Solid Waste and Climate Change: Perceptions and Possibilities

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Abstract

Climate change is a serious international environmental concern and the subject of much research and debate in recent years. It is estimated that 3.4 % of Green House Gases (GHGs) emit from waste sector and contributes to one fifth of global anthropogenic sources. Eventhougth the contribution is very small but still matters and it needs immediate actions to mitigate. Since, the world population is increasing day by day; the per capita waste generation also getting amplified consequently, lead to failure of proper waste disposal practices especially from developing countries. The unscientific method of waste disposal continuously emits GHGs, which is ultimately contributing to the global climate change. Hence, mitigating GHG emissions from proper waste management practices is to be given priority in developing countries. Compared with the other 15 sectors which are listed under Kyoto protocol, controlling and reducing GHG emissions from waste sector seems to be cost effective through Clean Development Mechanism (CDM). CDM is one of the flexible mechanisms, which acts as a means and technology transfer from developed to developing countries. This could lead to sustainable development of the host countries as well as economically reduces GHG globally. Hence, there is a great possibility in reducing GHG emissions and associated climate change impacts through appropriate waste management practices.

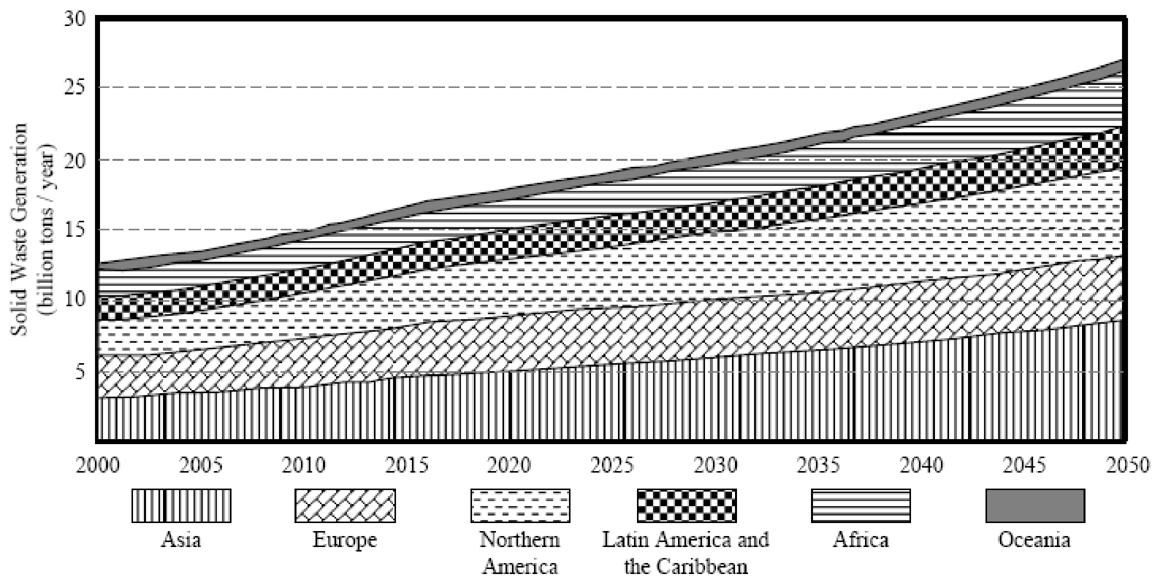
1.0 Introduction

The current generation encounters large number of problems which has multidimensional impact on all the life forms existing on the earth. One of the thriving problems is that of global warming and climate change mainly due to the anthropogenic release of GHGs i.e., mainly CO_2 and CH_4. The major consequences due to global warming were documented in recent days and they are,

- Rise in sea level due to melting of glaciers from Arctic and Antarctic regions
- Frequently occurring natural disasters like, cyclones, earthquakes, heat waves, flood, high drought and spreading of epidemic diseases
- Reduction in agricultural crop yield due to shifting of local climatic variables and
- Loss in biodiversity and impacts on ecosystem is leading to change in entire food web.

