IGES Policy Report

Practical Guide for Improved Organic Waste Management:

Climate benefits through the 3Rs in developing Asian countries

Sustainable Consumption and Production Group, Institute for Global Environmental Strategies

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Practical Guide for Improved Organic Waste Management: Climate benefits through the 3Rs in developing Asian countries

The Institute for Global Environmental Strategies (IGES) is an international research institute conducting practical and innovative research for realising sustainable development in the Asia-Pacific region.

The Sustainable Consumption and Production (SCP) Group aims to contribute towards realising sustainable patterns of consumption and production in Asia. Special attention is given to the flows of materials through society, activities by consumers and producers, and the environmental impacts associated with material flows. The research of the SCP group is based on life-cycle thinking and explores how actors, institutions and policies can influence society's utilisation of materials, to achieve practical policy results and make it more sustainable.

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Foreword

Historically, people in developing Asian countries used some of their organic waste as feed for domestic animals and left the remainder to degrade naturally, which returned nutrients to the soil. However, these practices changed with the onset of industrialisation and the accompanying changes in lifestyles. To meet the labour requirements of the new industries, people moved from rural to urban areas, resulting in larger and more densely populated urban settlements. Contemporary practices of dealing with organic waste gave way to less environmentally friendly alternatives, such as the disposal of waste along roadsides, riverbanks and empty spaces within the urban areas. This waste is a hazard to human health. It provides a source of food for disease carrying rodents and insects and pollutes waterways and soil. Further, it releases foul odours and creates an eyesore.

Local governments are responsible for providing services for waste collection, transportation and disposal. Due to budget and human resource constraints that most developing Asian countries face, they commonly employ open dumping as the means of disposal. Conventional approaches to landfill are not sustainable. Many landfills have a life of less than ten years. Local governments are increasingly finding it difficult to locate new landfill sites because of rising land prices and local resistance. The land that can be used for the disposal of waste is gradually becoming distant from the towns, making waste transportation costly.

In addition to the aforementioned problems, open dumping and landfill of organic waste contributes to climate change. Greenhouse gas emissions from the waste sector in Asia are increasing for a number of reasons. First, the total volume of waste disposed in landfills is increasing due to population growth and public programmes to increase waste collection. Second, sanitary landfills are increasingly favoured over other landfill alternatives; they produce large amounts of methane, a highly potent greenhouse gas. Third, some countries are seeking a financial dividend from landfills by taking advantage of the Clean Development Mechanism (CDM) of the Kyoto Protocol.

In this policy report the authors have compiled and analysed the most recent data on waste generation and the national policies related with waste management and climate change in ten countries in Asia. The study found that many countries in the region are now paying more attention to solid waste management from the perspective of climate change. Some countries are seeking to improve their waste management by employing the 3Rs (reduce, reuse, recycle) as a climate change mitigation measure.

While the national 3R policies are encouraging, implementation remains problematic. The authors have sought to deliver feasible solutions to promote the 3R practices for organic waste management. The report assesses examples of both successes and failures in the application of the 3R practices and extracts lessons for local governments and others attempting to implement the 3Rs. In addition, hierarchies for organic waste treatment technology are developed to help local governments and policymakers select the options best suited to local conditions, using a multi-criteria approach and reflecting resource efficiency concerns.

I congratulate the authors for completing this challenging assignment and believe that the findings will have value for policymakers and practitioners responsible for organic waste management in developing Asian countries.

Hideyuki Mori
President
Institute for Global Environmental Strategies

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We welcome feedback and comments on the report, which can be sent to the address below. The authors are solely responsible for any errors of fact or omissions in the report.

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Executive Summary

This policy report assesses GHG emissions trends in ten developing Asian countries by comparing emissions in 1994, 2000 and the present. The emissions estimates for 1994 and 2000 were obtained from the first and second national communications. The present GHG emissions are estimated by the authors using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories.

The national policies on climate change were reviewed to identify how each country views the waste sector from the perspective of climate change mitigation. The report also identified linkages between the 3Rs (reduce, reuse, recycle) and climate benefits by applying the lifecycle approach. The study found that the 3Rs could directly reduce GHG emissions from the waste sector and, through initiatives in the waste sector, contribute to reduction in other sectors.

The study analysed feasible solutions to promote the 3R practices for organic waste management and extracted lessons from examples of both successes and failures in the application of the 3R practices. In addition, hierarchies for organic waste treatment technology were developed to help local governments and policymakers select the most suitable options based on local conditions, a multi-criteria approach and resource efficiency concerns.

GHG emissions from the waste sector are likely to increase rapidly in proportion to the volume of waste dumped into landfills due to economic growth, population increase and improved waste management services in most Asian countries.

Until recently, greenhouse gas (GHG) emissions from the waste sector received little attention from most national governments in developing Asian countries due partly to their low share of the national GHG inventories (1.3% on average in 1994). However, this situation is changing. Methane is the most significant GHG emitted from the waste sector. It is generated during the anaerobic degradation of organic waste in landfills. Organic waste makes up the largest fraction of the waste stream in developing Asian countries. Our review found that municipal solid waste in the region comprised 40-74% food waste and 3-25% paper waste. Reduction of organic waste disposed of in landfills could, therefore, substantially decrease methane emissions from the waste sector.

Many countries in the region are now paying more attention to climate change mitigation activities in the waste sector. China, India, Indonesia, Thailand, the Philippines, and Bangladesh all include *improved waste management in their national climate change action plans. Amongst these countries, China, India, Indonesia and Thailand promote the 3Rs (reduce, reuse, recycle) as a GHG mitigation measure. The 3Rs for the waste sector aims to reduce resource consumption and waste generation, as well as increase resource recovery for further resource productivity, soil amendment and energy generation. In addition, the 3Rs could indirectly reduce GHG emissions from other sectors, such as energy, industry, and land use change and forestry.*

Within the 3R hierarchy, "reduce" is generally considered better than "reuse" and "recycle". Reduce can mean more sustainable exploitation of natural resources, lowering environment impacts throughout the product lifecycle. Reuse can extend the lifetime of a product and decrease the demand for additional production. Recycle can reduce the demand for extraction of virgin resources, though it requires higher energy and resource inputs compared to reuse and has the potential to generate negative environmental impacts. Still, even if recycle generates some GHG emissions, the net balance is in most cases lower than the conventional landfill practices.

For the recycling of organic waste, anaerobic digestion has advantages over composting because it can generate both soil amendment material and energy. Under well-managed conditions, anaerobic digestion could result in lower GHG emissions than composting. However, composting is cheaper and simpler than anaerobic digestion; therefore, composting is better suited to developing Asian countries where human resources and budgets are major constraints.

Waste separation at source is a prerequisite for the successful implementation of 'reuse' and 'recycle'. At the household level, waste separation could enable families to recover valuable materials such as metals and plastics as well as start household composting and anaerobic digestion. Waste separation is most effective when it is applied to large waste producing facilities such as restaurants, hotels and supermarkets.

Once organic waste separation at source is introduced, the waste should be divided into four sub-categories: food, paper, wood products, and grass (including plant residue and garden waste). Local governments may decide to use fewer categories, depending on handling capacity, quantity of waste and applicable treatment technology. The report recommends hierarchies for the separated organic waste that reflect the characteristics and potential use of each waste type. The hierarchies are based on three variables: resource efficiency, environmental impacts and climate benefits. Local governments may choose not to practice all the options under each hierarchy, but they can at least start with a few practices from the hierarchy that are considered appropriate for their local conditions.

For all types of organic waste, avoiding wasteful consumption is at the top of the hierarchy, followed by the reuse of products until they can no longer function properly, and then followed by recycling. Organic waste unsuited for recycling should be transferred to a resource recovery system and disposal facility. In practice, not all organic waste can be separated into good quality types and management options will need to reflect waste quality. Integration of options under the hierarchies is recommended to maximise resource efficiency and minimise environmental impacts.

In many cities, waste separation at source may not be conducted for a variety of reasons. Separation of mixed waste at the recycling facility (e.g., composting, anaerobic digestion) should be practiced. If no such facility exists, the unsorted waste should be pre-treated prior to landfill (to reduce the volume of waste and avoid methane generation under anaerobic conditions) or incinerated (to reduce energy requirements for burning). The pre-treatment process is generally called mechanical biological treatment (MBT) as it combines mechanical processes (e.g., waste segregation, shredding, and homogenisation) and biological processes (e.g., composting and anaerobic digestion). The pre-treated waste is more stable than fresh waste and has potential to be utilised for energy (e.g., refuse derived fuel (RDF)).

The direct disposal of fresh waste by landfill or incineration should be avoided as this impacts resource efficiency and contaminates the environment. If sanitary landfill of fresh waste is the only disposal method that local government can afford, a landfill gas management system should be installed or an aerobic landfill system should be employed.

Incineration of unsorted organic waste without pre-treatment is costly because the waste has high moisture content and therefore requires high energy input. If incineration is considered unavoidable, dioxin control and thermal recovery systems should be installed.

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1.1 Background

Climate change is recognised as a serious problem which can ultimately threaten human survival. There is now a widely shared consensus that radical reductions in greenhouse gas (GHG) emissions from human activities are urgently needed in order to prevent the disastrous consequences of manmade climate change. These mitigation efforts have to be based on life-cycle thinking in order to be effective. This means that they need to cover the upstream stages of natural resource extraction and industrial production as well as the downstream stages of consumption and end-of-life treatment. In addition, as will be further discussed in this report, efforts need to address the linkages between different life-cycle stages; how changes at one stage of the life-cycle of a product or material can increase or reduce the emissions of GHG at other stages.

GHG emissions from the waste sector are small compared to those from the energy and agricultural sectors. However, the GHG emissions from the waste sector are increasing rapidly due to the escalating waste generation seen in most countries. End-of-pipe waste management, based mainly on landfill disposal and in some cases incineration, can hardly be regarded as sustainable due to environmental impacts, GHG emissions and loss of resources.

The main objectives of this report are: (i) to show the magnitude of GHG emissions from municipal solid waste management and of the climate benefits of the 3Rs (reduce, reuse, recycle) for organic waste, and (ii) to evaluate technological options for organic waste management suitable for developing Asian countries and their potential contribution to GHG emission reduction.

Improvements to waste management are usually undertaken for other reasons than climate protection. Untreated waste is a public health issue and simple dumping can easily harm the environment. Given that these concerns are typically considered the main benefits of waste management improvement, climate benefits are sometimes referred to as "co-benefits." The evaluation presented in this report emphasises the potential for GHG emission reductions, but it includes a range of other benefits that are more likely to appeal to local stakeholders, such as cost saving, job creation, and energy generation.

1.2 Outline of the report

This report consists of four main sections. In the first part, it presents data from the national GHG inventories of a number of developing Asian countries, identifies the main sources of GHG emissions from the waste sector, and analyses the national climate strategies of the studied countries. The review of national climate strategies looks at whether and how these documents include actions aimed at reducing emissions from waste treatment and efforts to promote the 3Rs.

Secondly, the report presents data on the potential climate benefits of the 3Rs. It shows that improvements in waste management can reduce GHG emissions in two different ways: by reducing direct emissions from the waste sector and by influencing emissions reduction from other sectors. A key message here is that these indirect climate benefits are likely to be substantial but often overlooked.

Thirdly, this report explains how the 3Rs can be applied to manage organic waste. Organic waste is the largest component of municipal solid waste in developing countries and this waste stream is responsible for the majority of direct GHG emissions from the waste sector. Several technologies applied in various cities of developing Asia are presented, together with key characteristics and lessons learned. Finally, the report introduces management hierarchies indicating the most preferable treatment technologies for food, paper, wood and garden waste taking climate co-benefits, resource efficiency and energy input into consideration.

1.3 Expected outcome

We believe that proper organic waste management, providing local benefits as well as global ones in the form of climate change mitigation, is fully achievable in developing countries. However, local officials often lack knowledge on the linkages between solid waste management and climate change. We hope that this report can, to some extent, contribute to improving this situation.

We expect that the implementation of the 3Rs for sustainable organic waste management would increase once local stakeholders become fully aware of the climate co-benefits of this practice, including direct as well as indirect benefits. We also believe that the 3Rs can be successfully implemented in developing Asian countries if the relevant stakeholders consider local contexts and mainstream the 3Rs. As a matter of fact, various attempts have been made in many cities in the region. If useful lessons learned through these cases are fully shared among key local stakeholders, the 3Rs will be truly mainstreamed in handling organic waste in many cities in Asia. Hopefully, this policy report can help local governments in the selection and implementation of suitable technologies for organic waste management in their cities. It would also be valuable to other policymakers, local authorities and NGOs dealing with climate change mitigation and waste management, who should pay more attention to the 3Rs.

