IGES-WMR Working Paper 2009-001

Improved Organic Waste Management:

Climate Benefits through the 3Rs in Developing Asian Countries





Institute for Global Environmental Strategies

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Preface

This working paper is based on research carried out as commission work for the Ministry of Environment, Japan (MOEJ). After finalizing the contract with the MOEJ in March 2009, we have deepened our analysis of climate benefits through the 3Rs focusing on organic waste management. Among other things, we have developed separate treatment hierarchies for different kinds of organic waste and recommendations for selection of appropriate treatment technologies for these wastes.

The main objective of publishing this working paper is to disseminate our findings to government officials, NGOs, experts, and other participants of the "Inaugural Workshop of Asia Resource Circulation Policy Research" and the "Inaugural Meeting of the Regional 3R (Reduce, Reuse, Recycle) Forum in Asia" which will be held back-to-back on 9-12 November 2009 in Tokyo, Japan. By sharing our results with the participants in this meeting we hope to receive comments which can improve our work further.

The authors are thus grateful for any comments and feedback on this document. We are expecting to revise the report with a view to make it even more useful for decision makers and local governments in developing Asian countries. We will try to reflect all comments received before **10 December 2009** into a new edition which we expect to publish as an IGES Policy Report in early 2010.

Any feedback and comments can be sent to the address below:

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Finally, this report would not have been possible to finalize on time without great and generous support from all the members of the Waste Management and Resource Efficiency team of IGES, particularly from Dr. Yasuhiko Hotta and Mr. Lewis Akenji.

Executive Summary

I. Greenhouse gas emissions and the waste sector: overview

According to the initial national communication to the United Nations Framework Convention on Climate Change (UNFCCC), greenhouse gas (GHG) emissions from municipal solid waste (MSW) in 1994 of ten studied countries: China, India, Indonesia, Thailand, Viet Nam, Malaysia, Philippines, Bangladesh, Cambodia and Laos, accounted for 0.13 – 15.2% of the national GHG inventories (average 1.3% for the region). However, it is estimated that the per-capita GHG emissions from MSW in the studied countries has substantially increased due to several factors such as increase of waste generation and collection for disposal in landfills.

Organic waste is the largest source of GHG emissions from the waste sector in the studied countries where open dumping and use of landfills are most common. MSW comprised 40-74% food waste and 3-25% paper waste. It is estimated that if 30% of food and paper wastes in these countries were managed by 3Rs practices, 25.3-63.5 $MtCO_2eq$ could be reduced, which is almost equivalent to net GHG emissions from Bangladesh in 1994. Therefore, a proper management of these wastes is of high importance.

Climate policies of these studied countries were reviewed. China, India, Indonesia, Thailand, Philippines, and Bangladesh emphasized improved waste management in their national climate change action plans. Amongst these countries, only China, India, Indonesia and Thailand indicated the 3Rs as measures for GHG emissions mitigation.

II. Greenhouse gas emissions reduction through the 3Rs

The 3Rs aim to reduce resource consumption, reduce waste generation, as well as increase resource recovery to further productivity, for soil amendment and for energy use. Our research found that applying the 3Rs can reduce GHG emissions at various stages and from several sectors, with direct benefits to the waste sector and indirect benefits to energy, industry, and land use change and forestry sectors.

Application of 3Rs to organic waste could reduce more GHG emissions compared to landfilling. However, the reduction potential varies, depending on technology and management practices.

Organic waste separation for reuse and recycle could also enhance separation of inorganic materials for recycling, and thus could reduce GHG emissions from production and consumption of inorganic materials.

III. The 3Rs and technology available for organic waste management in developing Asian countries

Technology applicable in developing Asian countries and available for reduce, reuse and recycle of food, paper, grass and wood wastes are reviewed in this report. The practices and technologies presented in this reports are i) reduction (e.g. reduce over-consumption), ii) reuse (e.g. animal feed, ground covers), and iii) recycle (e.g. composting, anaerobic digestion, biological extraction, pyrolysis, fuel briquettes, mechanical biological pre-treatment, and landfill gas recovery).

Among the 3Rs hierarchy for municipal organic waste management, reduce is better than reuse and recycling. Reduce can avoid overall environmental impact and reserve stock of natural resources. Reuse can extend the lifetime of a product and decrease demand need for additional production. Recycling can reduce demand for extraction of virgin resources. It however requires higher energy and resource input compared to reuse and has potential to generate negative environmental impacts. Still, even when recycling generates some GHG emissions, the net balance is still lower than the conventional thrown-away and landfill practice. For recycling of organic waste, anaerobic digestion is attractive over composting. Composting may release both methane and nitrous oxide and it has a trade-off of energy recovery.