As clearly declared in the IPCC Fourth Assessment Report on ''Climate Change", a substantial reduction of GHG emissions is now required to tackle global warming and to reduce the environmental consequences. Various anthropogenic sources contribute to this problem and aggravate its effects including burning of fossil fuels for purposes like power generation, vehicular propulsion and industrial usage, deforestation, agriculture and waste sector. Among the number of anthropogenic sources, Municipal Solid Waste (MSW) and Wastewater (WW) are grouped under waste sector and which is considered as one of the significant sources for contributing global climate change. In most of the developed and developing countries with increasing population and urbanization, it remains a major challenge for municipal/local authorities to collect, recycle, treat and dispose of increasing quantities of

MSW in a proper way. The amount of MSW generated and its physico-chemical characteristic varies with country, city and seasons. Figure 1 depicts the trend in MSW generation from developed and developing countries. It was observed that the solid waste generation ranged between 0.1 and 0.5 t/capita/year in low-income countries; whereas, between 0.2 and 0.6 t/capita/year in middle-income countries; 0.3 and 0.8 t/capita/year in high-income industrialized countries (Bogner *et al*., 2007).



Source: Yoshizawa (2007)

Figure 1. Prediction of global MSW generation rate

Further, the biodegradable food materials and yard wastes normally dominate in MSW of developing Asian countries while paper and hardboard dominate in developed countries (Visvanthan and Trankler 2004). The high percentage of organic fraction from developing Asian countires indicates that the technology is needed for waste processing prior to final disposal.

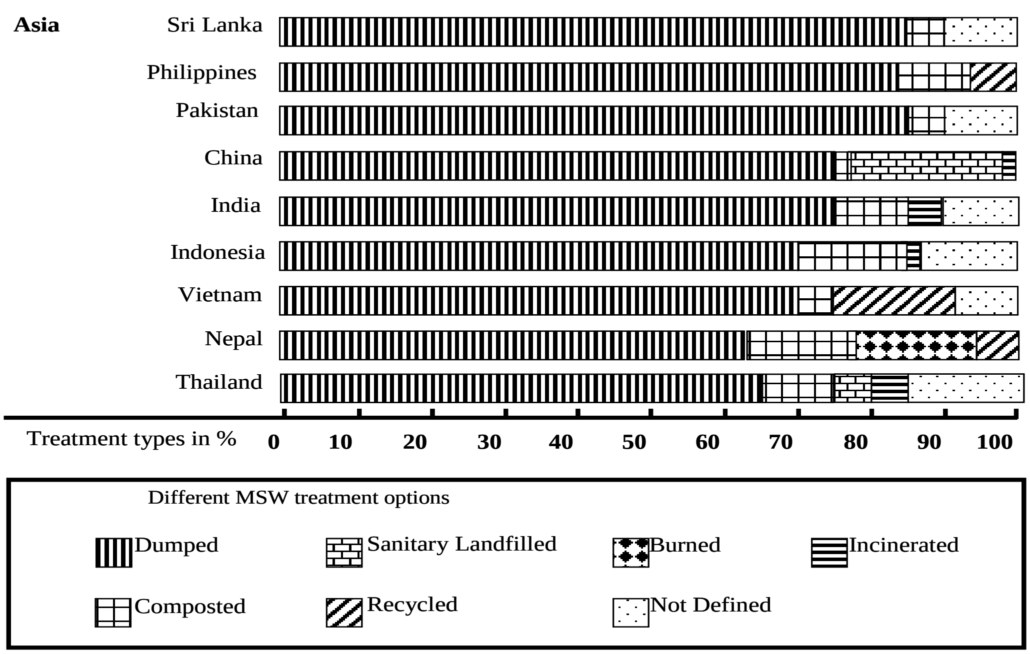
2.0 Waste management in developing Asian countries

Due to increasing economic growth rate and population the per capita MSW generations in Asain countries are expected to increase and far exceed than the developed countries. The collection and segregation of MSW is managed by the respective municipal and local bodies. The predominant waste collection system in most of the Asian cities is through communal bins and door to door collection system. High fractions of organics (more than 60 %) lead to a dense and humid waste that affects the collection and transport system. Hence, the percentage of collected MSW to the amount of disposed MSW is 22 to 80%. Table 1 depicts the percentage distribution of individual components in MSW from major Asian countries. The low proportion of recyclables in MSW can be attributed to the market value of recyclables. In developing economies, recycling occurs at every stage of the system, leaving only a small portion that ultimately reaches the open dumps/landfills for final disposal. However, income level, economic growth, lifestyle, and location strongly influence MSW composition and also collection/recycling efficiency.

