CHAPTER 1

INTRODUCTION

1.1 Rationale/Problem Statement

Municipal solid waste (MSW) management is becoming an increasingly complex matter in many Asian countries due to ever increasing volume of the waste generation and the negative impacts on the environment, health and safety. In Asian countries, rapidly growing populations, rapid economic growth and rise in community living standards have accelerated the generation rate of MSW, causing its management to be a major challenging issue. (Ngoc and Schnitzer, 2009). In Asia, MSW surpasses 760,000 tonnes/day and as estimated in 2025, this figure will increase to 1.8 million tonnes (Norbu et al., 2005).

At present, there are many problems associated with MSW management due to inadequate institutional facilities and its influences on shortage of expertise, financial resources, and legal and administrative enforcement of environment regulations (Visvanathan et al., 2004). Coupled with this, the lack of public awareness and environmental ethics has led to uncontrolled solid waste disposal. In most cities, waste management is inadequate, a significant portion of the population does not have access to a waste collection services and only a fraction of the generated waste is actually collected. On average, up to 50% of residents lack, collection services in urban areas of low and middle income countries (Al-Khatib et al., 2010). Systems for transfer, recycling and/or disposal of solid waste are unsatisfactory from the environmental, economic, and financial points. Thus, many developing Asian countries are practicing open dumping and semi-engineered landfilling as the main disposal methods. Most of the generated MSW, ending up with mountains of waste, often pushed haphazardly onto river banks and immersed in low lying marshes, devastating wetlands and even golden beaches (Ngoc and Schnitzer, 2009) and has caused severe deterioration of environment.

The quantum of pollution can be quantified for a nation based on the estimated waste generation rate. In Asia, total methane generation potential may be much greater than 54 Gg during the degradation process due to daily generated waste (IPCC, 2006). Methane emission from open dumping and non-engineered land filling is the third highest anthropogenic methane emission source which is the foremost greenhouse gas (GHG) for global warming (IPCC, 2007). Moreover, world annual non-CO_2 GHG emissions from landfilling are 761 $MtCO_2eq$ and they have significantly influenced global climate change issues (EPA, 2006). In addition, the foul liquid called "leachate" emitted in the process of decomposition, mixed with the rainfall in wet tropical climates, causes many health and environmental problems after contamination with surface water bodies and groundwater table. Moreover, more sophisticated MSW methods also could contribute for significant environmental and health effects such as generation of toxic fly ash, flue gas containing heavy metals, dioxins and furans from incinerators and production of GHGs, odor, and leachate from inappropriate composting piles etc. Due to all these environmental burdens from mismanagement of MSW, severe health impacts (especially cancer, reproductive outcomes and mortality) can be observed in most of developing countries (Giusti, 2009). Furthermore, the poor waste management systems coupled with the tropical climatic conditions; result in increasing the environmental burdens due to high GHGs emission and toxic leachate production potential which influence at local, regional and global levels (Norbu et al., 2005).

In addition to the environmental burdens, there are many economic and social burdens associated with the present poor MSW management approaches in Asia. In particular, suitable landfill sites/dumping sites are becoming more difficult to find as urban areas expand and incur costs related to the consequences of waste disposal. Moreover, plans for the construction of a new waste disposal facility or treatment plant normally meet fierce opposition from the local community due to the fear of potential adverse health effects, the association of these facilities with odours, noise, visual intrusion, and the reduction in value of land and property. (Ngoc and Schnitzer, 2009; Giusti, 2009). At present, there are large costs involved in collection and transportation and in providing conveniently located and environmentally responsible landfill facilities (Ngoc and Schnitzer, 2009). For instance, MSW management methods consume enormous amount of energy as a result of inefficient transportation, operation and maintenance activities in most of the Asian countries. It also has significant influences on depletion of non-renewable resources as well as it leads to economical losses.

To overcome the drawbacks of existing MSW management systems, development of sustainable solid waste management methods is crucial; and responsible local authorities are urgently seeking appropriate solutions. As an initial step to this end, "tools" need to be developed for assessing the sustainability of MSW management systems which will help to evaluate existing systems as well as identify possible areas of improvement.