IV. Policy recommendation on organic waste management hierarchy and selection of appropriate waste treatment technology

Successful implementation of reuse and recycle can be achieved if waste separation at source is promoted and practiced. Once organic waste separation at source is introduced, this waste should be divided into four sub-categories: food, paper, wood products, and grass (including plant residues and garden wastes). However, local governments may decide to reduce the number of categories based on handling capacity, quantity of waste and treatment technology.

Due to a problem of land scarcity and social resistance to new landfill construction, if waste separation at source fails, mechanical-(aerobic) biological treatment (MBT) is recommended for pre-treating the waste before dumping into landfill or incinerating. MBT can reduce moisture content and volume of waste (thus reducing space for land filling and energy use for incineration), enhance organic waste degradation under aerobic conditions (thus avoiding methane emissions), and enhance sorting of valuable resources from pile of inert waste (associate resource recovery).

A recommended 3R hierarchy for food waste management is reduce over consumption, reuse high quality leftover food for human consumption, reuse medium quality food waste for animal feed, recycling by anaerobic digestion, composting, MBT, and landfill gas recovery, respectively. Anaerobic digestion provides more benefits and generates lower potential GHG emissions compared to composting. However, the investment is higher than composting. Therefore, the government may need to consider the local need and investment capacity before choosing between these options.

Paper is more stable but contributes larger methane emissions per unit compared to food waste. A favorable hierarchy for paper is in line with reduction, reuse, reform, recycle (paper to paper), energy recovery (fuel briquette) and use of residues after burning for soil improvement. For this waste, incineration is more favorable than landfill gas recovery due to lower risk in GHG emissions. However, unsorted paper, which mixes a high ratio of food waste and plastics should be treated by aerobic MBT prior to landfill.

A recommended hierarchy for wood waste is reuse, repair, fire wood, new product development (e.g. mushroom media), fuel briquette, incineration, biochar, composting, controlled open dumping, and sanitary landfill equipped with methane collection system. Reuse, repair, fire wood, mushroom media, and composting are being practiced in developing Asian countries. However, fuel briquette and use of residue from burning and incineration as a soil conditioner is not yet well adopted. Controlled open dumping in designated area is more favourable than landfill disposal due to its potential for resource recovery and avoiding methane emissions.

Grass and garden waste can degrade naturally on the ground, however it looks ugly. Therefore, it is recommended that the management hierarchy should be in line with soil mulching, fodders for livestock, composting, grass products (e.g. construction brick), fuel briquette, biochar, anaerobic digestion, incineration, and sanitary landfill equipped with methane collection system. Grass may be added and co-processed in composting and anaerobic digestion of food waste in order to adjust waste input quality.

A decision diagram is provided to facilitate decision making by local governments. In practice, practitioners mentioned that only 30% of organic waste can be separated in good quality. Local authorities may not be able to apply all recommended 3R hierarchies, and may instead select some of the options based on waste quantity, waste characteristics, local context, interest of local residents, beneficiaries of the technology as well as personnel and investment capacity.

Contents

List of tables

List of figures

List of boxes

I.
Introduction

Climate change is recognized 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 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 can increase or reduce the emissions of GHG at other stages.

The study presented in this report looks at the linkages between municipal solid waste (MSW) management and the 3Rs (reduce, reuse, recycle) on the one hand and GHG emissions on the other. More specifically, the study investigates how improvements in the end-of-life stages – such as separate collection of food waste and increased recycling – can have climate benefits. It should be pointed out that improvements of waste management in most cases are undertaken for other reasons than climate protection, such as health protection. Hence, the related climate benefits are sometimes referred to as "co-benefits."

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 selected countries. The review of national climate strategies looks at whether and how these documents include actions aiming 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 from other sectors. The latter indirect benefits can be, for example, emissions from steel production which can be reduced if more steel is recycled (assuming that recycling leads to a decrease in the production of new steel.) The difference between the direct emissions related with waste treatment and disposal, and the indirect effects that different end-of-life management options can have on emissions at other life-cycle stages and in other sectors are discussed. A key message here is that these indirect climate benefits are likely to be substantial but often overlooked. An indication of this lack of attention given to the climate benefits of the 3Rs is provided by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). This major report devotes one full chapter to GHG emissions from the waste sector, but the climate benefits related with the 3Rs are only mentioned in a couple of paragraphs.

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 for resource recovery from organic waste are described and case studies show some experiences of using these technologies.