Table 1. MSW composition from developing countries

Host Country	Physical composition of MSW (all values are given in %)					
	Organic components	Paper	Plastic	Glass	Metal	Others
India	41.8	5.7	3.9	2.1	1.9	44.6
Nepal	80.0	7.0	2.5	3.0	0.5	7.0
Bangladesh	84.4	5.7	1.7	3.2	3.2	1.8
Thailand	48.6	14.6	13.9	5.1	3.6	14.2
Myanmar	80.0	4.0	2.0	0.0	0.0	14.0
Indonesia	70.2	10.6	8.7	1.7	1.8	7
Philippines	41.6	19.5	13.8	2.5	4.8	17.8
Malaysia	43.2	23.7	11.2	3.2	4.2	14.5
Japan	31.2	44.8	9	7	6	2

Figure 2 illustrate the various MSW disposal practices from developing Asian countries. Looking at the most common disposal methods, open dumping dominated than any other waste disposal method and an associated environmental problem such as GHG emissions, is also serious from these countries. Since the waste management decisions are often made locally, without direct consideration of GHG mitigation; it is likely that the importance of the waste sector for reducing emissions has been underestimated from developing countries. Therefore, good waste management practices are to be considered to promote GHG mitigations.



Source: www.cwgnet.net

Figure 2. Distribution of commonly used MSW disposal technologies from developing Countries

3.0 GHG emissions from waste disposal practices

The waste sector is accountable for approximately 5 % of the global green house budget with total emissions of approximately 1,300 $MtCO_2$-eq in 2005 is reported by IPCC. This 5% consist of methane (CH_4) emission from anaerobic decomposition of solid waste and carbon dioxide (CO_2) from wastewater decomposition. Only CH_4 is accounted for the estimation of GHG emissions from solid waste management practices not CO_2 despite its Global Warming Potential (GWP) upon release. This is due to the general consensus that CO_2 from waste decomposition is of biogenic origin and hence does not add to the overall GHG emissions that contribute to global warming (IPCC, 2006).

Landfilling, composting and incineration are considered as the most common treatment technologies for MSW worldwide. Among them landfilling is expected to increase due to developing countries movement away from open dumping to landfilling. Various independent theoretical and experimental studies suggest a large variation of GHG generation from 1 ton of waste, ranging from 40 m^3 to 250 m^3 (Lou and Nair 2009). This is understandable as Landfill Gas (LFG) generation is highly dependent on a variety of factors, one such crucial factors determining GHG emissions is waste composition. However, there has been a movement to divert organic waste from landfills in order to reduce the negative environmental impact.

Composting has thus been widely acknowledged as an alternative to landfills. Aerobic decomposition from well managed composting results in the emission of CO_2 and H_2O. Due to the heterogeneous nature of a compost pile, some CH_4 may emit from anaerobic pockets formed within the piles (Bogner et al., 2007). The studies have shown that the majority of this CH_4 getting oxidized in to CO_2 in aerobic pockets and near the surface of the compost pile, making CH_4 emission negligible. However, the existence and continual usage of landfills now and in the future cannot be denied. Not all waste can be composted or recycled, and a certain portion of waste will inevitable be landfilled.

Estimated current GHG emissions from waste incineration are small, around 40 $MtCO_2$-eq/yr, or less than one tenth of landfill CH_4 emissions worldwide. Technology applications for thermal recovery (direct combustion of waste to recover heat) and fuel recovery (Refuse Derived Fuel - RDF and Packaging Derived Fuel - PDF production from waste) are not observed in most of the developing Asian countries. These technologies are found to have been best applied only in the developed countries. In developing countries, controlled incineration of waste is infrequently practiced because of high capital and operating costs, low heat value of the wastes, difficulties in maintaining the required operating conditions as well as a history of previous unsustainable projects. Although some pilot models have proved successful in developed countries, many details are yet to be determined in terms of implementation necessitating further research.