II
Greenhouse gas emissions and the waste sector

II Greenhouse gas emissions and the waste sector

2.1 National greenhouse gas (GHG) inventories and the waste sector

2.1.1 Past emissions

This section summarises the national anthropogenic GHG inventories of developing Asian countries, which were reported to the United Nations Framework Convention on Climate Change (UNFCCC) in the initial national communications (Table 1). The studied countries are China, India, Indonesia, Thailand, Viet Nam, Malaysia, the Philippines, Bangladesh, Cambodia and Laos.

The reported GHG emissions from the waste sector of developing Asian countries in the initial national communications were based on the estimated methane gas emissions from organic waste fermentation under anaerobic landfill conditions, in accordance with the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National

Table 1 National greenhouse gas (GHG) inventories of studied countries in 1994

Country	National GHG inventories in 1994 ($MtCO_2eq.$)*	GHG emissions from the waste sector in 1994 ($MtCO_2eq.$)		Sources
		MSW	% MSW to total emissions	
China	4,081	42.6	1.04	Chinese Government, 2004
India	1,252	12.2	0.97	MoEF, 2004
Indonesia	883	8.44**	0.96	MENLH, 1999
Thailand	325	0.411	0.13	MSTE, 2000
Viet Nam	154	1.39	0.90	MONRE, 2003
Malaysia	144	21.9	15.2	MOSTE, 2000
Philippines	169	4.25	2.51	IACCC, 1999
Bangladesh	76.3	1.31	1.72	MoEF, 2002
Cambodia	59.7	0.124	0.21	MOE, 2002
Laos***	24.2	0.240	0.99	STEA, 2000

* Sinks are not included.
** There is no indication of the GHG emissions solely from the municipal solid waste in Indonesia's initial national communication to the UNFCCC.
*** GHG inventory in 1990.

Greenhouse Gas Inventories (IPCC, 1996). It was evaluated that emissions from municipal solid waste (MSW) of these countries in 1994 were very low compared to the total emissions (0.13 – 2.51%), except for Malaysia (15.2%). GHG emissions in developing Asian countries in 1994 were mainly from the energy and agriculture sectors. As such, GHG emissions from the waste sector received little attention from some governments.

2.1.2 Present emissions

Amongst the studied countries, Viet Nam and Indonesia submitted their second national communications that present the 2000 national GHG inventories (as of 10 March 2011). Only the national communication from Viet Nam is available to the public (via the UNFCCC website).

GHG emissions from municipal solid waste in Viet Nam increased from 1.39 $MtCO_2eq$ in 1994 to 5.60 $MtCO_2eq$ in 2000; a four-fold increase. The contribution from the solid waste to the national inventory has also increased from 0.9% in 1994 to 3.7% in 2000 (MONRE, 2010).

It is predictable that present national GHG inventories of the other studied countries are also substantially increased due to the following reasons:

i) An increase in waste generation due to increase in population, economic growth and change of consumption patterns and lifestyles in this region. For instance, waste generation in Thailand increased from 29,540 ton/day in 1994 to 40,332 ton/day in 2007 (PCD, 2007). Similar trends are also found in other developing Asian countries, especially China where the rate of increase of waste generation was nearly 10% per year (Suocheng et al., 2001). Later on, it was reported that waste generation in China was already almost twice that of 1994 (Yamada, 2007). Additionally, it is predicted that municipal solid waste and urban food waste generation from 2005 to 2025 will increase by 51% and 44%, respectively. The largest increase will happen in Asia due to economic development. Such changes will lead to an increase of world methane emissions from 34 (782 $MtCO_2eq$) to 48 Gkg (1,104 $MtCO_2eq$), with landfill contributing 8-10% of global anthropogenic emissions (Adhikari et al., 2006).

ii) An increase in the rate of waste collection for disposal in landfills. The potential for methane emissions from organic waste increases when the waste is disposed of in a deeper landfill. Methane gas can be recovered for energy use, but most of the landfill sites in developing Asian countries are not equipped with methane gas collection systems. The most likely case is that methane gas from landfills is released to the atmosphere. In some cases, landfill gas collection systems are installed for methane gas recovering or flaring. However, Bogner et al. reviewed that the methane gas collection efficiency varies from as low as 20% to higher than 90% (Bogner et al., 2007).

iii) The inclusion of carbon dioxide emissions from the burning of waste containing fossil carbon such as plastics, according to the 2006 IPCC

Guidelines for National Greenhouse Gas Inventories[1]. As shown in Table 2, plastic waste shares 4-17% of waste composition in the studied countries. Often, this plastic waste is treated by open burning.

2.2 Waste composition and main sources of greenhouse gas emissions from the waste sector

In order to identify the components of municipal solid waste that are the main sources of GHG emissions from the waste sector, we reviewed the available data on waste generation and waste composition from various sources, [See: Table 2]. We excluded "suspicious" data, i.e., data that did not seem to reflect the level of economic development of the country. Overall, data at the national level in developing Asian countries is poor as it is based on the compilation of reports of local authorities, which in many cases include inaccurate or outdated information. National data is weakest in the least developed countries where it is mostly extrapolated from the waste composition and generation of a few big cities.

From the review of waste data, we found that the largest component of waste in

Table 2 Waste generation and composition in developing Asian countries

Country	Solid waste generation (million ton/yr)	Waste generation per urban capita (kg/day)	Waste composition (%)					
			Food	Paper	Plastic	Metal	Glass	Others
China[a]	120	1.15	50	15	10	3	3	19
India[b]	42[c]	0.40	40	5	4	1	2	48
Indonesia[d]	23[e]	0.76	74	10	8	2	2	4
Thailand[f]	15	1.10[d]	64	8	17	2	3	6
Viet Nam[g]	13	0.40	49	2	16	6	7	20
Philippines[h]	11	0.50	33	19	17	5	3	23
Malaysia[i]	9	0.90[j]	49	17	10	2	4	18
Bangladesh[k]	6	0.50	70	4	5	0.1	0.3	20.6
Cambodia[l]	0.5[m]	0.34	66	3	14	1	1	15
Laos[n]	1.2[o]	0.75	60	15			15	10

Remark: [a]Rissanen and Naarajärvi, 2004; [b]Toxic Link, 2002; [c]Kurian, 2007; [d]Zurbrügg, 2002; [e]Balifokus et al., 2006; [f]PCD, 2009; [g]World Bank, 2004; [h]Antonio, 2008; [i]JICA, 2006; [j]Lee and Hanipiah, 2009; [k]DOE et al., 2004; [l]Maclaren, 2005; [m]Sokha, 2009, [n]Keodalavong, 2007, [o]Borongan and Okumura, 2010.

[1] For the national inventories in 1994, GHG emissions from the waste sector were estimated based on potential methane emissions from landfill of organic waste only. However, it should be noted that the 2006 IPCC Guidelines were not yet adopted, and although they are more representative, estimates for emissions from burning of plastic based on these guidelines are done on a voluntary basis.

developing Asian countries is organic (33-74% food and 2-19% paper) and plastic (4-17%) waste. Organic waste is the main source of methane gas emissions through open dumping and landfill disposal practices. Plastic waste that contains fossil carbon is the main source of carbon dioxide emissions from burning.

In this study, we will focus on organic waste management as it is still considered the largest component of waste and largest source of GHG emissions from the waste sector in the studied countries. Proper management of organic waste can reduce methane emissions from the waste sector[2] and enhance resource recovery efficiency of other types of wastes.

2.3 Greenhouse gas emissions reduction through the 3Rs and organic waste

As aforementioned, waste generation in developing countries has increased continuously due to economic growth, and GHG emissions from the waste sector are predicted to increase substantially, correlating with increasing waste generation, improved waste collection coverage and increased use of landfills. Many local governments consider improved landfills as the priority option, but in most cases they do not have the resources to invest in high standard sanitary landfills equipped with leachate control and gas recovery systems. In addition, in Asian countries there is growing opposition from local residents to the construction of new landfills and incineration sites due to fears of pollution and health risks. Low availability of land suitable for landfill construction and competition with other uses further add to the problems related with landfill construction.

It is expected that the 3R approach can reduce the amounts of waste to be treated and thereby also prevent the conflicts that commonly occur between local authorities and residents over the siting of treatment facilities. However, the climate benefit of the 3Rs is unclear especially to local governments who expected to implement the 3Rs for sustainable waste management and climate change mitigation. Therefore, this section aims to investigate how the 3Rs can contribute to GHG emission reduction.

When discussing waste and climate change it is important to adopt a life-cycle perspective. Materials that become waste have already caused GHG emissions at earlier life-cycle stages, including the extraction of natural resources, the transportation of raw materials, the industrial processes and distribution. These emissions which have been "invested" into the material in order to give it certain properties and to move it to a certain location will be lost if the material is buried in a landfill. If reuse and recycle can reduce the need for new resources, these activities can also reduce the GHG emissions associated with the life-cycle of the materials in question.

2 For the second national communication under the UNFCCC, the IPCC has suggested using the global warming potential for 100 years of methane as 21 times stronger than carbon dioxide. However, the IPCC Fourth Assessment Report indicated that methane has a climate impact that is 25 times stronger than carbon dioxide (Forster et al., 2007).

Essentially, the 3R approach is based on the idea of using resources efficiently before their final disposal. Hence, appropriate waste management through the 3Rs can reduce GHG emissions from the entire life-cycle of resources. Fig. 1 demonstrates the climate benefits that can be achieved through the 3Rs and appropriate disposal practices.

During the production stage, the 3Rs aim to reduce the extraction of natural resources, reduce resource input for production without sacrificing product quality, and recycle resources for producing new products. This reduces emissions from land use change and from the forestry, agriculture, mining and industry sectors. During the consumption stage, the 3Rs aims to reduce the use of natural resources by reducing consumption and reusing resources - through refilling, repairing, and

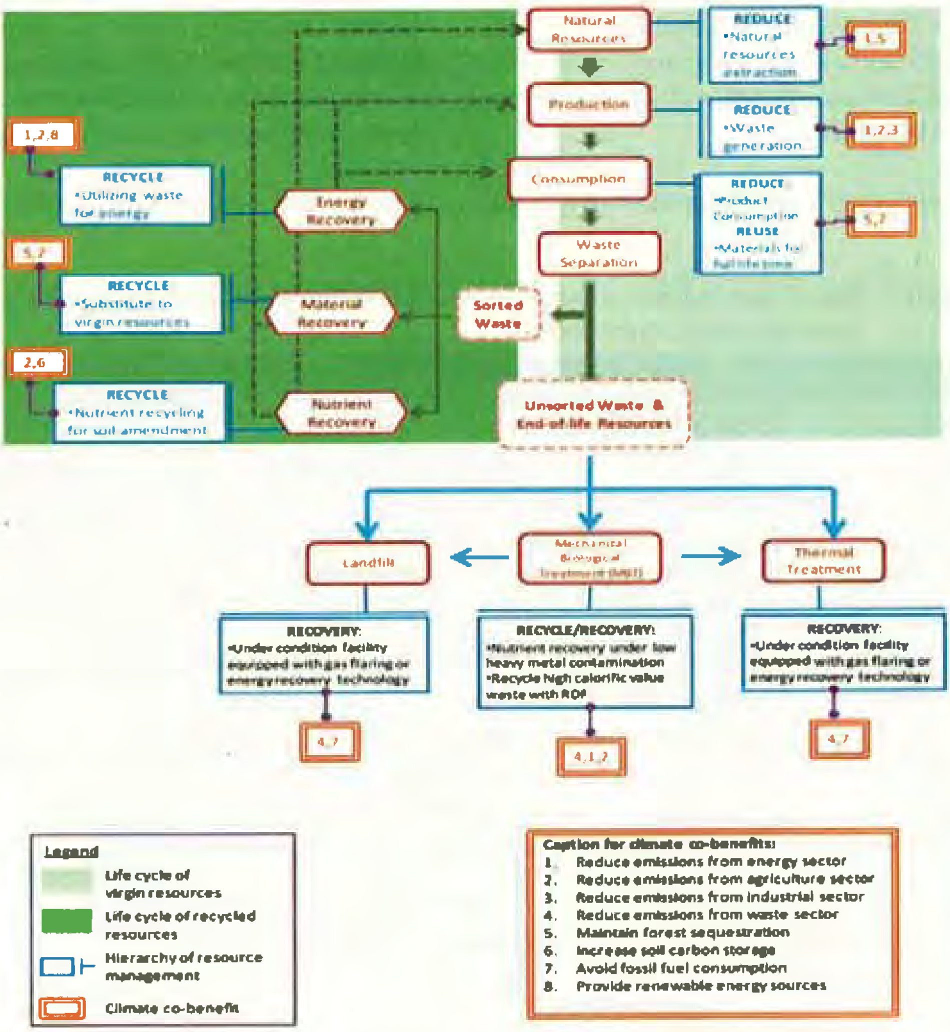

Fig. 1 3R practices at different life-cycle stages and their climate co-benefits refurnishing - thus reducing emissions from the land use change and forestry and the energy sectors.

