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Innovation in Solid Waste Management through Clean Development Mechanism in Developing Countries

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Abstract

Municipal Solid Waste (MSW) has emerged as a core issue, which needs to be tackled effectively in developing countries. The burgeoning population indicates increased MSW generation rates indirectly posing challenge to the final disposal. The final disposal is of critical importance as it largely impacts the environment and public health. A number of technologies are available for management and treatment of MSW but choosing the appropriate one depends on the nature of MSW and local conditions. Selecting the appropriate technology also helps to reduce the greenhouse gas (GHG) emissions, thereby mitigating climate change. The opportunity to reduce GHG emissions is offered by the Clean Development Mechanism (CDM). This paper reports how MSW can be managed effectively through CDM. 350 MSW projects have been registered under CDM across 56 developing countries. 51,292,568 metric tons of CO2e are estimated to be reduced through these 350 projects. China registered the maximum number of projects (102), followed by Brazil and Mexico registering 45 and 28 projects, respectively. Overall, 175 projects from China, Brazil, and Mexico account for about 51.63% of the total estimated emissions reductions. Asian region reported the highest number of projects (191) followed by South American region (123). 16 methodologies have been used as stand-alone as well as in combination for management of MSW through CDM and cover several areas through which the potential of MSW can be trapped. China and India used the maximum methodologies (9) followed by Brazil (7). Registering for CDM offers financial benefits as well as technology transfer and ultimately sustainable development. Source reduction and technology development to suit local needs are the areas where developing countries can focus. An integrated system for solid waste management is perfectly suitable for developing countries.

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1.0 Introduction

Millions of tons of solid waste are generated daily in the world needing collection, sorting, treatment, and final adequate destination. In developing countries, most of the solid waste generated is disposed in landfills and open air sites causing serious risks to public health and the environment (Lino and Ismail, 2013). Solid waste has emerged as a significant pressure on the environment, mostly due to the population growth, the changes in consumption habits and of the patterns of the communities' developments. Municipal Solid Waste (MSW) is the largest volume of residues produced worldwide; at the same time, the citizens' demands for an environmentally sound management of MSW have significantly increased during the last decades (Leme *et al*., 2014). Selecting the appropriate processing mode can not only reduce the impact of MSW on local environment, but also reduce greenhouse gas (GHG) emissions and save fossil fuels and mitigate of global climate warming (Wang *et al.*, 2015). In highly populated countries such as China and India and others such as Turkey, Mexico, and Brazil, almost 90% of the solid waste (whose major part is organic) considered as the principal source for producing methane is usually destined to landfills and dumps freely liberating huge quantities of carbon dioxide and methane to the atmosphere. Globally, landfills are the third largest anthropogenic source of methane, responsible for approximately 14% of estimated global methane emissions (Lino and Ismail, 2011).

Solid waste, including municipal waste and its management, is a major challenge for most cities and among the key contributors to climate change. GHG emissions can be reduced through recovery and recycling of resources from the MSW stream (King and Gutberlet, 2013). Due to initiatives such as the Clean Development Mechanism (CDM), reducing GHG emissions for a developing country can offer an important route to attracting investment in a variety of qualifying project areas, including waste management (Barton *et al.*, 2008). CDM can play a major role in managing MSW by motivating municipalities to go in for energy recovery projects, as it will bring in carbon credits, which makes the projects financially more attractive (Unnikrishnan and Singh, 2010).

2.0 Technologies used for MSW management

The technologies to treat MSW and further reduce emissions include landfilling with biogas recovery, composting of selected waste fractions, anaerobic digestion and thermal processes including incineration, gasification and pyrolysis. The applications of these technologies depend on local, regional, and national drivers for both waste management and GHG reduction (Lino and Ismail, 2013). Direct landfill and composting, due to their disadvantages, are gradually replaced by other technologies. In spite of the advantages derived from incineration of MSW, such as heat recovery, there are numerous disadvantages including production of large flue gas volumes, hazardous waste streams associated with the fly ash and a poor public image (Luo *et al.*, 2010). Vermicomposting of MSW was also suggested in some countries (Sim and Wu, 2010; Lim *et al.*, 2015). A more recent trend for the treatment of solid waste is the combination of incineration and energy recovery in the so called "waste-to-energy (WtE)" plants. This combination helps to solve two problems: one is the energy involved and the other is the environment (Byun *et al.*, 2011). Biomethanation or anaerobic digestion may be perceived as a potential alternative to treat MSW as it not only provides renewable source of energy but also utilizes recycling potential of degradable organic portion of solid waste generated by numerous activities (Ambulkar and Shekdar, 2004). MSW pyrolysis and gasification technology is an attractive way to treat MSW with less pollution emissions than other methods of treatment. Especially, it offers a potential of higher efficiency in energy production (Luo *et al.*, 2010).