However, recycling of waste reduces greenhouse gas emissions by preventing methane emissions from landfills or open dumps and by preventing the consumption of energy for extracting and processing raw materials. The magnitude of avoided GHG-emissions benefits from recycling is highly dependent on the specific materials involved, the recovery rates for those materials, the local options for managing materials, and (for energy offsets) the specific fossil fuel avoided (Smith *et al.*, 2001).

Life cycle activities associated with the different waste management strategies are not included in the IPCC emission calculations. However, for a more holistic approach, streamline life cycle activities should also be accounted when quantifying a waste management strategy impact on GHG emissions.

4.0 CDM and GHG emission mitigation in waste sector

At present, developing countries have no obligations to constrain their GHG emissions. But they are still able, on a voluntary basis, to contribute to global emission reductions by hosting projects under the Clean Development Mechanism (CDM). This could lead to sustainable development of the host countries as well as economically reduce greenhouse gas emissions globally. As of May 2009, the number of CDM projects in pipeline counted to be greater than 4,200 out of which 1,640 projects were registered with the annual average Carbon Emission Reduction (CER) of 301,268,738 CO_2-eq till the end of year 2012.

Out of which, 17.4 % (≅349 projects) of the CER is distributed from Sector 13 i.e., waste handling and disposal as shown in Figure 3. It can be seen that the maximum number (around 60 %) of CDM projects are in the Energy sector and that many are small renewable projects occurring in more than 40 countries. The registered CDM projects under Sector 13 with individual breakup from developing Asian countries including India, Bhutan, Nepal, Bangladesh, Thailand, VietNam, Myanmar, Cambodia, Indonesia and Philippines were presented in Table 2. From these developing countries only 62 projects were registered for CDM under sectoral scope 13 which is equivalent to 39,98,759 CO_2-eq of CERs. The projects are further inventorized under three main groups *viz.*, MSW, wastewater and others. The total number of projects registered under wastewater treatment appears to be maximum, where as CERs comparatively lesser (1,691,096 CO_2-eq) than the solid waste category (1,922,503 CO_2-eq).