During the waste management stage, once separation at source is practiced, valuable waste can be recovered for energy, material and nutrient supply which could contribute to households, industry and agriculture. The recycling or recovery processes can cause GHG emissions, but in most cases the emissions are lower than when virgin materials and the landfill of organic waste are used. For these recycling processes, GHG emissions from energy, agriculture, and land use change and forestry sectors can be reduced.

However, if separation at source is not practiced, there are other technical solutions available for recovering valuable nutrients and energy from organic waste, including mechanical biological treatment, sanitary landfill equipped with gas recovery and thermal recovery from incineration. These high investment solutions can reduce GHG emissions to some extent, but they have disadvantages in resource circulation efficiency. Therefore, we recommend practicing waste separation at source before these end-of-pipe solutions.

The 3Rs for organic waste management can reduce the direct GHG emissions from the waste sector by reducing the amount of organic waste disposed in landfills (Table 3).

However, when regarded from a life-cycle

Table 3 Direct and indirect climate co-benefits of 3R application for organic waste management in main sectors

Sectors	Climate benefits, direct and indirect
Waste	• Reduced methane emissions from landfill. • Once organic waste is separated, it could enhance separation of plastic waste for recycle (Schouw et al., 2002). Therefore, it could reduce carbon dioxide emissions from burning or incineration of plastic waste.
Energy and transport	• Reduced emissions from waste transportation and treatment, especially when community based and decentralised organic waste management is implemented. • Reduced emissions from energy use for production and distribution of products when reduced over consumption. • Reduced energy use for agriculture when compost is applied for soil improvement. • Reduced energy use for transportation and processing of agricultural and agro-industrial products when reduced over consumption. • Reduced emissions from fossil fuels by using energy recovered from waste.
Industry	• Reduced emissions from industrial processes by reducing product demand. • Reduced emissions from chemical fertiliser production (Favoino and Hogg, 2008).
Agriculture	• Avoided nitrous oxide emissions from farmland by reducing use of chemical fertiliser (Favoino and Hogg, 2008). • Increased soil carbon sequestration (Favoino and Hogg, 2008).
Land use change and forestry	• Reduced emissions from mining and deforestation.

Remark: The baseline for this comparison is that the waste would be either disposed of in a landfill without gas recovery or incinerated without energy recovery and ineffective flue-gas cleaning.
: Interpreted from Fig. 1 which was developed by the authors.

perspective, when composted municipal solid waste is applied for soil fertilisation, it can reduce GHG emissions from the agriculture sector by reducing nitrous oxide emissions from the use of chemical fertiliser and increase soil carbon storage which available for soil improvement and plant growth. Additionally, it can reduce GHG emissions from the industrial sector by reducing the production of chemical fertiliser (Favoino and Hogg, 2008).

Table 4 presents potential GHG emissions from the landfill disposal of food and paper wastes in the studied countries. This calculation is based on an assumption that all wastes are collected and disposed of in landfills. Potential GHG emissions are generally dependent on the quantity of the waste dumped, the depth of landfill and the landfill management system [See: Box 1 for details]. For this estimation, we use minimum and maximum default values for landfill depth which varied from unmanaged shallow landfills (lower range) to well managed sanitary landfills (upper range). Even though the organic contents are the same, potential GHG emissions from the deep landfill is higher than the shallow landfill because the aeration capacity of the deep landfill is lower than the shallow landfill.

Based on this estimation, the emissions from China were higher than those from other countries, followed by India, Indonesia, Thailand, the Philippines, Malaysia, Viet Nam, Bangladesh, and Cambodia. These GHG emissions can be reduced once the 3Rs for organic waste is applied.

Table 4 Potential GHG emissions from the landfill of food and paper waste in developing Asian countries

Country	Type of municipal solid waste (million ton/yr)*			Potential GHG emissions from the landfill of food and paper waste ($MtCO_2eq/yr$)	
	Total	Food	Paper	Food	Paper
China	120	60	18	25.2-63.0	20.2-50.4
India	42	16.8	2.1	7.0-17.6	2.4-5.9
Indonesia	23	17.0	2.3	7.1-17.9	2.6-6.4
Thailand	15	9.6	1.2	4.0-10.1	1.3-3.4
Viet Nam	13	6.4	0.3	2.7-6.7	0.3-0.7
Philippines	11	3.6	2.1	1.5-3.8	2.3-5.8
Malaysia	9	4.4	1.5	1.8-4.6	1.7-4.3
Bangladesh	6	4.2	0.2	1.8-4.4	0.3-0.7
Cambodia	0.5	0.3	0.02	0.1-0.3	0.02-0.04
Laos	1.2	0.7	No data	0.3-0.8	Not applicable
Sum	240.7	123.0	27.72	51.7-129.2	31.1-77.6

Remarks: Minimum value of potential GHG emissions from landfill reflects GHG emissions from the landfill of organic waste under shallow, unmanaged conditions and the maximum value stands for a deep, well-managed landfill.

Box 1 : Estimation of methane emissions based on the mass-balance approach

The IPCC guidelines provide two methods for the estimation of methane gas from landfill sites. The first one is a simple mass-balance method which assumes that all methane is released in the same year that the waste is disposed of. The latter is the first order decay (FOD) method that reflects a time factor for annual emissions estimation. Therefore, the FOD method provides a better estimation of annual emissions, while the mass-balance approach is suitable for comparing the potential to reduce methane emissions from alternative waste treatment methods (Jensen et al., 2000). For this study, we apply the mass-balance approach for estimating GHG emission reduction from waste management. The equation of this method is as follows:

CH_4 *emission (Mt/yr)* = ($MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1-OX)$

MSW_T = Total municipal solid waste generated (Mt/yr)
MSW_F = Fraction of MSW disposed to solid waste disposal sites (≤1)
MCF = Methane correction factor (≤1); here varied from 0.4 for unmanaged of shallow landfill (<5 m depth) to 1.0 for managed landfill
DOC = Fraction of degradable organic carbon (≤1); 0.15 for food, 0.17 for garden, park waste and other non-food organic putrescibles, 0.30 for wood and straw waste, and 0.40 for paper and textiles.
DOC_F = Fraction of DOC dissimulated (for this study, default is 0.5)
F = Fraction of methane in landfill gas (default is 0.5)
R = Recovered methane (Mt/yr)
OX = Oxidation factor (default is 0)

The recycling processes used for recovering materials from waste generate GHG emissions in themselves. However, for most materials and under most circumstances, these emissions are lower than those under a non-recycling scenario. In this study, potential GHG emissions from waste reduction, composting (degradation of organic matter under the presence of oxygen), and anaerobic digestion (degradation of organic matter under the absence of oxygen) was estimated using default values of the IPCC Guidelines. The default value of methane emissions based on wet weight was applied for food waste and that on dry weight for paper and grass [See: Box 1 for details]. This calculation shows wide ranges of potential emissions reduction from waste reduction, composting and anaerobic digestion (Table 5). Reducing one kilogram of food waste can reduce methane emissions from a landfill by 0.42 $kgCO_2eq$ compared to a shallow landfill and 1.05 $kgCO_2eq$ compared to a deep landfill without a gas recovery practice.

Composting and anaerobic digestion can reduce net GHG emissions, but its efficiency depends on technology and management efforts. In general, there is a lower potential for GHG emissions from anaerobic digestion than from composting. As shown in Box 2, potential GHG emissions from anaerobic digestion is ranged from 0-8 gCH_4/kg of wet waste (1 gCH_4/kg on average), but the potential emissions from composting ranges from 0.03 – 8 gCH_4/kg of wet waste (4 gCH_4/kg of wet waste on average). However, it is worth noting that this estimation does not include GHG emissions from waste transportation and operation of the facilities.

Some composting techniques (e.g., vermicomposting) can generate nitrous oxide which has a higher global warming potency than methane[3] (Hobson et al., 2005). Therefore, the composting of organic waste may contribute a larger amount of GHG emissions compared to that of shallow, unmanaged landfills (Table 5). It is recommended that local governments should avoid promoting the vermicomposting of organic waste and maintain aeration of the composting pile to reduce the risk of GHG emissions from

Table 5 Potential GHG emissions from waste reduction, composting and anaerobic digestion of organic waste

Organic waste	Potential net GHG emissions reduction compared to landfill ($KgCO_2eq/kg$ of organic waste)					
	Waste reduction		Composting		Anaerobic digestion	
	Compare to shallow landfill	Compare to deep landfill	Compare to shallow landfill	Compare to deep landfill	Compare to shallow landfill	Compare to deep landfill
Food waste	0.42	1.05	0.07-0.40	0.70-1.03	0.25-0.42	0.88-1.05
Paper	1.12	2.80	0.20-1.06	1.88-2.74	-	-
Grass	0.48	1.19	-0.44-0.42	0.27-1.13	-	-

Remarks: Ranges of emissions reduction from composting and anaerobic digestion are highly dependent on composting techniques and management practices.
: High emission in CO_2eq of composting, especially of grass, is caused by high global warming potential of nitrous oxide emitted from composting process, particularly vermicomposting.
- GHG emission savings from anaerobic digestion of grass and paper were not estimated due to their limitation on technology.

Box 2 : Default value for GHG emissions from biological waste treatment

GHG emissions from composting and anaerobic digestion depend on factors such as the type of waste composted, temperature, moisture content and aeration during the process (IPCC, 2006). In this study, the default range of values provided by the 2006 IPCC Guidelines was applied.

Treatment	Methane emissions (gCH_4/kg waste treated)		Nitrous oxide emissions (gN_2O/kg waste treated)		Remarks
	Dry weight	Wet weight	Dry weight	Wet weight	
Composting	10 (0.08 – 20)	4 (0.03-8)	0.06 (0.2-1.6)	0.3 (0.06 – 0.6)	- 25-50% degradable organic carbon and 2% nitrogen - 60% moisture content
Anaerobic digestion	2 (0 – 20)	1 (0 – 8)	Assumed negligible	Assumed negligible	

Note: Numerical value in bracket refers to ranges of potential emissions.

[3] For the second national communication under the UNFCCC, the IPCC has suggested using the global warming potential for 100 years of nitrous oxide as 310 times stronger than carbon dioxide. However, the IPCC Fourth Assessment Report indicated that nitrous oxide has a climate impact that is 298 times stronger than that of carbon dioxide (Forster et al., 2007).

composting.

As anaerobic digestion could also provide co-benefits of energy and nutrient recovery, it is more attractive than composting in terms of climate change mitigation, an alternative energy source and resource efficiency, but the cost is higher. Paper and grass contain more degradable organic carbon per unit of weight than food waste, and thus their potential GHG emission reduction is higher than that of food waste [See: Box 1 for reference].

The separation of organic waste from the rest of the waste stream for resource recovery could also make other recyclable materials cleaner and easier to handle (Schouw et al., 2002). Organic waste, particularly food waste, makes other materials dirty, smelly and wet, and it provides a food source for microbes and pests. The India National Action Plan on Climate Change has also emphasised that an increase of organic waste separation for composting could also increase the recycling of inorganic materials (PMCCC, 2008). Recycling of inorganic materials can sometimes reduce GHG emissions by up to 80-95% (Box 3) if virgin resources can be replaced. Effective recycling systems for these materials can therefore be very important for climate protection.

Box 3 : Climate co-benefit of materials recycling

The use of recycled materials can decrease GHG emissions compared to cases where virgin materials are used. As shown in the table below, recycling plastic and steel materials can reduce GHG emissions by 80-95%. GHG emissions reduction can also be achieved by mixing the recyclable materials with virgin materials.