The concept of sustainable development has become an important objective of policy makers, thus sustainability assessment "measures" are needed to identify appropriate policies in the fields of environment, economy, society, or technological improvement (Begic and Afgan, 2007; Singh et al., 2009; Kondyli, 2010). However, the biggest bottleneck today is lack of right signals or indicators to quantify the foremost sustainability aspects in a tangible way and to make policies and decisions at the right time (Hák et al., 2007). Therefore, in this research, a clear methodology is discussed on developing and quantifying appropriate midpoint and endpoint environmental, economic and social indicators to assess the three-dimensional sustainability. Furthermore, the developed indicators have been successfully applied to evaluate the three-dimensional sustainability in a tangible way, for existing and intended integrated MSW management systems in Thailand, Sri Lanka and India.

1.2 Literature Review

1.2.1 General overview of MSW

Globally, the estimated quantity of waste generation was 12 billion tonnes in the year 2002 of which 11 billion tonnes were industrial wastes and 1.6 billion tonnes were MSW (Pappu et al., 2007). About 19 billion tonnes of solid wastes are expected to be generated annually by the year 2025. According to Pappu, et al., Asia alone generates 4.4 billion tonnes of solid wastes and MSW comprise 790 million tonnes.

MSW includes wastes generated from residential, commercial, industrial, institutional, construction, demolition, process, and municipal services. However, this definition varies greatly among waste studies, and some sources are commonly excluded, such as industrial, construction and demolition, and municipal services. Solid waste streams can be characterized by their sources, by the types of wastes produced, as well as by generation rates and composition. Accurate information in these three areas is necessary in order to monitor and control existing waste management systems and to make regulatory, financial, and institutional decisions (World Bank Group, 1999). The composition of the waste is the most important parameter in order to design the appropriate treatment method. Generally, in most developed countries, highest fraction of solid waste consists of paper which is 20-70% MSW, while in developing countries it represents the high fraction of food waste which is up to 40-80% (Tchobanoglous et al., 1993). Waste generation rates are affected by socioeconomic development, degree of industrialization and climate. The generation of MSW differs from nation to nation according to economic status, population density, urban lifestyles, food habits, geographical conditions and other socioeconomic and cultural factors. Generally, the greater the economic prosperity and higher the percentage of urban population, the greater the amount of solid waste produced (Al-Khatib et al., 2010; Kathiravale and Yunus, 2008).

1.2.2 MSW generation and its impacts on environment

Generation rates of MSW vary according to the economic and social standing of a country. MSW could be considered to be produced in proportion to the economic productivity and the consumption rate of the population of the countries resources. For instance, the higher income countries generated more waste, recycle more and have the money to employ new technology to treat their waste. As for the lower income countries, the commercial and industrial activity is limited; thus, generation of recyclables is limited and large fraction of waste represents the bio degradable waste which is being open dumped (Shekdar, 2008; Kathiravale and Yunus, 2008). Table 1.1 summarizes the generation rates and management costs in global perspective.

Table 1.1: MSW generation rates in global perspective and the respective management costs according to the development level (Source: Kathiravale and Yunus, 2008)

Factor	Units	Low income	Middle	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
Sanitary landfill 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

In Asia, MSW management is becoming increasingly important for a variety of reasons. The continent is inhabited by 3.7 billion people, or approximately three-fifths of the world's population (Shekdar, 2008). The quantity of solid waste generation in Asia is also mostly associated with the economic status of a society. Table 1.2 shows the waste generation rates and composition for some of the Asian countries. It can readily be seen that waste generation rates are lower for developing economies that have lower GDP.

Table 1.2: Information on GDP, waste quantity and composition of MSW for some Asian countries (Source: Shekdar, 2008)