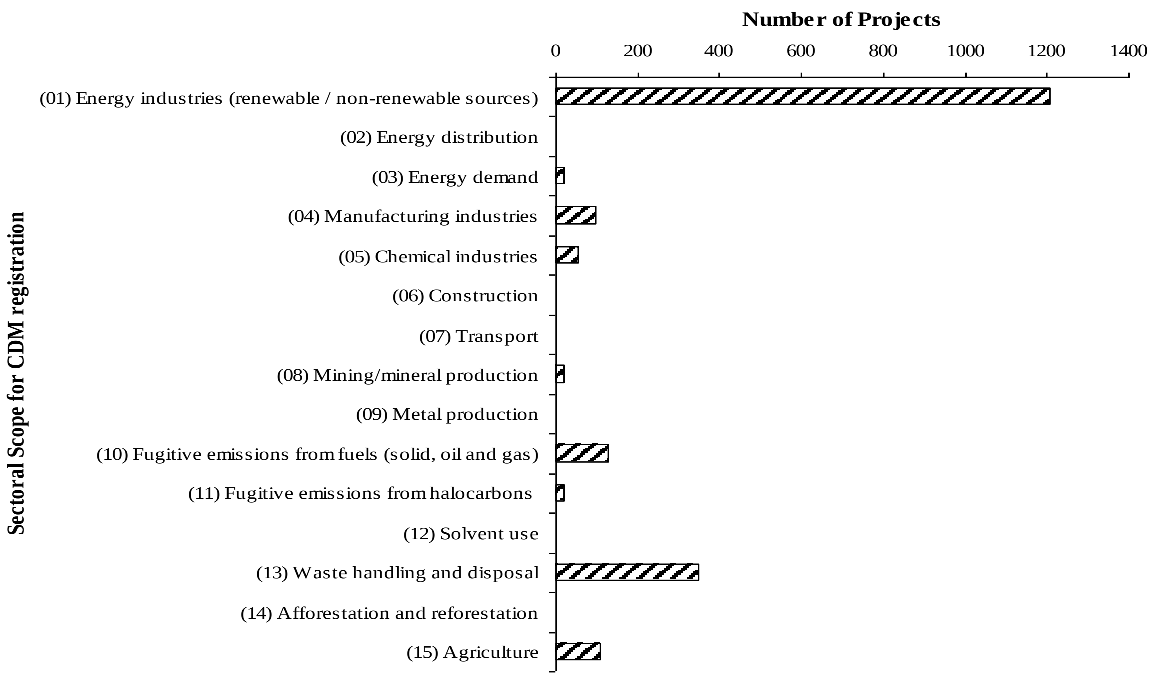


Figure 3. Distribution of CDM projects under different sectoral scope of UNFCCC

Out of 17 projects from developing countries in Solid waste category, composting of OF-MSW dominated than any other waste disposal practices. Whereas, the LFG recovery from landfills (account for 10.15% of emission reductions) dominated from developed countries *viz.*, Latin America, Carribean

Region and Brazil and around 95 % of the registered LFG projects are occur under CDM. Some projects are flaring gas, while others are using the gas for on-site electrical generation or direct project use. In general, costs and potential for reducing GHG emissions from waste sector are usually based on landfill CH_4 as the baseline. When reporting to UNFCCC, most developed countries take the dynamics of landfill gas generation into account; however, most developing and non-reporting countries do not as said by Bogner et al., (2007).

Table 2. Registered CDM projects and GHG reduction from developing countries

Host Country	Solid Waste		Wastewater		Others*		Total	
	Number of Projects	MT CO_2 reduction / annum	Number of Projects	MT CO_2 reduction / annum	Number of Projects	MT CO_2 reduction / annum	Number of Projects	MT CO_2 reduction / annum
India	6	5,33,508	8	2,51,441	5	1,38,811	19	9,23,760
Bhutan	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0
Bangladesh	2	1,69,259	0	0	0	0	2	1,69,259
Thailand	1	47,185	11	8,05,866	0	0	12	8,53,051
VietNam	2	2,79,969	0	0	0	0	2	2,79,969
Myanmar	0	0	0	0	0	0	0	0
Cambodia	0	0	1	50,036	1	51,620	2	1,01,656
Indonesia	3	1,80,192	6	4,49,352	1	1,66,000	10	7,95,544
Philippines	3	7,12,390	11	1,34,401	1	28,729	15	8,75,520
Total	17	19,22,503	37	16,91,096	8	3,85,160	62	39,98,759

Source: Sectoral Scope 13-Waste handling and disposal, UNFCCC- http://cdm.unfccc.int/Projects/projsearch.html

Incinerations have been widely applied in many developing and developed countries, especially those with limited space for landfilling such as Japan and many European countries. Globally, about 130 million tones of waste are annually combusted in more than 600 plants in 35 countries. The UNFCCC has also approved three municipal waste incinerators with 450,813 MT CO_2-eq reductions by treating MSW from developing countries in recent years. According to the CDM project database, the first few registered incineration projects are listed below from developing Asian countries,

- In November 2007, the CDM approved a project with two new municipal waste incinerators near Delhi, India (TIMARPUR-OKHLA Waste Management Company Pvt Ltd's (TOWMCL) integrated waste to energy, Project 1254).
- In May 2007, the CDM funded a gasification incinerator project for municipal solid waste in Bali, Indonesia (PT Navigat Organic Energy Indonesia Integrated Solid Waste Management (GALFAD), Project 0938).
- In April 2007, the CDM funded a refuse derived fuel incinerator for municipal solid waste in India (Shriram Energy Systems Ltd (SESL) 6 MW Municipal Solid Waste Based Power Project at Vijayawada & Guntur, Andhra Pradesh, Project 0959).

Compared to waste incineration and composting processes, which only mitigate future emissions, landfill CH_4 is generated from waste landfilled in previous decades, and gas recovery, in turn, reduces emissions from waste landfilled in previous years. Most existing CDM projects in developing countries for the waste sector do not consider these temporal issues since the unscientific dumping of waste.