Products		GHG emissions (kgCO_2eq./ton of product)			
Reference	Recycle	Reference product	Recyclable product	GHG Reduction	Reduction rate
Virgin plastic	Plastic profile	2,866	172	2,695*	94%
A mat made of virgin polypropylene	A mat made of recycled textile fiber	2,182	115	2,067*	95%
Virgin steel	Recycled steel	2,174	440	1,734*	80%
Steel	40% recycled steel	3,000	1,700	1,300**	43%
Aluminum	50% recycled aluminum	15,100-18,800	6,700	8,400-12,100**	56-64%
25% recycled glass	59% recycled glass	463	362	101*	22%

Sources: * Korhonen and Dahlbo, 2007
** Krauter and Rüther, 2004

2.4 Waste management and the 3Rs in national climate strategies

The impact of climate change is increasing - a number of countries have already suffered from natural disasters induced by climate change. Therefore, many countries are developing national action plans on climate change which cover both mitigation and adaptation strategies. Some countries have already completed their action plans (e.g., China, India, Indonesia, Thailand, Bangladesh and Viet Nam). The Philippines Malaysia, Laos and Cambodia are still developing theirs.

For this report, we reviewed how the selected countries accommodated waste management and the 3Rs in their national action plans for the mitigation of climate change. Even though the focus of this study was organic waste management, climate strategies on solid waste issues were reviewed as they can enhance the application of the 3Rs to organic waste management. The reviews also extend to the climate strategies of energy, agriculture as well as land use change and forestry sectors in order to identify how the 3R approach can contribute to the achievement of the national objectives in these sectors. For countries that did not announce a specific national action plan, the mitigation strategies written in the initial national communication to the UNFCCC were reviewed.

A summary of our findings is presented in Table 6. From the ten studied countries, six countries mentioned GHG emissions reduction in the waste sector: China, India, Indonesia, Thailand, the Philippines and Bangladesh. Amongst these, China, India, Indonesia, Thailand and the Philippines have stated explicitly that they intend to promote the 3Rs for climate change mitigation. It is noteworthy that the three with the largest GHG emissions from the waste sector (China, India and Indonesia) have emphasised the 3Rs in their national action plans for climate change. It is also worth pointing out that the Bangladesh Climate Change Strategy and Action Plan 2009 focuses on the development of final disposal sites (landfills) with gas recovery that can bring revenues under the Clean Development Mechanism (CDM) (Box 4).

Table 6 National climate change policy for the waste sector and the 3R approach in selected developing Asian countries

Country	Mentioning of the waste sector (municipal solid waste)	Mentioning of the 3R approach (or similar) to climate change	Sources
China	Yes	Reduce, Recovery, Utilisation	NCCCC, 2007
Indonesia	Yes	5Rs for industry & 3Rs for domestic waste	MENLH, 2007
India	Yes	Reduction, Recycling	PMCCC, 2008
Thailand	Yes	3Rs	ONEP, 2008
Philippines	Yes	3Rs	CCC, 2010
Bangladesh	Yes	No	MoEF, 2009
Viet Nam	No	No	MONRE, 2010
Malaysia	No	No	MOSTE, 2000
Cambodia	No	No	MOE, 2002
Laos	No	No	STEA, 2000

Note: Updated as of February 2011

Box 4 : CDM and the waste management

The Clean Development Mechanism is an international carbon trading mechanism under which industrialised countries can purchase certified emission reduction (CER) credits from emission-reduction (or emission removal) projects that are implemented in developing countries. Each CER is equivalent to one ton of carbon dioxide. Purchased CERs can be accounted for as reductions of the purchasing country and contribute to that country's efforts to meet its emissions reduction targets under the Kyoto Protocol.

Some projects from the waste sector can be registered to the CDM. Examples of registered projects are landfill gas energy recovery, waste biomass to energy, controlled combustion, composting of urban organic waste, refused derived fuel (RDF), landfill gas flaring, gasification, and anaerobic digestion (further information is available at http://cdm.unfccc.int/about/index.html).

This plan seems to be based on an end-of-pipe approach that does not promote resource efficiency.

For the Philippines, a specific climate change act became law in 2009 and a national framework strategy on climate change was finalised in 2010. The national framework emphasised the Ecological Solid Waste Management Act (RA9003) as the measure for climate change mitigation from the waste sector (CCC, 2010). The RA9003 act indicated the 3R practices for waste minimisation and utilisation (Congress of the Philippines, 2000), thus it could avoid GHG emissions from the disposal and treatment of municipal solid waste.

In all the studied countries, governments placed priority on the energy sector. Generally, governments give lower attention to the waste sector as the share of GHG emissions from this sector is lower. However, we observed that most countries that announced their action plans in 2007 or later have accommodated the 3Rs into their national action plans for climate change mitigation strategies. Some countries that have not yet included the 3Rs in their national action plans actually practice the 3Rs to some extent. Further, some have integrated the 3Rs into their national waste management plan. Therefore, it is likely that the 3Rs will be included in the new national action plans on climate change.

Our observation was that overall the studied countries are interested in waste-to-energy (e.g., biogas and landfill gas recovery), recycling of non-organic waste, composting, and promoting use of compost for reduction of agrochemical use (Table 7). India, the Philippines and Thailand mentioned waste separation at source, which this practice is very important for successful implementation of reuse and recycle. Further, the CDM seems to be attractive to the studied countries as they are expecting to sell carbon credits to developed countries. Brief summaries of the national action plans on climate change mitigation of the studied countries are presented in the *Appendix*.

Table 7 Summary of strategies for national climate change mitigation in the waste and related sectors

Countries	General 3R statement			Specific 3R strategy						Other policies that associate 3R implementation		
	Reduce	Reuse	Recycle	Waste separation at source	Composting	Anaerobic digestion	Landfill gas recovery	Incineration for energy recovery	Other waste to energy technology (e.g., fuel briquettes, bio-ethanol)	Promoting use of compost	Reducing use of chemical fertiliser	Promoting use of biodegradable products
China	O	O	O		O	O	O	O	O	O		
India			O	O	O	O			O	O		
Indonesia	O	O	O			O			O	O		
Philippines	O	O	O	O	O				O	O		
Thailand	O	O	O	O	O				O		O	O
Bangladesh							O					

III
3R technologies for organic waste management in developing Asian countries

III 3R technologies for organic waste management in developing Asian countries

As explained in part *II (Overview)*, organic waste is the largest component of waste in the studied countries. Depending on how it is managed, it can be viewed as a social burden (i.e., its transportation and disposal is expensive to tax payers). Alternatively it can be viewed as an asset; for example, its recycling can provide local employment, its nutrients can contribute to soil fertilisation, and it can be used to generate energy.

This section reviews how the 3Rs can be applied for efficient organic waste management. The different components of the 3Rs, including waste reduction by avoided over-consumption, reuse, and recycle (including nutrient and energy recovery) are explained. A few success stories and failures are presented. It should be noted that the technological options discussed here are, in principle, based upon actual examples practiced in developing countries in Asia, so that the feasibility to apply those options is more clearly understood by the stakeholders in this region.

Organic waste in this study covers food, paper, wood and grass.

- Food waste discussed in this study is generated by households, restaurants, supermarkets, fresh produce markets, schools, organisations and cafeterias. As we focus our work on municipal solid waste, the technology reviewed here does not cover technology applied by large scale food industries or food processing factories.

- Paper waste refers to paper discarded by households, schools and organisations in the municipality area.

- Wood waste includes wooden furniture and construction wood waste generated in the municipality. It does not include wood waste generated by industrial activities; for example, saw mills and large-scale furniture factories.

- Grass waste includes garden waste, bush residue and fallen leaves from the municipal area. This report does not cover waste generated in agricultural areas since collection and treatment of agricultural waste typically is not the responsibility of the municipalities. However, the technologies introduced here are also possible to apply for efficient agricultural and industrial organic waste treatment.

3.1 Reducing

"Reducing" here refers to reduced over-consumption and reduced unnecessary waste by careful preparation of raw materials or by careful use of goods. Rethinking the way goods are produced and consumed is considered very important for effective implementation of the 3Rs and particularly for waste reduction. This is because of the increase of waste generation due to modern materialistic lifestyles which are rapidly emerging in Asian developing countries. Through "reduce", GHG emissions from a number of sectors can be avoided or reduced, including agriculture (food and resources production), land use change and forestry (deforestation for agriculture and woods), industry (food, paper and furniture industries), energy (harvesting, production, transportation and waste treatment), and waste (emissions from biological degradation and burning).

Food waste is a major component of municipal solid waste and it accounts the largest share of GHG emissions from the waste sector. The best way to reduce food waste is to understand food needs of household members before purchasing, cooking or ordering food. The practices of throwing away leftover food and having a wide variety of food on the table as a sign of wealth in the studied countries contributed to the large quantity of food waste. Asian people normally prepare or order large amounts of food for parties, ceremonies and festivals. Food leftover after events or the daily meals are often viewed as evidence of wealth. Therefore, there is considerable potential in the studied countries to reduce GHG emissions through improved planning of parties and ceremonies. Reduction of conspicuous food consumption would also reduce household expenditures.

Superior quality leftover food can be stored and used for the preparation of new meals, as is traditionally practised by the middle and lower income Chinese households (mixed soup) and northern Thai households (mixed curry). Recently, refrigeration is accessible to most urban residents, thus leftover food can be stored and used to prepare new types of dishes such as mixed fried rice and the frying of leftover chicken for salads, which also adds variety to the household diet.

Residents can practice both a reduction in conspicuous consumption of food and the use of leftover food for meal preparation. There is a need to educate people on the issues of food, nutrition and health to promote this policy. One caveat is that the use of leftover food for cooking is suitable for reducing food waste generation from the individual household and may not be suitable for industrial-scale food preparation due to food standard requirements and health concerns.

Paper accounts for around 3-25% of total municipal solid waste. Paper waste mainly comes from offices, schools, and organisations. The reduction of paper use in developing countries can be achieved through encouraging use of double-sided printing, donation of school text books, and so on.

3.2 Reusing

Reusing here refers to two activities: i) the use of old products with or without repair for their original purposes. For example, the old wooden furniture of a wealthy man reused with a little repair by a poorer family; and ii) the use of a product that cannot function as it is in its original state can serve as a new type of product with little or no processing. For example, paper that was originally produced for writing or printing on both sides was used and cannot be used for its original purpose anymore. However, it can be used as a wrapping material or reshaped as a paper bag which is typical in developing Asian countries.

The reuse of organic materials can reduce GHG emissions in the same way as reduction. However, reuse may generate some GHG emissions during transportation and processing.

Leftover food that is unsuitable for human consumption can be used for animal feed. This can be practiced for food, vegetable and fruit waste, though it should be noted that some Muslims do not accept the use of leftover non-halal meat for animal feed.

Giving leftover food directly to animals can be considered a form of reuse. However, it may be considered as "recycling" if advanced processing is involved in the production such as pelletised feed. Production of feed pellets can increase the use of food waste in a larger scale because the feed can be easily stored and distributed over a wide area. Furthermore, nutrients may be added to meet animal feed standards and to increase market competitiveness of the products.

Using leftover food for animal feed is a traditional practice in the studied countries where pets, pigs, livestock or fowl are raised at home. In some urban areas, the collection of food scraps from markets or restaurants for animal feed is practiced by the informal sector. For example, vegetable waste from markets in some Thai cities is sold to duck farms (Box 5). Food waste from some restaurants in Laos (Box 6) and Cambodia are collected for pig feed.

The use of organic waste for animal feed requires collection and transportation, which adds to the costs, and the system will not be workable if it is not cost-effective. Therefore, reusing food waste as animal feed by farmers is mainly applied to large sources of waste such as markets, restaurants, cafeterias and hotels, as it is economically viable for the waste collectors. Due to the recent increase in the price of animal feed, the practice of food waste collection for animal feed is expected to increase. Recently also, the private sector in Japan is paying attention to food waste as a source of animal feed in order to reduce costs (Maeda, 2008).

The United States Department of Agriculture (USDA) (2002) found that China exported and imported hundreds of millions of dollars worth of animal feed produced from food waste each year from 1995 to 2000. Investment in food waste for animal feed could thus become very lucrative. However, one caveat is that the use of organic waste for animal feed is not applicable to spoiled and/or contaminated food, including rotten vegetable waste, as it may affect the animals' health.

Plant residue such as trimmings, leaves, and grass can be applied directly for soil mulching. This practice requires low labour input and low investment. The use of plant residue for soil mulching can avoid GHG emissions from land filling and composting. Wooden furniture and housing parts no longer needed by the owner but still in good condition can be distributed to others

Box 5 : Vegetable waste collection for duck feed in Thailand

Many of small-medium scale duck farms in Thailand raise their ducks in harvested paddies during the dry season. Harvested paddies provide free sources of feed to ducks. Most of paddy farmers allow ducks to enter their land with no complaint.

