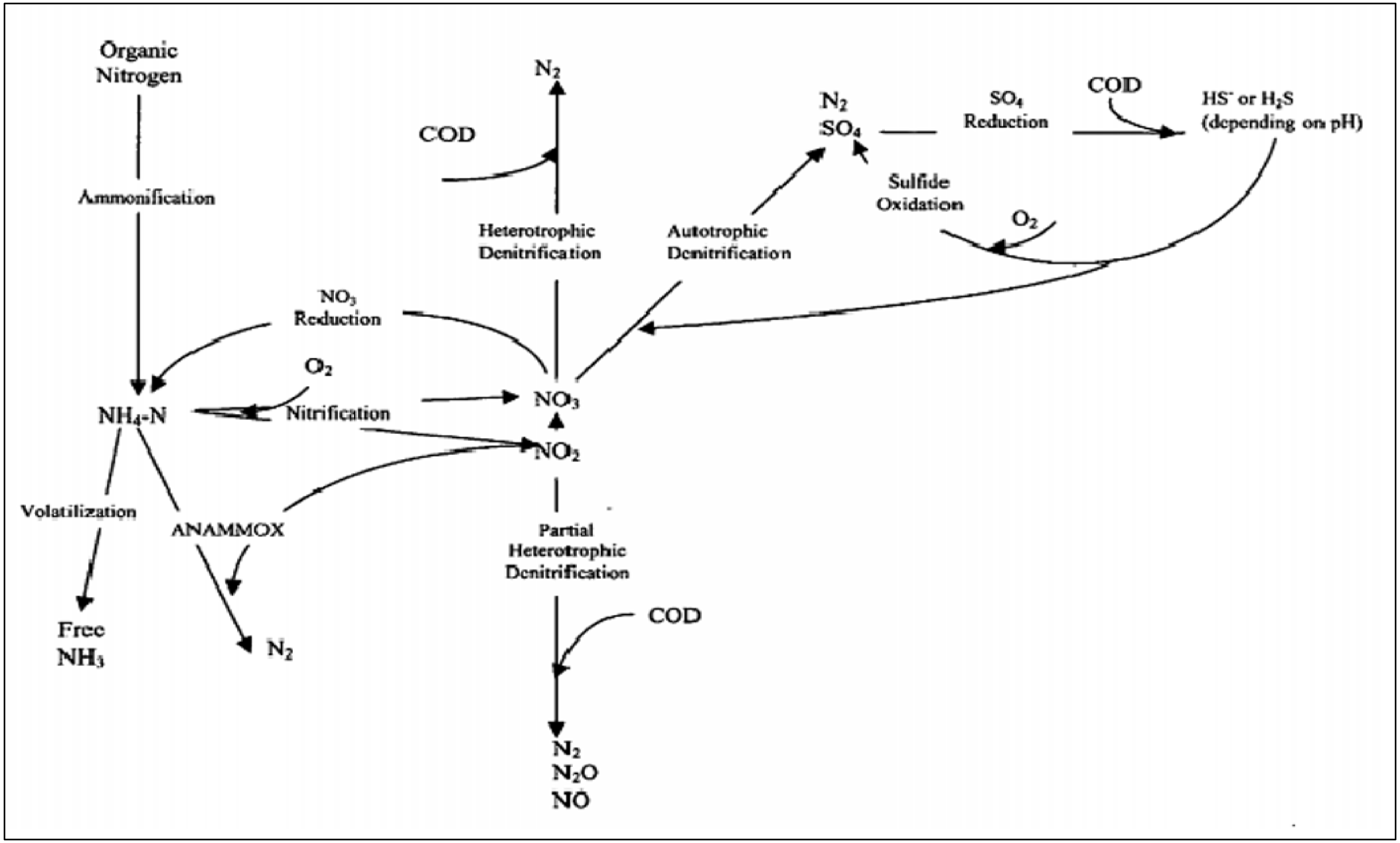


Figure 2.13: Potential pathways of nitrogen transformation and/or removal in a sanitary landfill (Reproduced from Berge & Reinhart, 2005)

Biological methods are highly effective in treating leachate from the young landfills containing a large amount of readily biodegradable organic acids (Timur *et. al.,* 2002). The ammonia-nitrogen in leachate is derived from the nitrogen content of the waste. The concentration is dependent on the rate of solubilization and/or leaching from the waste. Leachate composition is quite variable, depending highly on waste composition, moisture content of the waste, and age of the landfill.

Ammonium nitrogen (NH_4-N) is responsible for the long aftercare time of landfills since the fate of organic and inorganic nitrogen compounds is different in waste materials. (Huber-Humer *et.al,* 2010). Ammonia is not a greenhouse gas, so its impact on the environment is not as harmful as methane. However, there are some adverse health effects that may result from exposure to the gas. Ammonia has a pungent odor may cause irritation to respiratory tract. Apart from that, ammonia gas can dissolve in the moisture on skin and form ammonium hydroxide, a corrosive chemical that can cause skin irritation (Matheson, 2002). The ammonium flushing based on mass of ammonia-nitrogen that can be leached from the waste is controlled by the volume of water passed through the landfill (Berge *et. al.,* 2005). Reducing ammonia-nitrogen concentrations by washout and dilution to acceptable levels within a landfill requires the addition of large volumes of water. The Institute of Waste Management Sustainable Landfill Working Group (1999) reported that at a solid waste moisture content of 30% (wet weight basis) and an initial liquid-phase ammonia-nitrogen concentration of 5833 mg/L as N, a flushing volume of approximately 2.4 m^3/tonne of waste was necessary to reduce the nitrogen concentration to 2 mg/L as N (Berge *et. al.,* 2005). It was also noted that studies had been conducted suggesting that flushing volumes between 5 and 7.5 m^3/tonne of waste were needed to adequately reduce nitrogen concentrations in the landfill (Berge, 2006; Berge *et. al.,* 2005). No time frame for this reduction to occur were given. The effectiveness of flushing will be dependent on conductivity of the waste, as it will be harder to introduce liquid in areas of lower permeability. Flushing results in the removal of ammonia-nitrogen from landfills by adding large volumes of water, which must be treated externally. When operating landfill as a bioreactor, leachate is recycled, and hence ammonia-nitrogen is continually recirculated to the landfill leachate treatment system while additional ammonia is solubilized into the leachate. Because landfills are heterogeneous and may support several different microenvironments simultaneously (for example aerobic, anaerobic, and anoxic), several combinations of nitrogen transformation processes mentioned may be present (Berge, 2006; Berge *et. al.,* 2005). Additionally, understanding the fate of nitrogen may aid in developing methods to remediate old landfills (Ritzkowski *et. al.,* 2003). The C/N decreases sharply when the landfill is young, and stays low for a long time. The decrease of C/N reflects that high organic contents in the acid phase and its sharp decrease in the methanogenic phase and low C/N as time proceeds, is a result of the nitrogen availability in leachate (Ritzkowski *et. al.,* 2003).