3.0 Methodology

The project search tab for CDM on the United Nations Framework Convention on Climate Change (UNFCCC) website was used to shortlist registered CDM projects, which focussed on MSW treatment and management. These shortlisted projects mainly belonged to three CDM sectoral scopes: waste handling and disposal, agriculture, energy industries (Renewable/non- renewable sources) and transport. The details of the CDM projects *viz*. number of projects per country, the estimated emission reductions per country, the number of methodologies used per country were obtained and compiled.

4.0 Analysis of MSW - CDM projects

350 MSW treatment and management projects were shortlisted from the UNFCCC website until May 2015. These projects were spread across 56 developing countries. The resulting estimated emission reductions are 51,292,568 metric tons of CO_2e. The projects used 16 methodologies for the treatment and management of MSW.

The maximum number of projects were registered in China (102), followed by Brazil (45) and Mexico (28). 102 projects implemented in China resulted in an estimated reduction of 12,787,750 metric tons of CO_2e. 45 projects in Brazil and 28 projects in Mexico lead to an estimated reduction of 10,643,320 and 3,053,588 metric tonnes of CO_2e respectively. 2 projects each were registered in 14 countries and 1 project each was registered in 26 countries. Figure 1 depicts the number of projects and the corresponding emission reductions from these projects in each country.

The projects are geographically well-spread. The geographical distribution of projects in presented in Table 1. 22 countries from Asia reported 191 projects leading to an emission reduction of 23,202,256 metric tons of CO_2e. From Africa, 15 countries registered 25 projects leading to reduction of 4,243,329 metric tons of CO_2e. 2 projects were registered from 2 countries in the European region. These 2 projects resulted in an emission reduction of 40, 762 metric tons of CO_2e. 9 projects were registered from 8 countries in North American region while 123 projects were registered from 9 countries in the South American region. The emission reductions in the North American region are 1,261,113 metric tons of CO_2e while that in the South American region are 22,545,108 metric tons of CO_2e.