During the rainy season, the duck farm owners in peri-urban areas need to find feed for ducks and vegetable waste from the agricultural markets is a good alternative source. The farm's staff will negotiate with vegetable shop owners to separate vegetable waste. There is no formal pattern of agreement. Sometimes the duck farm provides a specific container for the vegetable shops and these shops separate the waste for the duck farm with no monetary benefits. However, the shop owners do not need to bring their waste for disposal. Sometimes, the negotiations are made with the market owner and the duck farms will pay a small amount of money to the market owner. One advantage of this is that the market owner will ask the shop owners in the market to collect waste for a designated point.

This practice could help reduce the cost for transportation and reduce the volume of waste for disposal in the landfill. A survey carried out by the authors in Thailand in 2008 found that around five tons per day (4.6% of total municipal organic waste) from the markets of the Nonthaburi Municipality were sold to duck farms. A similar practice was also found in the Phitsanulok Municipality.

As a strategy to prevent an Avian flu outbreak, Thailand controls the farming of ducks in fallow paddy fields (NNBT, 2008) by requesting farmers to keep their ducks in enclosures during outbreaks and in the cold season[1] (Pichittoday, 2008). Therefore, it can be expected that the collection of organic waste from the vegetable and fruit markets, restaurants and cafeterias for duck feed will increase.

Box 6 : Food waste collection for pig feed in Laos

Small to medium scale pig farms in Laos try to reduce expenses for pig feed by using locally available feed stocks such as rice bran, leftover food and indigenous vegetables that they can find on the land and in water resources. For farms that are located in peri-urban areas, food waste from noodle shops and restaurants is a good alternative.

Farm staff will negotiate with shop owners to separate leftover food for them and the staff will go to collect the food waste every night. Some restaurants provide free leftover food for the pig farms, but some sell it for a very low price. By this practice, restaurants can reduce the work to find a place for disposing of the leftover food which is basically liquid. Sometimes restaurants tell local governments that they do not produce waste, thus they avoid paying a waste collection fee. Local governments can also reduce cost for collection and transportation of food waste to the disposal site.

either by donation or by sale (Fig. 2). Wood waste from construction sites can be reused as supporting material (poles), making furniture, as housing parts and small wood waste can be used as fuel.

Fig. 2 Separation of wood furniture for reuse in Wat Suankaew, Nonthaburi, Thailand (Photo by Dr. Yasuhiko Hotta, IGES)

3.3 Recycling

Recycling involves a complex set of activities in a process to recover resources from waste. Recycling requires more time, labour input, higher investment and may produce more GHG emissions during the process than reuse and reduce. A product from the recycling process is normally different from the original one. Recycling should, in principle, be applied to organic materials that cannot be reused. Recycling can cause some GHG emissions, but these can be expected to be smaller than the GHG emissions that would occur as a result of landfill disposal.

The objectives of recycling organic waste are to recover valuable nutrients and energy. Nutrient recovery includes composting and biological extraction. Energy recovery from the use of fuel briquettes helps to reduce waste. Some technologies enable multiple benefits such as anaerobic digestion (biogas and nutrients) and pyrolysis (heat and biochar). The mechanical biological treatment (MBT) of mixed waste could recover nutrients for soil improvement and other inorganic materials (e.g., plastic and metals) for recycling.

3.3.1 Recycling of sorted organic waste

1) Composting

Composting is a technique to enhance degradation of organic matter by aerobic organisms. Composting is a traditional practice for agricultural waste, however, it is also applicable to municipal organic waste. The composting of municipal organic waste (MOW) is practiced in the studied countries, particularly in China, Thailand, Cambodia, Bangladesh, Indonesia, the Philippines, India, and Viet Nam. However, the average composting of MOW in the studied countries, as reported by several researchers (e.g., Visvanathan and Trankler, 2006; Prasad et al., 2008), ranged only from 5-15%.

Composting techniques include very simple ones, such as windrow composting (Fig. 3), in-basket composting (Fig. 4) and vermicomposting (Fig. 5) to more complicated ones, such as the in-vessel system (Fig. 6). Composting requires regular management, such as waste

Fig. 3 Windrow composting of municipal organic waste in Phnom Penh, Cambodia

Fig. 4 In-basket composting of municipal organic waste in Bangkok, Thailand (Photo by Toshizo Maeda, IGES)

Fig. 5 Vermicomposting pilot plant in Samui Island, Thailand

Fig. 6 In-vessel composting in Samutsongkram, Thailand

separation and plant operation. Table 8 summarises the characteristics of these different composing technologies.

The windrow method has disadvantages: a long time is required for the composting and steady labour input is needed to turn over the compost pile. Therefore, the windrow method is more suitable for regions where labour costs are low.

The in-vessel system is expensive and high technical operating skills are required making it mostly unsuitable for developing regions. Several researchers have noted that developing countries (such as China and India) find the in-vessel composting system difficult. It is mostly designed for large-scale operations that require large volumes of controlled waste input. It is very difficult for developing countries to provide this input as most of them lack waste separation at source. Therefore, many large-scale composting plants fail (Zurbrügg et al., 2002). Also the quality of the resulting compost is usually too low to be accepted by farmers. While household and community-based composting projects are more successful in terms of compost quality and operation controls than large-scale composting, their extension and adoption is still low.

Compost can contribute to sustainable agriculture by reducing agrochemical use. However, the compost market is often not well established. Sometimes farmers claim that land treated with compost is less productive than land treated with chemical fertilisers. Therefore, an NGO in Bangladesh fortified urban compost with chemical fertiliser.

Composting can reduce the GHG emissions from the waste sector, but some researchers reported that composting also releases nitrous oxide and methane. Vermicomposting releases nitrous oxide, which is a more potent GHG than methane. Nitrous

Table 8 Comparison of composting techniques

Composting technique / Element	Windrow	In-basket (Takakura method)	In-vessel	Vermi-composting
Investment	Low-medium (small scale: labourer, land; large scale: labourer, land, tractor)	Low-medium (small scale: labourer, land, microbial; large scale: labourer, land, tractor, microbial)	High (Machines, land)	Low-medium (Land, earthworms)
Labour input	High (turnover the composting pile)	High (turnover the composting pile)	Low (most work done by machinery)	Low (no requirement to turnover the composting pile)
Land requirement	High	Medium	Low	Medium
Time requirement	3 months	2-3 weeks for fermentation and 2-3 weeks for maturation	8-12 hours in vessel and 40 days for maturation	2 months
Technical requirement	Low (moisture and temperature control)	Medium (moisture and temperature control and microbial inoculation)	High (Machine operation)	Medium (earthworm care)
Environmental impacts	CH_4 emission when aeration is low	CH_4 emission when aeration is low	GHG emissions from energy use and CH_4 emission when aeration is low	NO_x emission

Note: Codified from various literature sources

oxide emissions are positively correlated with the number of earthworms in the compost (Frederickson and Howell, 2003). Further, Tamura and Osada (2006) found that the moisture content of the compost pile is also positively correlated with nitrous oxide and methane emissions. Therefore, the composting system should be selected carefully and should be managed to maintain the aerobic conditions of the pile. Composting should be accelerated through the management of the wet and dry ratio of the waste pile. Dried plant residue, leaves, sawdust, and rice husk can be added to increase the dry ratio of the pile.

Boxes 7 and 8 provide examples of successes and failures of the composting project in Indonesia.

2) Anaerobic digestion

Anaerobic digestion is a treatment process allowing degradation of organic waste under the absence of oxygen and then releasing a mixture of biogas (methane, carbon dioxide, nitrogen, etc.). The biogas that contains a high

Box 7 : Successful case: Decentralised composting in Surabaya, Indonesia

In Surabaya, community based composting was successfully introduced utilising local resources, with low-cost and low-tech composting technology. The initiative was taken in 2000 by Pusdakota, a university-based NGO that conducted an awareness campaign and ran composting projects. From 2004, under the Kitakyushu Initiative for Clean Environment (KI), the city was provided with technical assistance in composting and had recorded a 10% waste reduction from 1,500 tons/day in 2005 to 1,300 tons/day in 2007. Free compost baskets were distributed to 16,000 households and active participation from householders resulted in a reduction of 16 tons/day of organic waste (Maeda, 2009). In addition, 12 composting centres were developed to treat market and household wastes and thus resulted in a reduction of organic waste by 40 tons/day (Prapti, 2009).

A market for produced compost is provided by the Surabaya city government which purchases it for use in city parks. In order to extend Surabaya's achievements, the KI Secretariat developed Surabaya's Solid Waste Management Model in cooperation with Kitakyushu City as a compost replication model that aims for a 10% reduction of waste in other Asian cities (Maeda, 2009). A success factor of this project is getting active involvement of multi-stakeholders such as local NGOs, community groups, city governments and foreign technical assistance. Actual replications of this composting technology can be found in Indonesia and the Philippines.

Based on preliminary estimations, we calculate that organic waste reduction through composting in Surabaya can avoid methane emission by 3.9-57.7 tCO_2eq/day and contribute 16.8 tons of compost per day (calculated by the author based on the IPCC guidelines).

Box 8 : Failure case: Composting project in Java region, Indonesia

This project was financially supported by the Global Environment Facility Trust Fund of the World Bank for the Western Java Environmental Management Project (WJEMP) under the Compost Subsidy Program. The project was implemented in the cities of Jakarta, Banten and Western Java provinces from 2004 to 2006. Forty-five plants ranging from small, medium and large scale received subsidies of 1.58 million USD (1 USD ≈ 10,256 Indonesian Rupiah). Two types of subsidy programmes were introduced to the compost producers: i) a production increase subsidy was provided to compost producers to meet the production quota targets and to fulfil the administrative and technical requirements, and ii) a retroactive subsidy was provided by paying 10% of the total production cost to small, medium and intermediate compost producers which had fulfilled the administrative and technical requirements in 2002-2004 (Prapti, 2009).

This project could achieve its objective of promoting compost on a commercial scale. As a result, the project could produce 218 tons of compost per day (World Bank, 2007). Prapti (2009) reviewed that almost 50% of co-producers of WJEMP became stagnant compost producers after the project end because this project mainly relies on subsidies. The market was also driven by subsidies from the government. There was a lack of involvement of concerned stakeholders including compost users (e.g., farmers, plantations, city parks and the forestry sector), the related departments of local governments and related agencies at the national level (e.g., the Departments of Forestry, Trade and Industry and the Ministry of Small and Medium Enterprise). In addition, at the end of the project there was no clear mechanism for producers to proceed and no market for produced compost.

Therefore, Prapti (2009) suggests that a non-subsidy incentive such as production standardisation aid, the creation of a healthy market (people to people) and capital accessibility should be highlighted to revitalise this composting project.

percentage of methane can be used for electricity generation and heat.

Anaerobic digestion is typically manufactured using cow and pig manure. The generated biogas can be used for cooking and electricity generation. In most of the developing Asian countries this technology is quite new for municipal solid waste management. The rate of implementation of this technology is still low as the investment, maintenance costs and technical skills required are much higher than that required for composting.

This review found that the studied countries mainly focus on large-scale anaerobic digestion (Fig. 7) and most projects have failed because of over-capacity (e.g., Müller, 2007) and because they have not adapted to local conditions. Therefore, it can be concluded that large-scale anaerobic digestion is unsuitable for developing countries especially where organic waste separation at the sources is not common. Small-to-medium scale (less than 50 tons of waste per day) projects (Fig. 8) that generate biogas from municipal organic waste are best suited to developing countries because they require less investment, are easier to operate, and are better fit to the types and volumes of municipal solid waste. Boxes 9 and 10 provided examples of successes and failures of an anaerobic digestion project in India.

In the future the number of anaerobic digestion plants can be expected to increase. National and local governments are very interested in this technique as it can contribute to achieving their national objectives on sustainable agriculture, food and energy security.

Fig. 7 A large scale anaerobic digestion plant in Rayong, Thailand

Fig. 8 A decentralised anaerobic digestion in Kerala, India

3) Biological extraction

Biological extract is a form of organic liquid fertiliser that contains various

Box 9 : Successful case: Decentralised anaerobic digestion in Thiruvananthapuram, Kerala, India

Thiruvananthapuram is the capital of Kerala state, southern India. Waste generation in this city is 137 tons/day. Most waste is dumped into landfills (ENVIS centre-Kerala, 2009). Around 1999 an NGO, BIOTECH, started to run a household level biogas plant for kitchen waste treatment and production of gas for cooking. The cost of a one cubic meter capacity household biogas plant ranged from 219 – 365 USD. Approximately 16,000 units of household biogas plants were installed (as of February 2010). The produced gas is used for cooking and could replace 30-50% of LPG gas stoves used for cooking. The digester effluent can be used for soil fertilisation (Heeb, 2009). Through continuous development, BIOTECH has installed many anaerobic digestion plants for kitchen waste treatment on various scales.