Fourthly, the report introduces management hierarchies indicating the most preferable treatment technologies for food, paper, wood and grass taking climate co-benefits, resource efficiency and energy input into consideration. A decision diagram, which is intended as a guide for decision makers on how to select appropriate organic waste management options for local circumstances is also provided.

We believe that proper organic waste management, providing local benefits as well as global ones in the form of climate change mitigation, is an affordable task for local governments. 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 implementation of 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 3Rs. Through education and training, awareness of 3Rs should be promoted as a key factor for decision making (particularly on selecting type of technology and project scale) and project implementation.

Hopefully, this policy report could help local governments in selection and implementation of suitable technologies for organic waste management in their cities. It would also be valuable to other policy makers, 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: overview

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

This section summarizes the national anthropogenic GHG inventories of developing Asian countries, which were reported to the UNFCCC in the initial national communications (***Table 1***). The studied countries are China, India, Indonesia, Thailand, Viet Nam, Malaysia, Philippines, Bangladesh, Cambodia and Laos. These countries are now preparing their second national communications which will present the 2000 national GHG inventories. Since these communications are not yet complete the discussion on this section is based only on the initial national communication.

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

Country	National GHG inventories in 1994 ($MtCO_2$eq.)*	GHG emissions from the waste sector in 1994 ($MtCO_2$eq.)		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	MNRE, 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.

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 IPCC guidelines. 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%). As shown in ***Table 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.

Table 2 GHG inventory by sector in studied countries in 1994

Unit: $MtCO_2eq.$

Country	Energy	Agriculture	Industrial process	Land use change and forestry*	Waste	Total	Sources
China	3,007	605	283	-390	162	3,667	Chinese Government, 2004
India	744	345	103	14.3	23.2	1,229	MoEF, 2004
Indonesia	222	84.5	0.0329	164	8.44	479	MENLH, 1999
Thailand	130	77.4	16.0	61.9	0.740	286	MSTE, 2000
Viet Nam	25.6	52.4	3.81	19.4	2.56	104	MNRE, 2003
Malaysia	97.9	4.97	6.91	-61.1	26.8	75.5	MOSTE, 2000
Philippines	50.0	33.1	10.6	-0.126	7.09	101	IACCC, 1999
Bangladesh	15.2	28.1	1.28	7.84	1.31	53.7	MoEF, 2002
Cambodia	1.88	10.6	0.0498	-17.9	0.273	-5.10	MOE, 2002
Laos**	0.93	5.70	0.0000	-104	0.240	-97.1	STEA, 2000

*The net emissions after accounting for carbon sinks.
** GHG inventory in 1990.

It is very doubtful that the reporting of emissions from the waste sector in the national GHG inventory submitted to the UNFCCC is accurate. Some waste is disposed of informally by residents (***Fig. 1***). Some is dumped into rivers and other water bodies. These practices make it very difficult to estimate the amount of waste and the potential methane gas emissions.

However, it is predictable that national GHG inventories for the second national communication to the UNFCCC of the studied countries will substantially increase due to the following reasons:

i) 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 3***, plastic waste shares 4-17% of waste composition in the studied countries. Often, these plastic wastes are treated by open burning.

ii) 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 increase of waste generation rate 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, there is a prediction that municipal solid waste and urban food waste

[1] It should be noted that these guidelines are 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.

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 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).

iii) Increase of waste collection rate for disposal in landfills. The potential of 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.

Fig. 1 Illegal dumping and traces of open roadside burning

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

In order to identify which components of municipal solid waste are the main sources of GHG emissions from the waste sector, we reviewed available data on waste generation and waste composition from various sources, see ***Table 3***. 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 developing Asian countries is organic (40-74% food and 3-25% paper) and plastic (4-17%) wastes. 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.

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, GHG emissions from open burning of solid waste are included in the second national communications. Thus, the main sources of GHG emissions from the waste sector are organic and plastic wastes.

In this study, we will focus on organic waste management as it is 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.

Table 3 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	45-55	10-20	5-15	2-4	2-4	2-36
India[c]	42[b]	0.4 (0.2-0.6)[b]	40	5	4	1	2	47
Indonesia[e]	22.5[d]	0.76[e] (0.6-0.85)[d]	74	10	8	2	2	2
Thailand[f]	14.7	1.1[g]	64	8	17	2	3	3-6
Viet Nam[h]	12.8	0.4 (0.3-0.7)	55-65	4-25[i]	16	6	7	20
Philippines[j]	11[k]	0.5	45	16	15	6[l]	<9	15
Malaysia[m]	8.7	0.9[n]	49	17	10	2	4	18
Bangladesh[o]	4.87[p]	0.41	68	10	5	0.3	1.1	15.6
Cambodia[p]	no data	0.34	66	3	14	1	1	15
Laos[q]	no data	0.75	60	10-15			10-15	10