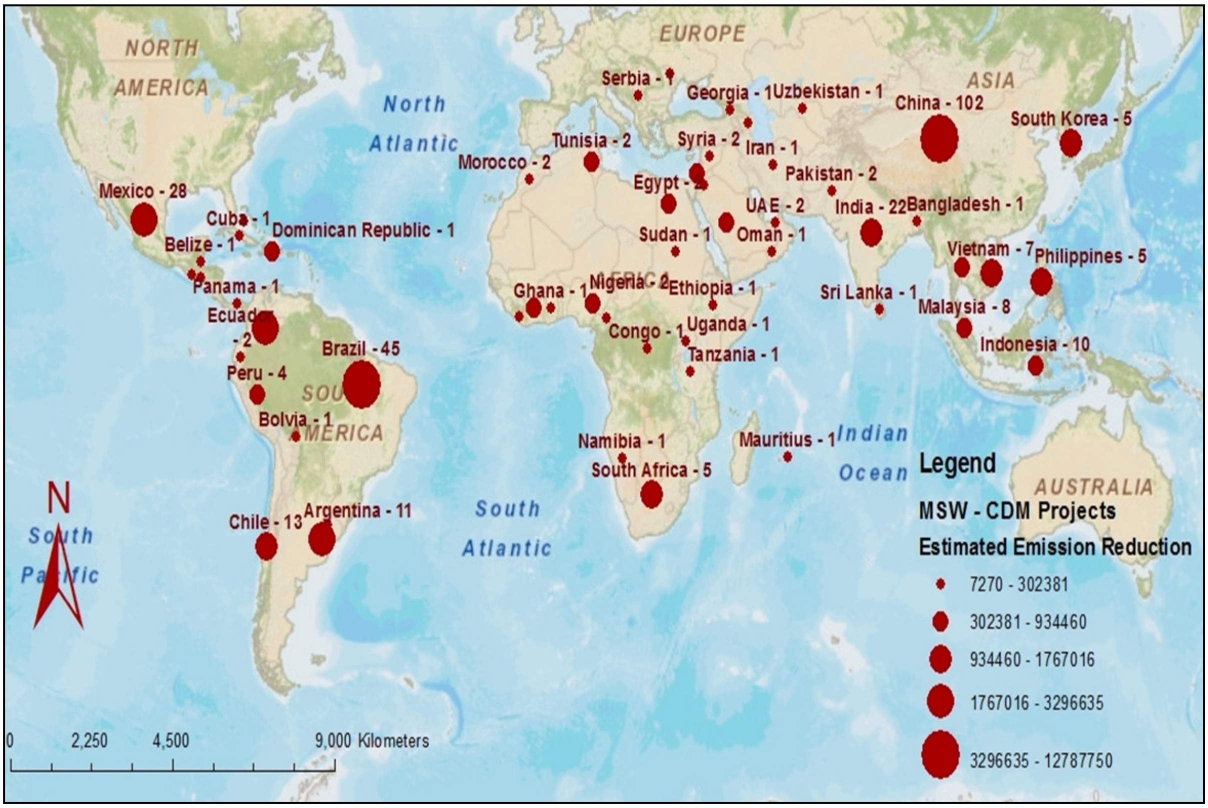

Fig. 1. Distribution of projects across countries

Table 1: Geographical distribution of projects

Region	Number of countries	Number of projects	Estimated Emission Reductions
Asia	22	191	23,202,256
Africa	15	25	4,243,329
Europe	2	2	40,762
North America	8	9	1,261,113
South America	9	123	22,545,108

16 methodologies have been used as stand-alone as well as in combination for management of MSW through CDM. 4 methodologies are used for large-scale projects, 9 methodologies are used for small-scale projects, and 3 methodologies referred as consolidated methodologies (having features of methodologies used for large-scale and small-scale projects) are used. The number of methodologies used in a country is presented in Figure 2.

Of the 16 methodologies used all over the world for the management of MSW, China and India used the maximum methodologies (9), followed by Brazil that used 7. 2 methodologies were used in combination by 26 countries while 1 methodology was used by 27 countries.

The methodologies used for large-scale projects are landfill gas capture and flaring where the baseline is established by a public concession contract (AM0002), simplified financial analysis for landfill gas capture projects (AM0003), landfill gas recovery with electricity generation and no capture or destruction of methane in the baseline scenario (AM0011) and alternative waste treatment processes (AM0025).

The small-scale project methodologies used are thermal energy production with or without electricity (AMS I. C.), grid connected renewable electricity generation (AMS I. D.), switch from non-renewable biomass for thermal applications by the user (AMS I. E.), renewable electricity generation for captive use and mini-grid (AMS I. F.), avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment (AMS III. E.), avoidance of methane emissions through composting (AMS III. F.), landfill methane recovery (AMS III. G.), methane recovery through controlled anaerobic digestion (AMS III. AO.), and introduction of bio-CNG in transportation applications (AMS III. AQ.).
The consolidated methodologies used are flaring or use of landfill gas (ACM0001), grid-connected electricity generation from renewable sources (ACM0002) and alternative waste treatment processes (ACM0022). AM0002, AM0003, and AM0011 methodologies are not active and are replaced by ACM0001. Table 2 shows the mitigation opportunities that are offered by the methodologies used.

Table 2: Mitigation opportunities offered by methodologies used

METHODOLOGY	MITIGATION OPPORTUNITIES
ACM0001	Destruction of methane emissions and displacement of a more-GHG-intensive service