- 175 toilet-linked biogas plants. These plants can be equipped with an additional inlet for kitchen waste input. The size is 2 m^3. The gas produced is used for cooking.
- 220 biogas plants in hotels, schools, hospitals and other institutions with a size of 4-10 m^3. The biogas produced is used for cooking. Biogas generation from a large size digester (50 m^3) can be assisted with an electric generator.
- 45 market level plants have already been built. It is possible to treat 250 kgs of waste per day with a 25 m^3 plant.

BIOTECH is very successful in implementing decentralised anaerobic digestion for kitchen waste treatment in Kerala. Heeb (2009) found that the success factors of this case are i) making individual politicians aware of the importance and benefits of the appropriate municipal solid waste management, ii) the service quality of the operation and maintenance agencies, iii) long-term contracts to avoid influence from sudden political changes, and iv) valuable service to the community (improved waste management and generation of biogas for cooking, electricity, etc.).

Box 10 : Failure case: Anaerobic digestion in Lucknow, India

Lucknow has one of the largest biomethanation plants for processing municipal solid waste in the world. Investment in and development of the plant by an Asia-based consortium operating in 2003 aimed to produce 5 MW of power from 400-500 tons of organic waste input per day. When in operation, the Uttar Pradesh local government intended to involve local waste pickers for waste collection and separation. The investor cooperated with a local NGO, Exnora and trained waste pickers (Forsyth, 2007). Unfortunately, this plant was forced to close in late 2004 because it could not secure a sufficient, regular supply of organic waste and the waste input to this facility was highly mixed with non-degradable waste (Kurian, 2007).

types of beneficial microorganisms. It is also referred to as Effective Microorganism (EM), bio-extract or biological liquid fertiliser. Biological extraction is achieved by fermenting waste, microbial culture and sugar sources under anaerobic conditions for 5-7 days (Fig. 9). The product can be stored for one year under anaerobic conditions. The practice may generate methane gas. However, there is currently no scientific information available on GHG emissions from biological extraction.

In Thailand, biological extract is used as

Fig. 9 Biological extraction of food waste in Samutsongkram, Thailand

organic fertiliser, toilet and wastewater deodorant, composting starter, cleaning detergent for toilets and pet houses, insecticide, wastewater treatment substances, as well as medicine to prevent poultry and livestock infection (Sawisit, 2008). Further, Bunnithi (no date) notes that biological extract can also be used for showering pets, reducing toxic chemicals from vegetables and fruit, reducing the smell of fish, controlling mosquitoes, ants and houseflies and cleaning accessories.

Biological extraction requires less time than composting and anaerobic digestion. It also requires lower labour input than composting. The disadvantage of biological extraction is that the product is more difficult to store than compost. The liquid contains a high concentration of microbial which requires feed and appropriate temperatures. Therefore, the practice of bio-extraction is still small in scale and involves small groups of people.

The practice of biological extraction of municipal solid waste is found in the municipalities of Pathumthani and Nonthaburi, Kradang Nga (Samutsongkram) and the Bangkok Metropolitan Administration, Thailand. A pilot project in the Pathumthani Municipality produced biological extract from December 2006 to September 2007 and the municipality was able to reduce waste flow to the landfill by 9.2 tons (approximately one ton per month) (Pathumthani Municipality, 2007). The municipality produced 15.4 tons of biological extract and reduced municipality expenses by 2,500 Baht (approximately US$74, excluding the costs for transportation and labour).

The impacts of biological extract production on GHG emissions are not well understood. Research is required to ensure that an inappropriate technology for climate change mitigation is not being promoted.

4) Pyrolysis

Pyrolysis is a very new technology for urban organic waste treatment. Pyrolysis is the thermal treatment of biomass at moderate temperatures under anaerobic conditions. It is basically the same process that has been used for a long time to produce charcoal from wood. This technology is applicable to organic waste from urban yard trimmings, land clearing, pallets, wood packaging, paper and other organic waste with a low moisture content. Products from pyrolysis are bio-oil, gas and biochar.

The bio-oil is expected to be used as bio-fuel, but the required purification is presently too expensive to make bio-fuel production for vehicles economically viable. Biochar is highly stable and offers a long-term form of carbon sequestration. It has been used for soil improvement in Amazonia for thousands of years. Biochar can reduce nitrous oxide emissions and nitrate leaching into water as well as improve crop productivity. It is considered to be 'carbon negative' (Winsley, 2007).

Pyrolysis is reportedly the most expensive waste treatment technology and is the most sensitive to economies of scale (ACE, 2002). It requires large-scale project development to reduce the cost of waste treatment per ton. Therefore, this technique is not suitable to municipal solid waste management in developing Asian countries. However, it may be economically viable if agricultural waste is used and the indigenous knowledge on charcoal production is adopted.

5) Fuel briquettes

A fuel briquette is a block of flammable material that is used for starting and maintaining a fire. It can be used as an alternative to fuel wood, charcoal and kerosene. The briquette is produced from the high calorific value organic waste such as paper, sawdust, wood and plant residues. Since the 1970s, the briquette technique has been known to the developing countries of Africa and the Asia-Pacific.

Briquette use is suited to urban fringe areas where residents practice agriculture and do not have a sufficient electricity and gas supply, such as in Laos, Nepal and Cambodia. Furthermore, fuel briquettes could potentially be sold to industries that use coal or wood for processing, such as the cement and rubber industries. However, there is the concern that hazardous materials, such as printed paper and contaminating lead, are being mixed for briquette production.

Examples of the 3R practices for sorted municipal organic waste are summarised in Table 9.

3.3.2 Recycling of unsorted waste

It is recognised that careful separation at source is hard to achieve for any significant amounts of organic waste, particularly for food waste that normally comes with packaging. Unsorted waste that contains a high portion of organic waste should be treated properly regarding the resource efficiency approach. This report introduced two methodologies that associate resource efficiency: mechanical biological treatment (MBT) and sanitary landfill equipped with a gas recovery system. MBT can avoid methane emissions from the direct landfill of organic waste and enhance the segregation of valuable materials for recycling. Sanitary landfill does not associate resource efficiency directly, but methane gas can be recovered for energy use. Comparison of these technologies is presented in Table 10.

Other treatments such as semi-aerobic landfill, aerobic landfill and landfill soil cover that can avoid methane emission but does not promote the utilisation of resource efficiently are not presented. However, these techniques are recommended where MBT and landfill gas recovery are not economically implemented.

Table 9 Examples of 3R practices for sorted municipal organic waste

Management option / Element	Reducing over-consumption	Food	Animal feed	Soil mulch	Compost	Biogas	Biological extract	Biochar	Fuel briquettes
3R category	Reduce	Reuse	Reuse	Reuse	Recycle	Recycle	Recycle	Recycle	Recycle
Suitable type of organic waste	Food, paper, wooden furniture and construction	Food	Food, vegetables, fruits, grass leaves	Plant residue	Food, vegetables, fruits and plant residue	Food, vegetables and fruits	Food, vegetables and fruits	Paper, plant residue, wood waste	Paper, plant residue, wood waste
Required waste quality	-	Very high	High	Medium	Medium (low heavy metal)	Medium (low heavy metal)	Medium (low heavy metal)	Low (low heavy metal, if the charcoal is applied for soil conditioning)	Low (no dioxin emitting waste)
GHG emission reduction in other sectors	Agriculture, energy, industry, land use change & forestry, food industry	Agriculture, energy, industry, land use change & forestry, food industry	Feed industry	Energy, agriculture, synthetic fertiliser industry	Agriculture, synthetic fertiliser industry	Energy, agriculture, synthetic fertiliser industry	Agriculture, industries	Energy, agriculture, synthetic fertiliser industry	Energy, land use change & forestry
Environmental impacts	-	-	-	-	- CH_4 emission under aerobic conditions - NOx emission when vermicomposting is practiced	CH_4 emission when gas is leakage	Has potential for CH_4 emission	-	Wastewater

Table 9 (continued)

Management option / Element	Reducing over-consumption	Food	Animal feed	Soil mulch	Compost	Biogas	Biological extract	Biochar	Fuel briquettes
Socio-economic benefits	Saving household expenditure	Saving household expenditure	Saving farm expenditure	Saving farm expenditure	Saving farm expenditure	Saving household expenditure	Saving farm expenditure	Saving farm expenditure	Saving household expenditure
Investment	None	None	Very low	Very low	Low to medium	High	Low to medium	High	Low
Technical requirement	No	No	No	Low	Medium	High	Medium	High	Medium
Potential project scale	Household to large scale	Household	Household to community	Household to community	Household to municipality	Household to municipality	Household to municipality	Community to municipality	Household to municipality
Example of practicing countries	Thailand	China, Thailand	Cambodia, China, Thailand	Thailand	Bangladesh, Cambodia, Indonesia, etc.	India, Thailand	Thailand	-	Cambodia, Nepal

Table 10 Comparison of mechanical biological treatment and sanitary landfill for gas recovery

Management option / Element	Mechanical biological treatment	Sanitary landfill for gas recovery
3R category	Recycle	Recycle
Suitable type of organic waste	General household waste	General household waste
Required waste quality	None hazardous and uninfected waste	None hazardous and uninfected waste
GHG emission reduction in other sectors	- Possible for energy, industry and agricultural sectors when RDF and compost are utilised	- Possible for the energy sector when the gas is used
Environmental impacts	- CH_4 emission from biological process when aeration is not sufficient - Foul odour and leachate contamination when the biological process is improperly managed.	- CH_4 emission (≥40% of biogas generated in the landfill) - Leachate contamination when the leachate treatment facility does not function properly. - Foul odour and unsanitary when the landfill site is not managed properly.
Socio-economic benefits	- Income generation from selling of recyclable waste, compost and RDF	- Revenue from selling biogas or electricity
Investment	- Land: requires large space of land for the biological process (windrow composting) but it is usable for approximately two times longer than the sanitary landfill - Machines for waste shredding and segregation	- Land: two times larger than MBT for long term implementation - Landfill gas recovery system
Technical requirement	- Knowledge on biological process and segregation of recyclables, RDF and compost	- Knowledge of landfill gas recovery system and electricity generation
Potential project scale	-Small to large municipality	- Medium to large municipality
Example of practicing countries	Phitsanulok, Thailand	Bangkok, Thailand

Note: Codified from various sources

1) Mechanical Biological Treatment (MBT)

MBT is a set of integrated techniques for stabilised and extracted valuable materials from municipal solid waste before disposing of non-valuable substances by landfill or incineration (Fig. 10). It is carried out by two main processes: i) mechanical treatment – shredding and homogenising waste before sending it for biological treatment, and segregating valuable waste after the biological process such as compost-like products, plastic, etc., before dumping the inert waste into the landfill or incinerator; and ii) biological treatment - fermenting mixed waste under aerobic condition (composting) or anaerobic condition


Fig. 10 **Mechanical Biological Treatment of the Phitsanulok Municipality (Photos by Dr. Suthi Hantrakul, Phitsanulok Municipality)**

(anaerobic digestion), thereby avoiding methane emissions from landfill disposal. MBT can reduce the volume of waste (thereby extending the lifetime of the landfill), reduce methane emissions, and reduce landfill leachate contamination of water resources. It can also reduce moisture content of the waste thus saving energy when incineration is employed.

GHG emissions from MBT itself are similar to those of composting (IPCC, 2006). Further, Hong et al. (2006) found that MBT combined with landfill and MBT combined with incineration scenarios contributed to a lower total environmental impact potential (including GHG emissions) than a standalone landfill and incineration.

The compost-like product can be applied as a soil amendment if it has low contamination of heavy metals. If the product contains high levels of heavy metals it can be used as a cover matter for new MBT or landfill. The use of this product as a cover matter can reduce GHG emissions from the landfill by 10-fold (Abichou et al., 2009).

The segregated plastic waste can be sold as a refuse derived fuel for intensive thermal energy use facilities if it is not contaminated with chlorine (such as polyvinyl chloride). It is also possible to convert plastic waste to liquid oil. Other valuable materials can be segregated and sold in the recycling market.