Country	GDP per capita (estimated for 2007 USD)	Waste generation (kg/capita/day)	Composition (% wet weight basis)						
			Biodegradable	Paper	Plastic	Glass	Metal	Textile/leather	Inert and other
Hong Kong	37385	2.25	38	26	19	3	2	3	9
Japan	33010	1.1	26	46	9	7	8	-	12
Singapore	31165	1.1	44.4	28.3	11.8	4.1	4.8	-	6.6
Taiwan	31040	0.667	31	26	22	7	4	9	-
South Korea	23331	1.0	25	26	7	4	9	2.9	-
Malaysia	12702	0.5-0.8	40	15	15	4	3	3	20
Thailand	9426	1.1	48.6	14.6	13.9	5.1	3.6	-	14.2
China	8854	0.8	35.8	3.7	38	2	0.3	-	47.5
Philippines	5409	0.3-0.7	41.6	19.5	13.8	2.5	4.8	-	17.9
Indonesia	5096	0.8-1	74	10	8	2	2	2	2
Sri Lanka	5047	0.2-0.9	76.4	10.6	5.7	1.3	1.3	-	4.7
India	3794	0.3-0.6	42	6	4	2	2	4	40
Vietnam	3502	0.55	58	4	5.6	1.6	1.5	1.8	27.5
Lao PDR	2260	0.7	54.3	3.3	7.8	8.5	3.8	-	22.5
Nepal	1760	0.2-0.5	80	7	2.5	3	0.5	-	7

It is noticeable that waste streams are comprised of 55% or more organic matter in most of the developing Asian countries (Table 1.2). In addition, MSW consists of high moisture content around 50-70% especially due to high fraction of food waste, (Shekdar, 2008; Visvanathan et al., 2004).

At present, most of the developing Asian countries practice open dumping or non engineered landfills as the main waste disposal methods due to lack of financial resources and lack of appropriate technologies. Looking at the most common disposal methods of some developing Asian nations, open dumping is 60% in India, 85% in Sri Lanka, 65% in

Thailand and 50% in China (Visvanathan et al., 2004). As a result, existing MSW management methods in most of Asian countries causes enormous environment degradation. For instance, mismanagement of solid waste has resulted in many environmental problems like ground water contamination and surface water contamination, air pollution, releasing hazardous and carcinogenic substances to the environment, decrease values of properties, affect on the ecosystem especially aesthetic nuisance due to odor, noise, dust and damages to landscapes due to soil erosion (Visvanathan et al., 2004).

At present, MSW has contributed significantly to global warming potential due to the GHGs emissions from collection and transportation and final disposal. For instance, methane emission from mostly practiced MSW methods such as open dumping and non engineered land filling contributes to a major share of anthropogenic methane which is the foremost GHGs for global warming (IPCC, 2007). "Leachate" generation potential during the degradation process accounted as 600 L/year/tonne of wastes from dumpsites (Schroeder et al., 1994) and this highly polluted leachate can easily contaminate with surface water bodies and groundwater table. Finally all these reasons combined, have created severe problems on human health (Kathiravale and Yunus, 2008).

More sophisticated MSW methods, such as incineration and composting, have also created some environmental and health effects including generation of toxic fly ash, flue gas containing heavy metals, dioxins and furans from incinerators and production of GHGs, odor, and leachate from inappropriate composting piles. The potential environmental degradations caused by different MSW methods are summarized in Table 1.3.

Table 1.3: Major environmental impacts from MSW management (Source: Alvarez et al., 2000; Giusti, 2009)

Type of technology	**Environmental damage**				
	Damage to Water	Damage to Air	Damage to Soil	Damage to Landscape	Damage to Climate
Landfilling	Leachate (heavy metals, synthetic organic compounds)	CO_2, CH_4, odour, noise, VOCs	Heavy metals, synthetic organic compounds	Visual effect, vermin	Worst option for GHGs emission
Incineration	Fall-out of atmospheric pollutants	SO_2, NOx, N_2O, HCl, HF, CO, CO_2, dioxins, furans, PAHs, VOCs, odour, noise	Fly ash, slags	Visual effect	GHGs emissions

Composting	Leachate	CO_2, CH_4, VOCs, dust, odour, bioaerosols	Minor impact	Some visual effect	Small emissions of GHGs
Anaerobic digestion	Leachate	VOCs, NH_3, H_2S, odour	Minor impact	Some visual effect	Small emissions of GHGs
Land spreading	Bacteria, viruses, heavy metals	Bioaerosols, dust, odour	Bacteria, viruses, heavy metals, PAHs, PCBs	Vermin, insects	Small emissions of GHGs
Recycling	Waste water	Dust, noise	Land filling of residues		Minor emissions
Waste transportation	Spills	CO_2, SO_2, NO_x, SO_x, dust, odour, noise, spills	Spills		Significant contribution of CO_2