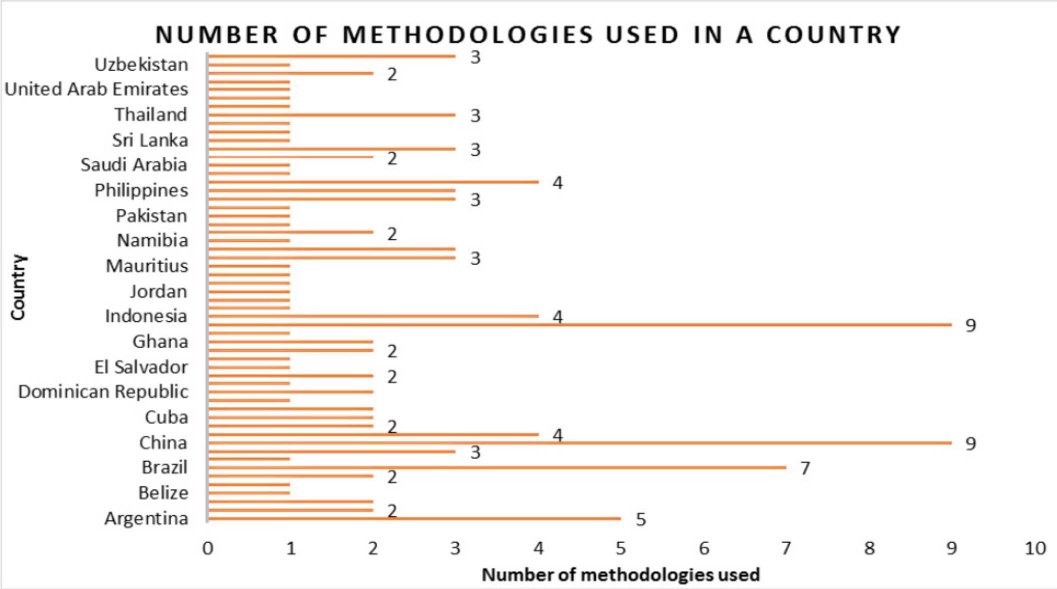

Fig. 2. Number of methodologies used in a country

Table 3: Mitigation opportunities offered by methodologies used

METHODOLOGY	MITIGATION OPPORTUNITIES
ACM0002	Displacement of electricity that would be provided to the grid by more-GHG-intensive means
ACM0022	Methane emissions due to anaerobic decay of organic waste are avoided by alternative waste treatment processes. Organic waste is used as renewable energy source
AM0002	Replaced by ACM0001
AM0003	Replaced by ACM0001
AM0011	Replaced by ACM0001
AM0025	Methane emissions due to anaerobic decay of organic waste are avoided by alternative waste treatment processes
AMS - I. C.	Displacement of more-GHG-intensive thermal energy production, displacement of more-GHG-intensive heat and power generation
AMS - I. D.	Displacement of electricity that would be provided to the grid by more-GHG-intensive means
AMS - I. E.	Displacement of more-GHG-intensive, non-renewable biomass-fuelled applications by introducing renewable energy technologies
AMS - I. F.	Displacement of electricity that would be provided to the user(s) by more-GHG intensive means
AMS - III E.	Avoidance of methane emissions due to prevention of anaerobic decay of biomass in waste. Use of biomass in waste as energy source
AMS - III F.	Avoidance of GHG emissions by alternative treatment process
AMS - III G.	Destruction of methane and displacement of more-GHG-intensive energy generation
AMS – III. AO.	Methane formation avoidance
AMS – III. AQ.	Displacement of more-GHG-intensive fossil fuel for combustion in vehicles

5.0 Results and Discussion

Municipal solid waste has emerged as a core issue to be tackled effectively in developing countries. Most of the developing countries are struggling for the management of MSW. The ineffective management of MSW can be traced to barriers like partial or no segregation of waste that increase the landfill load, lack for indigenous technology, inappropriate transportation of waste, lack of secondary storage space, improper disposal techniques, and scarce technical and managerial inputs for proper handling and treatment of waste, etc. Few countries underestimate the potential of MSW to generate products that can produce energy and thus, are a bit apprehensive to establish WtE projects. Regulation for management of MSW is present in most countries but effective implementation is a drawback.

CDM offers an opportunity for turning to new technologies, generating revenue for the project proponent as well as the country and leading to sustainable development. As on May 2015, 56 countries have cashed upon the CDM opportunity. These countries registered 350 projects through which 51,292,568 metric tons of CO_2e emission reductions are estimated. Of the 350 projects, China registered the highest (102), followed by Brazil (45) and Mexico (28). Overall, these 175 projects from China, Brazil, and Mexico account for about 51.63% of the total estimated emissions reductions. The elements that are central to the implementation of large number of CDM projects in China and Brazil are explained.

China is grappling with the problem of MSW and has emerged as a serious issue, which pose a challenge with regard to environmental quality and sustainable development (Dai *et al.*, 2011). The Law of the People's Republic of China on the Prevention of Environmental Pollution Caused by Solid Waste is the main legislation specifically pertaining to solid waste management and pollution control (Chen *et al.*, 2010). Zhang *et al.* (2011) found that the main treatment methods used in China are landfill, composting, burning, and anaerobic digestion, all of which produce greenhouse gas such as methane and carbon dioxide during processing.