MBT is being successfully practiced in the Phitsanulok Municipality of Thailand. There is no problem of leachate and very little waste volume is dumped into the landfill.

2) Sanitary landfill equipped with gas recovery system

Landfill disposal is practiced by the burial of mixed municipal solid waste into a designated area and covering it with soil. Landfills can be classified as uncontrolled landfills, controlled landfills, and sanitary landfills.

Generally, over half of the waste dumped into landfills in developing Asian countries is organic waste that could be converted to methane gas under the anaerobic conditions of the landfill site. Methane can be recovered for energy use in the forms of gas and electricity (SCS Engineers, 1994) (Fig. 11). Unfortunately, most landfills in this region are not equipped with gas recovery systems. Therefore, it is recommended that a sanitary landfill should be constructed for the disposal of non-recyclable materials and mixed waste that cannot be separated

Fig. 11 Sanitary landfill with gas recovery system in Thailand (Photo: Komsilp Wangyao).

efficiently for recycling.

Unsorted food waste may be dumped into a sanitary landfill if a gas recovery system is installed. However, it should be regarded as the last option due to the high investment required and the difficulty in the collection of methane gas. Some researchers report that the achievement of methane emissions reduction from landfill gas recovery projects is relatively low; one project only managed to achieve 34% of estimated emission reductions (Plöchl et al., 2008). Additionally, the landfill gas utilisation for power generation is often not economically attractive on its own. The project should be associated with a feed-in tariff[4] and a CDM financial mechanism (Plöchl et al., 2008).

Several governments like Malaysia, Bangladesh and China are interested in landfill gas recovery because of the CDM. Some projects are already registered under the CDM, such as 'landfill gas utilisation at Seelong Sanitary Landfill in Malaysia', 'Landfill gas extraction and utilisation at the Matuail landfill site in Dhaka Bangladesh', and 'Mianyang landfill gas utilisation project in China' (CDM, 2009).

Cambodia is interested in the collection of methane gas from old landfills. This strategy could be a good approach to reduce GHG emissions from the old landfill site. However, preliminary investigation of landfill gas quantity and ratio of methane gas are required.

[4] A financial incentive set by the government to help private sectors invested in environmentally sound business. The system is varied depending on the individual country's policy.

IV
Policy recommendations : Hierarchies for selection of appropriate waste treatment technology

IV Policy recommendations : Hierarchies for selection of appropriate waste treatment technology

As described in the previous sections, several 3R activities can be applied to reduce methane emissions from the anaerobic fermentation of organic waste in landfills and GHG emissions in other non-waste sectors. Each waste treatment technology has its specific strengths and weaknesses in implementation and, therefore, the local governments should consider the local contexts prior to the selection of the technology: waste quantity, waste characteristic, waste generation behaviour, land availability, investment capacity, personnel, scale of implementation, beneficiary from technology, interest of local residents, stakeholders participation and negative impact of technology. Preliminary studies and public hearings should be carried out prior to the decision making. Whatever the case, the effective implementation of the 3Rs usually requires active participation of several stakeholder groups, especially on waste separation at source.

It was predicted that developing Asian countries will experience fast growth of waste generation due to rapid economic development. The waste will burden the local governments which typically lack investment capacity, lack personnel both in term of quantity and quality, and confront high social resistance to constructing waste disposal sites (e.g., landfill and incineration). The 3Rs are therefore highly important to solve the said problems.

This section aimed to investigate the appropriate organic waste management hierarchies for 3R implementation based on climate co-benefits, resource efficiency and energy balance. The hierarchies presented what can be regarded as the most appropriate options for the main types of organic waste. Alternative options are provided for unsorted organic waste. Although the hierarchies indicate what treatment options are more desirable in general, the local governments also need to consider the local contexts in order to find out what options are applicable for their cities.

Among the organic waste stream, food waste is the largest component and most difficult to handle as it degrades rapidly, produces smells and provides a food source for animal and microbes. Paper and wood wastes are stable forms of organic waste that can last for years. Therefore, the management hierarchy of these wastes should be different in term of resource efficiency and climate co-benefits.

Significant factors for setting the management hierarchy are presented in

Table 11. For the municipality that takes full responsibility for the disposal of waste generated in the municipal area, the promotion of waste reduction and reuse is required to reduce waste flows to the final disposal site. Current waste management practices in most areas do not meet the environmental standards and the services do not cover all of waste generated due to lack of personnel and budget for collecting waste and constructing disposal sites. Therefore, the current practices could contribute a large amount of methane emissions from landfills and open dumping of organic waste where methane collection is not practiced. For social needs, we considered food and energy security, poverty reduction and income distribution as factors. For the technological aspects, a higher priority is given to technology that could utilise the resource efficiently, contribute the least GHG emissions and require low energy and monetary input.

As presented in the following sections, the top of each hierarchy indicates the most desirable option based on technology, municipal benefits and social aspects. High priority is given to resource efficiency, energy saving and environmental impact. The lower parts of each hierarchy show other options in decreasing priority. In practice, a mixture of some of these options is recommended, depending upon local circumstances, including waste sources and composition and the various limitations of each local government.

As waste separation at source is required for the 3Rs, we have divided organic waste into four major groups: food, paper, wood and grass. These waste groups have different characteristics, thus the proposed management hierarchy is different for each type.

4.1 Food waste

In the studied countries, food, fruit and vegetables are the largest source of organic waste, and sometimes they can account for more than 80% of the municipal organic waste generation (see Table 2). Food waste (including fruit and vegetables) has high moisture content, low calorific value, high nutrient value and degrades rapidly.

Historically, this waste was fed to domestic pets, household livestock and poultry. However, in urban areas, this waste, smelly and unattractive, is now for the most part being discarded in bins together with other waste. It becomes a food source for disease carriers such as houseflies, rodents and cockroaches.

Taking account of Asian behaviour on

Table 11 Significant factors for development of organic waste management hierarchy

Technology aspects	Municipality benefits	Social aspects
• Low GHG emissions • Efficient resource recovery • Low energy input • Low monetary investment • Low environmental impact • Simple and easy to handle	• Could reduce waste flows to final disposal site • Could reduce the cost for waste collection and disposal • Could reduce the environmental impact from waste treatment	• Improve food security • Improve energy security • Reduce poverty and create income for residents • Associate income distribution

food consumption, reduction of the over-demand of food leading to waste needed to be highlighted. Very high quality leftover food should be used for human consumption and the rest for animal feed. Food waste that is inappropriate for animals should be treated - whether by anaerobic digestion or composting depends on local needs for the output. Anaerobic digestion can generate both biogas for household use and nutrients for soil improvement, therefore it is more preferable than composting (Fig. 12). However, the investment and technical requirements for the implementation of anaerobic digestion are higher than composting, therefore local governments may choose to implement composting because it has monetary benefits and is technically affordable.

Biological extraction is not proposed here due to lack of scientific data on GHG emissions from this practice. However, biological extraction is better than the landfill of food waste without methane collection, as valuable nutrients in the extract can be applied for soil improvement.

In many cities, waste separation at source may not be conducted for a variety of reasons. Separation of mixed waste at the recycling facility (e.g., composting, anaerobic digestion) should be practiced. If no such facility exists, the unsorted waste should be pre-treated by MBT prior to disposal at a landfill or incinerator. The pre-treated waste is more stable than fresh waste and has potential to be utilised for energy (e.g., refuse derived fuel (RDF)).

Fig. 12 Recommended integrated food waste management hierarchy for developing Asian countries

The direct disposal of fresh waste by landfill or incineration should be avoided as this impacts resource efficiency and contaminates the environment. If the sanitary landfill of fresh waste is the only disposal method that local governments can afford, a gas recovery system should be installed or an aerobic landfill system should be employed. The incineration of unsorted organic waste without pre-treatment is costly because the waste has high moisture content and therefore requires a high energy input. If incineration is unavoidable, dioxin control and thermal recovery systems should be installed.

4.2 Paper waste

Paper has high calorific value and low moisture content, therefore, it is suitable for thermal treatment. However, a management hierarchy should start with efforts to reduce paper use in order to decrease the environmental impact from deforestation, production and treatment (Fig. 13). Good quality paper should be reused. For example, both sides of the paper can be used and then reused for wrapping. The non-reusable paper can be mixed to produce other kinds of products such as bricks or pots that would produce a less environmental impact compared to recycled paper production. The use of paper for fuel briquettes is our next preference as we considered that the end-of-life of those products can be used as a

Fig. 13 Recommended integrated paper waste management hierarchy for developing Asian countries

soil conditioner.

Thermal treatment such as pyrolysis, controlled combustion and the incineration of paper is preferable to landfill disposal due to its high calorific value that makes it consume less energy for incineration. Methane emissions from the landfill can be avoided by a further incineration of the paper. Biochar and ash from these thermal treatments can be used for soil improvement once heavy metal contamination is lower than the required standard.

The composting of unsorted papers is not recommended as it could result in low quality compost (e.g., contamination by heavy metals) (AfOR, undated). For paper that was mixed with high moisture and low calorific value contents, other options such as MBT and landfill gas recovery should be applied.

4.3 Wood waste

Wood waste from furniture and construction sites has high calorific value and is large in size. It is easy to be burnt and its carbon dioxide balance is neutral. Wood waste degrades slowly and does not generate foul odours. This waste can last for years when it is kept away from moisture. The establishment of a wood waste disposal centre is recommended to enhance the utilisation of this waste on a large scale.

It is recommended that the hierarchy of

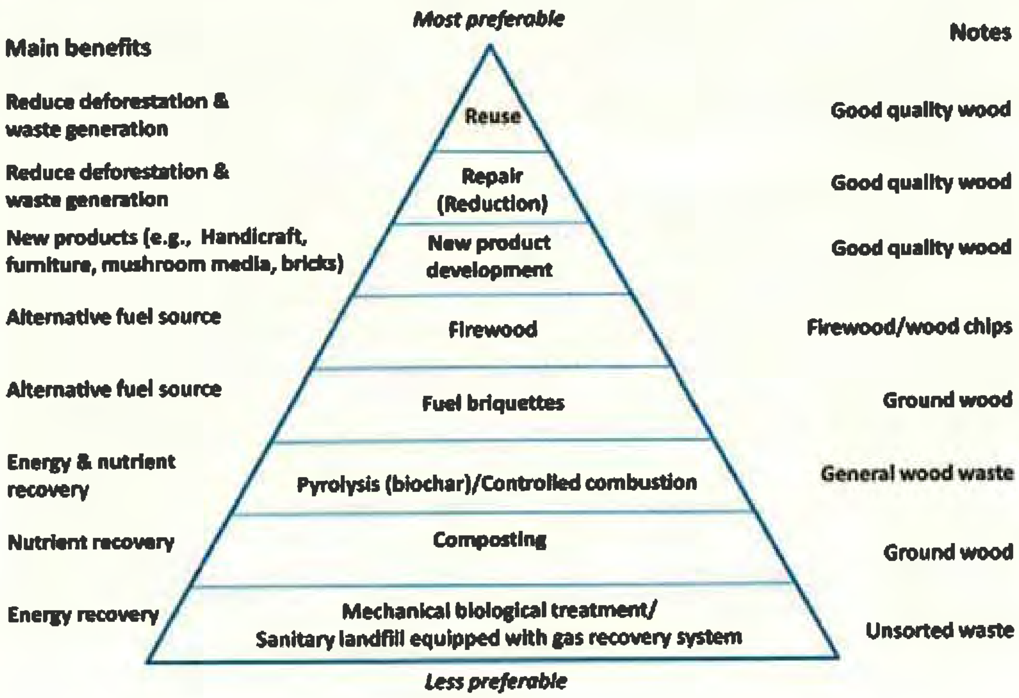

Fig. 14 Recommended integrated wood waste management hierarchy for developing Asian countries

this waste should start with the reuse and repair of wood products (Fig. 14). Used wood products (e.g., baby furniture) can be distributed to other people who want it. Generally, old furniture and wood waste thrown away by wealthy people are often reusable by others. Repair is the second preference, as some additional materials are required. Some wood may be used as a material for handicrafts, furniture, mushroom media and bricks. Product development from wood waste could generate income for residents.

Once the wood is not appropriate for repair and reuse and the market potential for wood derived products is low, a thermal treatment technology is recommended. Direct use of wood waste as firewood is easier and cheaper than making fuel briquettes. Pyrolysis and controlled combustion are also alternatives to thermal recovery, but it requires a higher investment. Residue from the thermal process, such as char and ash, are applicable for soil conditioners.