5.0 Integrated solid waste management and GHG mitigations

The mitigation of GHG emissions from waste must be addressed in the context of Integrated Solid Waste Management (ISWM). The major ISWM activities are waste prevention, recycling and composting, and combustion and disposal in properly designed, constructed, and managed landfills. Also pretreatment of waste by Mechanical-Biological Treatment (MBT) is another approach, which can reduce the significant volume of waste for further treatment. These different waste management activities have varying impacts on energy consumption, GHG emissions, and carbon storage as shown in Table 3. Therefore, the mitigation of GHG emissions from waste relies on multiple technologies, whose application depends on local, regional and national drivers for both waste management and GHG mitigations. For example, recycling reduces greenhouse gas emissions by preventing methane emissions from landfills or open dumps and by preventing the consumption of energy for extracting and processing raw materials.

Table 3. Waste management strategy and GHG sinks

MSW Management Strategy	GHG Sources and Sinks		
	Raw Materials Acquisition and Manufacturing	Changes in Forest or Soil Carbon Storage	Waste Management
Source Reduction	Decrease in GHG emissions. Relative to the baseline of manufacturing	Increase in forest carbon sequestration (for organic materials)	No emissions/sinks
Recycling	Decrease in GHG emissions due to lower energy requirements (compared to manufacture from virgin inputs) and avoided process non-energy GHGs	Increase in forest carbon sequestration (for organic materials)	Process and transportation emissions associated with recycling are counted in the manufacturing stage
Composting (food discards, yard trimmings)	No emissions/sinks	Increase in soil carbon storage	Compost machinery emissions and transportation emissions
Combustion	No change	No change	Non-biogenic CO_2., N_20 emissions. Avoided utility emissions, and transportation emissions
Landfilling	No change	No change	CFL emissions, long-term carbon storage, avoided utility emissions. And transportation emissions
Anaerobic Digestion	Reduces the fuel energy consumption	Increase in soil carbon storage	Plant machinery emissions, Transportation emissions

Source: USEPA, 2006

6.0 A scenario for MSW management and GHG mitigations

Considering typical Asian city as a case with a living and floating population of 1 million and percapita MSW generation of 1kg/day, the total waste being managed by the year is around 365,000 tons. It is assumed that the percentage distribution of individual components in the waste stream as given in the Table 4 for calculating GHG emission and mitigation. The organic fraction of 60 % (219,000 t/year) from the MSW can be source segregated either for composting or anaerobic degradation. The plastics

(4%), paper (6%), glass (2%) and metal (1%) contents which are approximately contributing to that of 47,450 t/year can be collected separately for appropriate recycling to mitigate GHG emissions and the remaining 23 % (83,950 t/year) of inert can be landfilled. The chemical characteristics considered as Carbon (30 %), Nitrogen (1.1 %) and Moisture (55 %) in MSW. The three different scenarios were considered i.e., composting and anaerobic digestion for organic waste in the study based on the review of most common waste disposal method prevailed in the developing Asian countries and integrated with recycling of valuables for GHG emission calculation. Landfilling option is not considered since difficulties in getting lands for operation in the present scenario from developing countries.

Table 4. Typical waste composition considered for scenario development

Waste Components	Distribution (%)	Total Quantity (t/year)
Organic contents	60	219,000
Paper	6	21,900
Plastics	4	14,600
Glass	2	7,300
Metal	1	3,650
Wood	1	3,650
Green waste	3	10,950
Inert materials	23	83,950
Total	**100**	**365,000**

6.1 Scenario -1: Composting

In this scenario it is assumed that the biodegradable organic content from the MSW is completely stabilized by aerobic windrow composting method and used as manure. Biological conversion factor for composting is assumed i.e., 0.084 for the GHG emission calculation. It is estimated that around 18,396 t CO_2 will be emanate from the complete biological conversion of organic components from the MSW under aerobic conditions. But generally composting process will be extended between 30 and 45 days until getting C/N ratio of less than 20, since, the complete biological conversion of C content will take long time. Hence, the correction factor of 0.5 is applied in the GHG emission calculation assuming that only 50 % of organic content is processed/converted under composting technology in the field. Finally around 9,198 t CO_2 will be estimated to release from the composting process and remaining C content will be applied to the C sink soil. Since the CO_2 emission from the biodegradable organic is considered as biogenic, the emission of 9,198 t CO_2 will not be considered as mitigation of GHG. But the composting of biodegradable organics will avoid the uncontrolled dumping of waste in open dumps, which is considered to be the major setback for developing country and continuous source of methane emission.