A lot of economic problems can also be noticed in existing MSW management methods. One of the major reasons for poor MSW management systems in Asia, is mainly due to limited government budgets which it is not even sufficient to provide sufficient collection service (Al-Khatib et al., 2010). At present, most improved MSW management operations are extremely expensive and cannot fit into municipal budget. For instance, incineration appears to be an attractive option. However, this method is agreed to be an inappropriate approach for most of the developing countries due to its high financial start-up and operating capital requirements. In addition, composting can be introduced as a somewhat more low-technology approach to waste reduction. However, composting is not practiced well in Asia, and it is still not overwhelmingly successful due to high operating and maintenance costs, the high cost of compost compared to commercial fertilizers, and the available market (Ngoc and Schnitzer, 2009). Even though, waste recycling activity is an attractive solution because it is an economically viable undertaking. This undertaking is currently accomplished by medium-scale or household enterprises, and is predicted to grow where it offers a beneficial economic impact. All these financial aspects should be evaluated during the design phase of every element of the system to avoid the collapsing during its functioning phase (Shekdar, 2008).

A wide range of negative social impacts, have been caused due to poor MSW management methods and those impacts have badly affected on the quality of life people of the community. Poorly operating MSW management practices such as landfill and incineration have created a huge threat to human health due to the environmental emissions, and there are hardly any benefits to the local community people. Thus, most of the time, plans for the construction of a new waste disposal facility or treatment plant is normally met with fierce opposition from the local community due to the fear of potential adverse health effects (Giusti, 2009; Ngoc and Schnitzer, 2009).

To overcome all those environmental economic and social problems, development of sustainable solid waste management methods is a vital issue and most of the local authorities in Asia are urgently seeking sound and safe technologies.

1.2.3 Concept of sustainability development in MSW management

As pointed out by Troschinetz and Mihelcic (2009), ''The increasing volumes of waste being generated would not be a problem if waste was viewed as a resource and managed properly'' and this innovative thinking would drive the entire system towards sustainability. Unfortunately, as society becomes more advanced, simple expedient solutions are no longer sufficient to solve the ever-growing MSW disposal problems. The solution for these problems would be continued thinking of creating an Integrated Solid Waste Management (ISWM) system which includes the reclamation of useful material and energy and environmental considerations, in the concept of sustainable development (Kathiravale and Yunus, 2008). In order to achieve this, ISWM systems should combine, efficient collection service, appropriate treatment technologies to treat the different fraction of waste (biological treatment, thermal treatments, material recycling) and residual material disposal services. This type of ISWM systems would enhance the economic feasibility and social acceptability via income generation potential, improving living standards etc. (Wilson, 2007; McDougall et al., 2001). However, the sustainability of such MSW systems depend on some key aspects such as policy and legal framework, institutional arrangement, operational management, appropriate technology, financial management and public participation (Scipion et al., 2009; Shekdar, 2008). If a nation can develop ISWM systems including the above key elements, the systems has capability to provide services to the public, employ a sizable number of people and conserve significant amount of resources and give maximum protection in the environment. This may help to strengthen the prolonging sustainability of the system.

Achieving ''sustainable development'' requires methods and tools to help quantify and compare the environmental, economic and social impacts (Rebitzer et al., 2004). In other words, to quantify the systems sustainability, appropriate indicators is necessary, especially for convincing information on drawbacks of existing systems and benefits of appropriate ISWM systems (Singh et al., 2009; McCool and Stankey, 2004). Perhaps the biggest obstacle one faces today is the lack of right signals or indicators to make policies and decisions at the right time (Hák et al., 2007). Therefore, the development and use of appropriate sustainability indicators is necessary to evaluate three-dimensional sustainability of MSW management methods prior to making decisions on selection and implementation.