The development trend of MSW disposal shows that the capability of landfill disposal has steadily risen while composting has reduced year by year because of the risk of weak demand for compost, which is influenced by both economic and psychological factors. As for incineration, the disposal capacity dramatically increased (ten fold over ten years) and is still undergoing staggering growth (Chen *et al.*, 2010; Zheng *et al*., 2014). To overcome the problems faced, China has strengthen the MSW management by including it as a priority area of reducing GHG emissions by compiling "China's National Climate Change Programme" in 2007. Thus, the important role of MSW in global GHG emission reduction has been attracted much attention leading to registration of CDM projects (Wang *et al.*, 2015). This could one factor for China to register the highest number of projects in this area. Also, to promote the effective management of MSW, China is targeting cities that want to acquire the title of "environmental protection model cities" or "eco-cities." However, one of the standards for obtaining these titles is MSW safe disposal rates must be at least 85% and 90%. Therefore, waste minimisation and safe disposal are usually included in action plans of these cities, having positive influence on MSW disposal industry (Zheng *et al*., 2014).

About 98% of MSW is deposited in landfills and dumping sites in Brazil (Lino and Ismail, 2013). Almost 64% of urban solid waste collected is disposed in sanitary landfills, 16% in controlled landfills, 18% in open sky dumps, 2% is recycled and a negligible fraction is incinerated (Agostinho *et al*., 2013). In Brazil, landfilling seems to be a good solution for waste treatment, to the extent that more economical and environmentally adequate solutions are not possible to implement. However, it is not easy to convince the population to accept the construction of a nearby landfill (Loureiro *et al*., 2013). The lack of space for new landfills in metropolitan areas, is forcing the cities to rethink the use of WtE options (Leme *et al*., 2014). According to the Second Brazilian Inventory of Greenhouse Gas Emissions, solid waste was responsible for emitting 1.2% of total emissions in Brazil. In terms of methane, Brazil accounts for 6.1% of total emissions in the country.

The "National Policy on Solid Waste" released in 2010 was the basis to develop the steps in planning by the federal government to reduce GHG emissions in Brazil (Loureiro *et al*., 2013). The Law provides the principles, objectives, and instruments for the management of solid waste, including the responsibilities of producers and the local governments, the guide to the management of hazardous waste and the economic instruments to be applied

(Leme *et al*., 2014). Also, Brazil's National Energy Plan 2030 states the energetic use of MSW in an alternative (renewable and non-conventional) energy source (Maier and Oliveira, 2014). This is a key factor for Brazil registering several landfill energy projects whose profitability is increasing in the last years (Leme *et al*., 2014).
The methodologies used for MSW management cover several areas through which the potential of MSW can be trapped. It covers trapping of landfill gas and its flaring, composting in aerobic conditions, gasification to produce syngas, anaerobic digestion with biogas collection, production of refuse-derived fuel, biomass-based cogeneration, production of biogenic compressed natural gas to be used in transportation applications. These processes help in generating useful by-products, ultimately leading to the reduction of methane, carbon dioxide, and nitrous oxide.

Asian region reports the highest number of projects (191). This could be attributed to the large size of the continent and number of countries present in the region. Asia comprises of China and India, which are the major third world nations and are in the top spot in terms of the number of registered CDM projects. 45% of the total estimated emission reductions are contributed from the Asian region. In Africa, 25 projects were registered from 15 countries. African continent comprises of about 33 least developed countries making it less favourable to implement CDM projects. 9 countries in South American continent registered 123 projects. The reason for high number of projects could be a strong regulatory framework for management of MSW and public awareness. Most of the countries in the North American and European regions are developed; hence, the scope of implementing CDM projects in developing countries of these continents is not much.

6.0 Conclusions

Developing countries should largely utilise a resource like MSW. Regions where MSW is generated in large quantities should go in for WtE projects, which helps in generating useful by-products and thus protects the environment. Registering for CDM offers financial benefits as well as technology transfer, which is essential for development of third world countries. Governments have prioritised MSW management in their policies and view CDM as a mechanism to minimise the emissions from this sector, contributing to climate change mitigation.

7.0 Recommendations

To reduce the volume of MSW that reaches the landfill, source reduction should be prioritized. Mass media can play a significant role in urging the public to segregate the waste. Labelling the products as recyclable or non-recyclable by manufacturing organizations can help in better understanding of the public. Treatment technologies for MSW should be developed based on the type of waste generated and suiting the local needs. For developing countries, an integrated system for solid waste management as proposed by Shekdar (2009) suits perfectly. The system comprises of policy and legal framework, institutional arrangements, use of appropriate technology, operations management, financial management, public participation and awareness and action plan for improvement. Stakeholders need to realise their role and act accordingly.

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