6.2 Scenario -2: Anaerobic Digestion

In this scenario, the anaerobic treatment of organic fraction is considered for mitigating GHG emissions from MSW. The organic conversion factor of 0.029 along with the correction factor of 0.7 (70% of organic fraction converted into biogas) is considered to calculate equivalent CO_2 emission. It is estimated that 4,445 t CO_2 will be released at the end of anaerobic degradation and the digestate can be applied to C sink soil with proper pretreatment. The CH_4 from the anaerobic digester i.e., around 21 times GWP than the produced CO_2, can be used as fuel for energy production that will intern reduce the consumption of fossil fuels. The digestate from the anaerobic reactor can be applied to C sink soils as manure after proper treatment.

6.3 Scenario -3: Recycling

In this scenario, it is considered that the valuable materials from the waste stream were source segregated and 100 % recycled to reduce the raw material consumption. The conversion factors considered for paper, plastics, glass and metal were 0.6, 0.3, 4 and 0.08, respectively. Cumulative of 47,012 t CO_2 can be reduced by recycling of materials by 100 % from the waste stream. Recycling of waste further reduces GHG emissions through lower energy demand for production (avoided fossil fuel) and by substitution of recycled feed stocks for virgin materials.

As presented in Table 5, the anaerobic digestion for organic waste and recycling of valuables together will reduce the emission of 56,210 t CO_2 equivalent into the atmosphere. On the other hand composting along with proper recycling strategy will reduce the emission of 51,457 t CO_2 equivalent.

Table 5. Scenario development for waste disposal practices and GHG mitigation

Waste Management options	Waste Quantity (kg)	Conversion Factor*	Correction factor	GHG emission (t CO_2)
Anaerobic Digestion (AD)	219,000 (Organic)	0.029	70 % (0.7)	9,198
Aerobic Composting		0.084	50 % (0.5)	4,445
Waste Recycling			100 % (1)	
Paper	21,900	0.6		13,140
Plastic	14,600	0.3		4,380
Glass	7,300	4.0		29,200
Metal	3,650	0.08		292
AD + Waste Recycling	266,450 (Organic + Recyclables)	-	-	56,210
Aerobic Composting + Recycling		-	-	51,457

*Note: * the conversion factor from –USEPA,2002 and IPCC, 2006*

From the scenario developed, the recycling of waste materials from the urban waste will mitigate more than 85 - 90 % of CO_2 emission by the process of recycling whereas the management of organic waste only contributing to 10 – 15 %. The recycling of waste for GHG mitigation is not under the scope of CDM, but still it should be considered by the developing countries as potential way to reduce their GHG emissions and intern that will reduce the global warming potential and climate change impacts.

7.0 Conclusion

In the race towards urbanization, many developing countries have witnessed the overflow of MSW and depletion of natural resources at an alarming rate. Unlike developed nations, final disposal of MSW in developing Asian countries is usually a matter of transporting the collected MSW to the nearest available space for disposal. Though the predicament of solid waste management is a regional one but it has its imprint on the global scenario. The main impact is that threat to global climate change through continuous emission of GHGs. An analysis of the various sectoral scopes under CDM registry, it is quite revealing that the municipal solid waste project has the largest potential GHG emission reduction more than the all the other projects put together from developed and developing countries. Often there is no single best option for MSW management; rather, there are multiple measures available to decisionmakers at the municipal level where several technologies may be collectively implemented to reduce GHG emissions and achieve public health, environmental protection and sustainable development objectives. Hence, the mitigation of GHG emissions from waste must be addressed in the context of integrated waste management. In the recent years, 3R (Reduce, Reuse, Recycle) initiatives have been promoted as the part of integrated waste management and resource consumption to reduce the GHG emissions from MSW. Hence, the appropriate integrated practices and perceptions will mitigate possible GHG emissions from waste sector in the developing Asian countries.

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