1.2.3.1 Importance of sustainability indicators for assessing MSW management systems

The concept of sustainable development has become an important objective of policy makers (Böhringer and Jochem, 2007). Therefore, sustainability indicators are increasingly recognized as a useful tool for policy making and public communication in conveying information on various countries and corporate performance in fields such as environment, economy, society, or technological improvement (Begic and Afgan, 2007; OECD, 2008; Singh et al., 2009; McCool and Stankey, 2004; Warhurst, 2002). As pointed out by Warhurst (2002) to understand the past and future, development of sustainability, indicators would be the key evaluation tool for a system. Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)' (Meadows, 1998). Moreover, by visualizing phenomena and highlighting trends, indicators can simply, quantify, analyze and communicate the enormous complexity of our dynamic environment to a manageable amount of meaningful information (Singh et al., 2009). Thus, indicators have been widely used for monitoring and assessment of numerous environmental impacts of operations, and are increasingly used in social and economic arenas (Warhurst, 2002).

Conceptually, appropriate indicators play three important roles in sustainability assessments. First, they help to depict the existing condition of systems that are often complex, multi-faceted, and interdependent. Second, depending upon feedback mechanisms, indicators facilitate evaluating the performance of various management actions and policies implemented to achieve sustainability. Third, they alert users to impending changes in social, cultural, economic, and environmental systems (McCool and Stankey, 2004). To be effective, indicators must be credible (scientifically valid), legitimate in the eyes of users and stakeholders, and salient or relevant to decision makers.

Thus, development of appropriate indicators to represent the large number of relevant issues, and selecting indicator sets and aggregating them into fewer indices are most challenging aspects of indicator development (Hák et al., 2007). Sound indicators would be the correct path towards sustainability and for promoting a systemic measurement as a probing tool for evaluating and selecting of MSW management technologies (Chen et al., 2009; UN, 2001). Prior evaluation of proposed MSW management system by using appropriate sustainability indicators would be very useful for avoiding failures that may cause during its functioning. In addition, this information will be useful for local authorities who are responsible for waste handling and management on the decision making process (Böhringer and Jochem, 2007; Borghi et al., 2009; Hák et al., 2007; Meadows, 1998; Scipioni et al., 2009; Ramos, 2009; Wilson et al., 2007; UN, 2001; Kondyli, 2010). Therefore, sustainability indicators can be used to select the optimal management scenario for a particular municipality (Den Boer et al., 2007), especially for planning new integrated MSW management systems and optimization of existing waste management systems.

1.2.3.2 Information gap on developing sustainability indicators

Even though many scientists have recognized that development of indicators for a system is the best method of assessing sustainability (Singh et al., 2009; Warhurst, 2002; Wolters and Danse, 2004; Ramos, 2009), there is an information gap on application of sustainability indicators in real situations and clear methodologies to develop sustainability indicators for different type of projects. As pointed out by Meadows (1998), "it is easy enough to list the characteristics of ideal indicators and it is not easy to find indicators that actually meet the ideal characteristics". Therefore, when it applies to MSW management, it is necessary to identify the foremost areas of MSW management systems in terms of the economic, environmental and social issues and to develop indicators to quantify those impacts. However, most studies focus only on environmental issues and few of them on economic issues to some extent. For the social dimension, qualitative measures are equally useful since some relevant social issues can be assessed only through qualitative measurement. In particular, the impacts may have larger degree of subjectivity that cannot be readily distilled down to one or more numerical measures (Hák et al., 2007; Warhurst, 2002). Thus, when developing complex indicators, integrating these data with quantitative data remains a critical methodological issue. Furthermore, James (1994) observed that in designing environmental performance indicators, the difficulty is not how to measure performances, but how to convert large amounts of data into meaningful information as a useful decision tool for environmental management. The same concern also applies to economic and social performance indicators.

It is noticeable that, there are no developed sustainability indicators for evaluating the three dimensions of MSW management system. Most of the time, less attention has been paid on economic and social issues which may be due to lack of data or difficulties in evaluating quantitatively (Böhringer and Jochem, 2007; Cleary, 2009). In order to overcome all those limitations, appropriate indicators should be developed based on in-depth investigation of foremost sustainability area such as economic, environmental and social issues for thorough evaluation of MSW management system (Figure 1).