Composting and mushroom production are applicable for wood that has been ground. For composting, the waste should be mixed with night soil or food waste to adjust the moisture condition of the composting pile and save water input. Mixing the wood waste with food waste helps improve the carbon and nitrogen (C/N) ratio of the composting pile. As mentioned in the previous section, the degradable factor of wood is very high, the aeration of wood composting pile should be ensured and nitrous oxide emitted composting technology such as vermicomposting should not be practiced.

4.4 Grass and garden waste

Grass and garden waste does not constitute a public nuisance compared to rapidly degradable organic waste. It burns easily and its carbon dioxide balance is as neutral as wood waste. However, it does generate methane if allowed to degrade slowly in landfills.

Grass, leaves and small branches from gardens should be treated differently from wood waste as each waste product is different in size and potential use (Fig. 15). The management hierarchy of grass should start with soil mulching and leave it to degrade naturally on the surface. This will function as a soil conditioner and as an erosion prevention measure. Use of this waste as fodder for livestock is desirable in peri-urban area where livestock is raised. If these options are not practical in the city, composting is highly recommended either by mixing it with food waste or composting only this type of waste. A good example of garden waste composting is found in Bangkok, Thailand (Fig. 16).

Some communities may try to produce new products using garden waste such as construction bricks, plates for walkways, etc. This practice would be difficult if it has no market demand. Use of garden waste for fuel briquette production is an alternative in developing countries where wood fuel is the major energy source. Controlled combustion and incineration is preferable after fuel briquettes and appropriate for areas that wood fuel is not being used widely. Ash of garden waste can be applied for soil amendment material thus contributing to food security.

A sanitary landfill is the last option to consider as it does not enhance efficient use of the garden waste and contributes methane emission to the atmosphere.

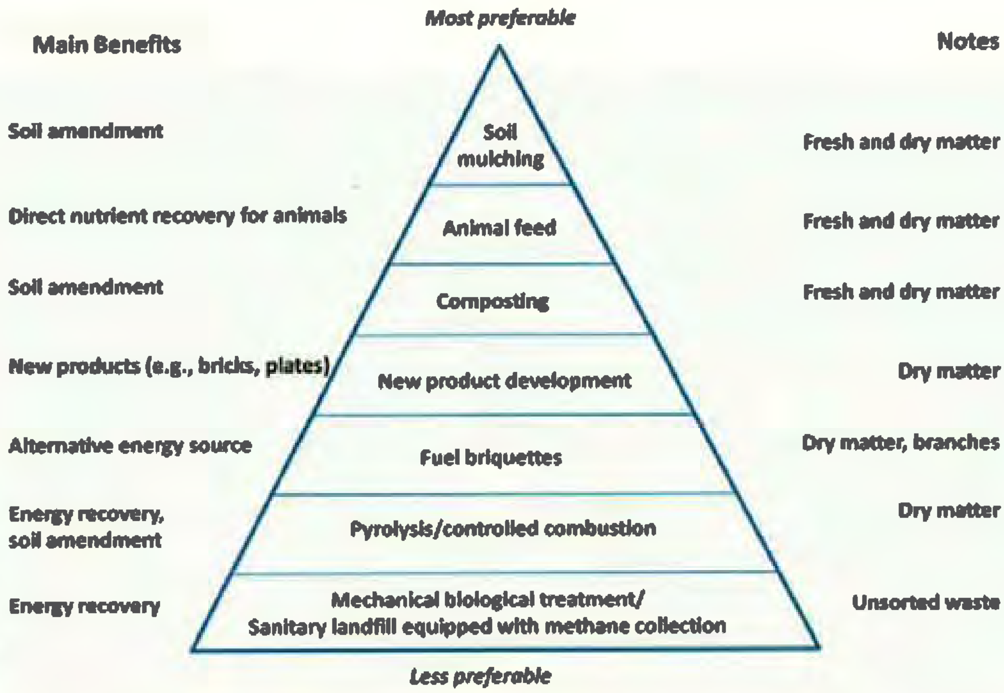

Fig. 15 Recommended integrated grass and garden waste management hierarchy for developing Asian countries

Fig. 16 Garden waste composting in Bangkok, Thailand

V
Conclusion

V Conclusion

The 3Rs could provide climate co-benefits to the waste sector and other sectors. However, there is little quantitative data on the climate co-benefits of the 3Rs in developing countries. This policy report aims to provide a better understanding of the links between waste management and greenhouse gas emissions. The exercise on GHG emission estimations presented in this report supports the argument that direct GHG emission reduction from the waste sector can be achieved through organic waste reduction, composting, and anaerobic digestion, as alternatives to landfill. A limitation of this study is that it does not include indirect emissions from waste collection, transportation and energy used for the operation of waste utilisation facilities. Further assessment based on lifecycle analysis should be carried out. By full accounting for the GHG emissions from these management activities, the net reduction from the 3R practices would be properly understood.

Currently, many governments in Asian countries are considering implementing the 3Rs in response to the global issue of climate change and their national need to improve municipal solid waste management. Waste separation at source is the major challenge facing Asian countries as most local governments lack experience in waste separation. A waste separation and collection model that is widely applied in developed and developing countries could be a good example for other countries. The exchange of experiences in the implementation of the 3Rs in the waste sector between developed and developing Asian countries is recommended for wider and successful application of the 3R practices. In addition, further research on the various benefits of the 3Rs and improved interaction between researchers and policymakers are needed to enhance implementation.

Local authorities should remember that the 3Rs require the active participation of the stakeholders, particularly the residents, while programmes to handle waste efficiently after segregation are also needed. Rethinking resource use and treatment is important for the implementation of 3R strategies. The 3Rs should be included in environmental education programmes, including an explanation of the multiple benefits of 3R practices and backed by quantitative studies.

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Appendix

Appendix
Summary of the national climate action plans in selected countries

1) China

China, which has the largest GHG emissions amongst the studied countries, established the National Coordination Committee on Climate Change to develop a series of policies and measures to address climate change. In 2007, the climate change programme was detailed in China's National Climate Change Programme, which was active until 2010.

China intends to promote energy conservation, improve energy efficiency, as well as promote the use of new and renewable energy (e.g., biomass), clean energy and carbon sink technologies. China is also promoting energy recovery from municipal solid waste treatment (e.g., waste incineration and energy from landfill gas) and biomass (e.g., fuel briquettes, liquid fuels and bio-ethanol).

China intends to increase biogas generation to reduce GHG emissions from the energy sector. Recently more than 17 million household biogas digesters were installed and generate 6,500 million cubic meters of biogas annually. Furthermore, over 1,500 large and medium-scale biogas digesters were constructed and generate around 1,500 million cubic meters of biogas annually. This practice is mainly applied for agricultural waste such as pig manure.

China is also applying the 3R approach to promote the development of clean production in the industrial sector and to accelerate the creation of a resource-conserving and environmentally-friendly society. For the construction sector, China is promoting the recovery and utilisation of construction rubbish and waste. China intends to promote the use of straw to produce plant fibreboard and plans to revise the relevant standard for material consumption of engineering projects to push forward material-saving technology processes.

China intends to shift from end-of-pipe waste management to whole-process management through the reduction of waste from the source, recovery and utilisation and non-hazardous disposal. Additionally, China plans to revise the laws on waste management (e.g., standards for waste classification and waste recovery), to reduce the amount of waste and to increase the recovery and utilisation of waste at the source.

The development of waste disposal and comprehensive utilisation technology will be accelerated for the small and medium sized cities as well as rural areas. Composting technology suited for China's circumstance and capacity will be promoted. Furthermore, a charging system for the disposal of domestic waste will be established and the fee for waste disposal will be increased. An incentive policy for enterprises investing in landfill gas power and waste incineration power projects will be formulated. For instance, these incentives include such things as a feed-in tariff and income tax relief and reduction within a certain period of time.

For the agriculture sector, China plans to improve agricultural production and increase carbon storage in agricultural ecosystems. China intends to promote the use of chemical fertiliser in reasonable quantities and increase the use of organic fertiliser to improve soil fertility and to reduce nitrous oxide emissions from its croplands.

The full document is available at www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf.

2) India

In 2008, the Prime Minister's Council on Climate Change of India announced the first National Action Plan on Climate Change. The plan to reduce GHG emissions from the waste sector is a part of the national mission for sustainable habitats. India plans to promote the recycling of material and improve urban waste management to achieve ecologically sustainable economic development. This action plan claimed that the recycling rate in India is already higher than that of developed countries[5]. India has found that recycling activities reduce the growth in energy use and GHG emissions due to the lower demand for virgin materials such as steel, aluminium and copper. Furthermore, India plans to focus on waste-to-energy technology and to encourage research on and development of bio-chemical conversion, wastewater use, sewage utilisation and recycling options.

The India National Action Plan on Climate Change indicated that the recycling rate could be further increased by separating the organic waste for composting and by providing the informal sector with access to finance and better technology for recycling. A special focus is also given to the development of decentralised biomethanation for waste-to-energy by using organic waste from vegetable markets, slaughterhouses and dairy production. However, the efforts to encourage composting and to generate energy from waste have not been successful and open dumping practices are still common. The national action plan indicated that a factor for this delay in development is because the waste management authorities in India were transferred from the state governments to the Urban Local Bodies since 1992 which has resulted in a low capacity to handle the waste.

5 The recycling rate in India is 70%, but in Japan it is only 53% (SME, 2007).

Furthermore, India plans to improve the productivity of rainfed agriculture under the concept of an ecologically sustainable green revolution. Hence, we believed that composting of organic waste will have an important role to play in contributing to the reduction of GHG emissions from the production and use of chemical fertilisers.

The full document is available at http://pmindia.nic.in/Pg01-52.pdf.

3) Indonesia

In 2007 Indonesia announced its National Action Plan Addressing Climate Change, which was prepared by the State Ministry of Environment. The top priority to reduce GHG emissions is promoting energy conservation and the utilisation of clean energy from new or renewable energy sources.

The clean technology and 5Rs approach (rethinking, reducing, recycling, recovering and reusing) will be introduced for energy saving in major industries including the pulp and paper, cooking oil and sugar industries. Furthermore, the organic waste produced by industries, such as tapioca and palm oil, will be converted to energy.

The 3R principles will be promoted to reduce GHG emissions from the waste sector. In order to fulfil the energy requirement of the community and industry, Indonesia intends to review its Regulation No. 67, 2005, to enhance the development of a waste-to-energy project for the CDM.

In the agriculture sector, the utilisation of environmentally-friendly, organic fertilisers and pesticides will be encouraged. Agricultural and agro-industrial waste can be applied for soil fertilisation. Indonesia is encouraging the fermentation of animal waste to produce biogas as an alternative energy source as well as to reduce methane emissions.

The full document is available online by typing 'National Action Plan Addressing Climate Change'.

4) Thailand

Thailand approved its Strategic Plan on Climate Change in 2008, which extends from 2008-2012. The strategy on GHG reduction activities from the waste sector includes promoting the 3Rs (e.g., composting and waste-to-energy) and avoiding open burning. Sufficiency economy is promoted for enhancing sustainable consumption. Clean technology is associated with the reduction of waste generation. In addition, waste separation at source is proposed to utilise the resource efficiently.

Thailand proposed to increase the use of biodegradable packaging in order to reduce plastic waste. This policy may lead to an increase of GHG emissions if this waste is treated by unsanitary landfill without a gas recovery system. However, the use of biodegradable plastic for food and organic waste would increase efficient organic waste separation and utilisation.

A policy to reduce the use of

agrochemicals in the agricultural sector is emphasised. Therefore, there is a potential that urban composting can fulfil the needs of the agriculture sector.

5) Bangladesh

Bangladesh announced the 2009 National Climate Change Strategy and Action Plan. The action plan mainly emphasises climate change adaptation as Bangladesh, as a low lying country dissected by some of the world's largest rivers, is very vulnerable to climate change.

The GHG emissions from Bangladesh are miniscule. However, Bangladesh is attempting to reduce GHG emissions by promoting a low carbon growth pathway and GHG emissions reduction from the energy, agriculture, forestry and urban waste management sectors. Currently, Bangladesh registered two CDM projects on solar energy and waste management. Bangladesh plans to develop similar activities for carbon credits.

For the reduction of GHG emissions from municipal solid waste, Bangladesh is interested in developing landfill sites in order to generate electricity as well as to sell carbon credits under the CDM.

The full document is available at www.moef.gov.bd/climate_change_strategy2009.pdf.

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