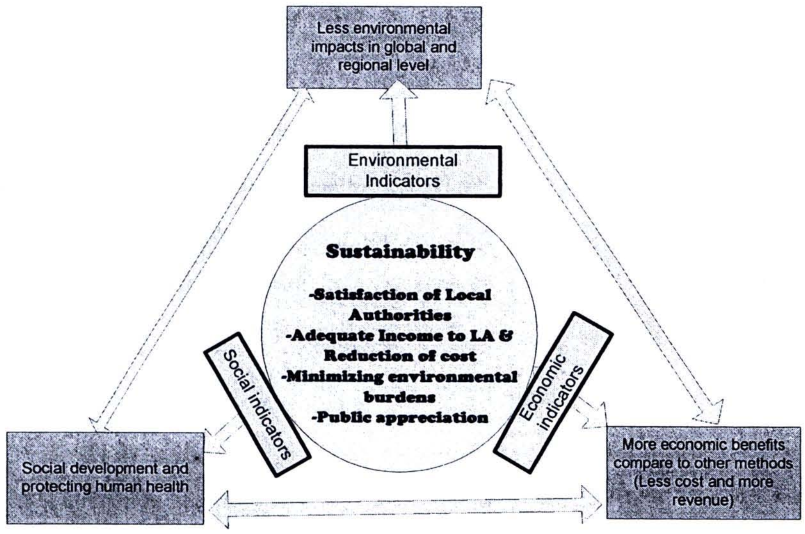

Figure 1.1: Foremost sustainability areas for indicators development

Moreover, development of endpoint composite indicators would be the perfect way of assessing sustainability since it can ideally measure multidimensional concepts which cannot be captured by a single indicator (OECD, 2008). Due to this reason, composite indicators have been increasingly recognized as a useful tool for policy making and public communication in conveying information on countries' performance in fields such as environment, economy, society, or technological development (Singh et al., 2009).

1.2.4 Life-cycle thinking – A tool for sustainability indicator development

To evaluate the performance of alternative MSW management systems, a life-cycle approach can be used as a useful method to make appropriate choices and to develop sustainability indicators (CALCAS, 2011; Eriksson et al., 2005). By applying life-cycle approach, priorities can be identified more easily and policies can be targeted more effectively so that the maximum benefit can be achieved relative to the effort expended (Buttol et al., 2007). Moreover, Life Cycle Assessment (LCA) is an essential tool for consideration of both the direct and indirect impacts of waste management technologies and policies (IPCC, 2007). For instance, the direct environmental impacts may be caused by surrounding systems, such as energy and material production which is required for functioning of the MSW management system and can be accounted via life-cycle perspective (Singh et al., 2009; Liamsanguan and Gheewala, 2008a). However, it would be complicated when it is applied to sustainable integrated MSW management systems since wide variety of treatment plants may be included in an integrated MSW management system (pre-treatment and selection plants, incinerators, composting plants, landfills etc). Thus, it is necessary to consider all the phases of life cycle in a systematic approach in each technology such as primary storage at the household level, collection, transportation, processing and final disposal. To assess economic and social sustainability traditional environmental LCA should be broadened within the same system boundaries and functional unit (Hunkeler, 2006). Considering all those aspects, inventory analysis can be done within a common LCA framework for the entire life cycle of particular MSW management system. Based on the inventory results, different types of indicators may distinguished.

1.3 Research Objectives

- To develop sustainability indicators as a supportive tool for decision makers in identifying appropriate strategies and policies for sustainable solid waste management options.
- To apply the developed indicators to assess the three-diamentional (environmental, economic and social) sustainability of the existing and intended integrated MSW management systems for selected case studies in Asia.

1.4 Research Scope

This research is focused on application of standard ISO 14040/14044 life cycle assessment concept in a "broaden" and "deepen" perspective to develop indicators for three-dimensional "Life Cycle Sustainability Assessment". Detailed life cycle inventory analysis is performed with respect to environmental, economic and social aspects within a common framework, for identifying critical issues that are closely associated with MSW management and subsequently to develop indicators for quantifying the ultimate damages/effects.

Then the developed indicators are applied for sustainability assessment of the existing MSW management practices in three representative Municipalities in selected Asian countries namely; Nonthaburi Municipality in Thailand, Kandy Municipality in Sri Lanka and Kolkata Metropolitan Cooperation in India. In addition, comprehensive investigations are performed on three-dimensional sustainability assessment of more sophisticated and potentially suitable integrated MSW management methods, to replace the existing inappropriate systems.