Sources: [a]Rissanen and Naarajärvi, 2004; [b]Kurian, 2007; [c]Toxic Link, 2002; [d]Balifokus et al., 2006; [e]Zurbrugg, 2002; [f]PCD, 2009; [g]IBRD, 1999; [h]World Bank, 2004a; [i]Hanoi University of Science, 2004; [j]World Bank, 2004b; [k]Aguinaldo, 2008; World Bank, 2001; [l]JICA, 2006; [m]Lee and Hanipiah, 2009; [n]DOE et al., 2004; [o]Waste Concern, 2005; [p]Maclaren, 2005; [q]Keodalavong, 2007.

[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 is 25 times stronger climate impact than carbon dioxide (Forster et al, 2007).

2.3 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 and Bangladesh. The Philippines, Viet Nam, Malaysia, Laos and Cambodia are still developing theirs.

For this report, we reviewed how the selected countries accommodated waste management and 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 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 3Rs approach can contribute to the achievement of the national objectives in these sectors. For countries that do 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 4***. 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, only China, India, Indonesia, and Thailand 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 emphasized 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 2008 focuses on the development of final disposal sites (landfills) with gas recovery that can bring revenues under the Clean Development Mechanism (CDM) (***Box 1***). This plan seems to be based on an end-of-pipe approach that does not promote resource efficiency.

Table 4 National climate change policy for the waste sector and 3Rs approach in selected developing Asian countries

Country	Mention of the waste sector (municipal solid waste)	3Rs approach to climate change	Sources
China	Yes	Reduce, Recovery, Utilization	NCCCC, 2007
India	Yes	Reduction, Recycling	PMCCC, 2008
Indonesia	Yes	5Rs for industry & 3Rs for domestic waste	MENLH, 2007
Thailand	Yes	3Rs	ONEP, 2008
Bangladesh	Yes	No	MoEF, 2008
Philippines	Limited	No	IACCC, 1999
Viet Nam	No	No	MNRE, 1999
Malaysia	No	No	MOSTE, 2000
Cambodia	No	No	MOE, 2002
Laos	No	No	STEA, 2000

Box 1: CDM and the waste management

The Clean Development Mechanism is an international carbon trading mechanism under which industrialized 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).

For the Philippines, a specific national climate change action plan is yet to be developed. Our review was therefore based on the initial national communication to the UNFCCC in 1999. However, the Philippines had already included 3Rs practices for waste minimization and utilization in the Ecological Solid Waste Management Act (NSWMC, 2000). The Philippines may choose to include the 3Rs in a future climate change mitigation plan because the share of MSW of the total national GHG emissions of this country was higher than for most of the other studied countries.

In all 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 5***). Only India and Thailand mentioned waste separation at source, that this practice is very important for successful implementation of reuse and recycling. Further, the CDM seems to be attractive to the studied countries as they are expecting to sell carbon credit to developed countries.

Brief summaries of the national action plans on climate change mitigation of the studied countries are presented in ***Appendix I***.

Table 5 Summary of strategies for national climate change mitigation in the waste and related sectors.

Countries	Waste management									Agriculture	Others
	Waste reduction	Reuse	Recycling of non-organic waste	Waste separation	Composting	Anaerobic digestion	Landfill gas recovery	Incineration	Other waste to energy technology	Promoting use of compost	
China	O	O	O		O	O	O	O	O	O	
India			O	O	O	O			O	O	
Indonesia	O	O	O						O	O	
Thailand	O	O	O	O	O				O	O (reducing use of chemical fertilizer)	- Promoting use of biodegradable products
Bangladesh					O		O		O		

III.
Greenhouse gas emissions reduction through the 3Rs

As discussed in part ***II*** *(Overview)*, 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. The 3Rs 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, for effective implementation, the 3Rs usually require active participation of several stakeholder groups.

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 recycling 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.

Essentially, the 3Rs approach is based on the idea of using resources efficiently before their final disposal. Hence, appropriate waste management through the 3Rs (reduce, reuse, recycle) can reduce GHG emissions from the entire life-cycle of resources as shown in ***Fig. 2***. During the production stage, the 3Rs aim to reduce the extraction of natural resources, reduce resource input for production without sacrificing product quality, as well as recycling resources for producing new products. This reduces emissions from land use change and forestry, agriculture, mining and industry sectors. During the consumption stage, the 3Rs aim to reduce the use of natural resources by reducing consumption and reusing resources - through refilling, repairing, and refurnishing - thus reducing emissions from land use change and forestry and energy sectors.

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

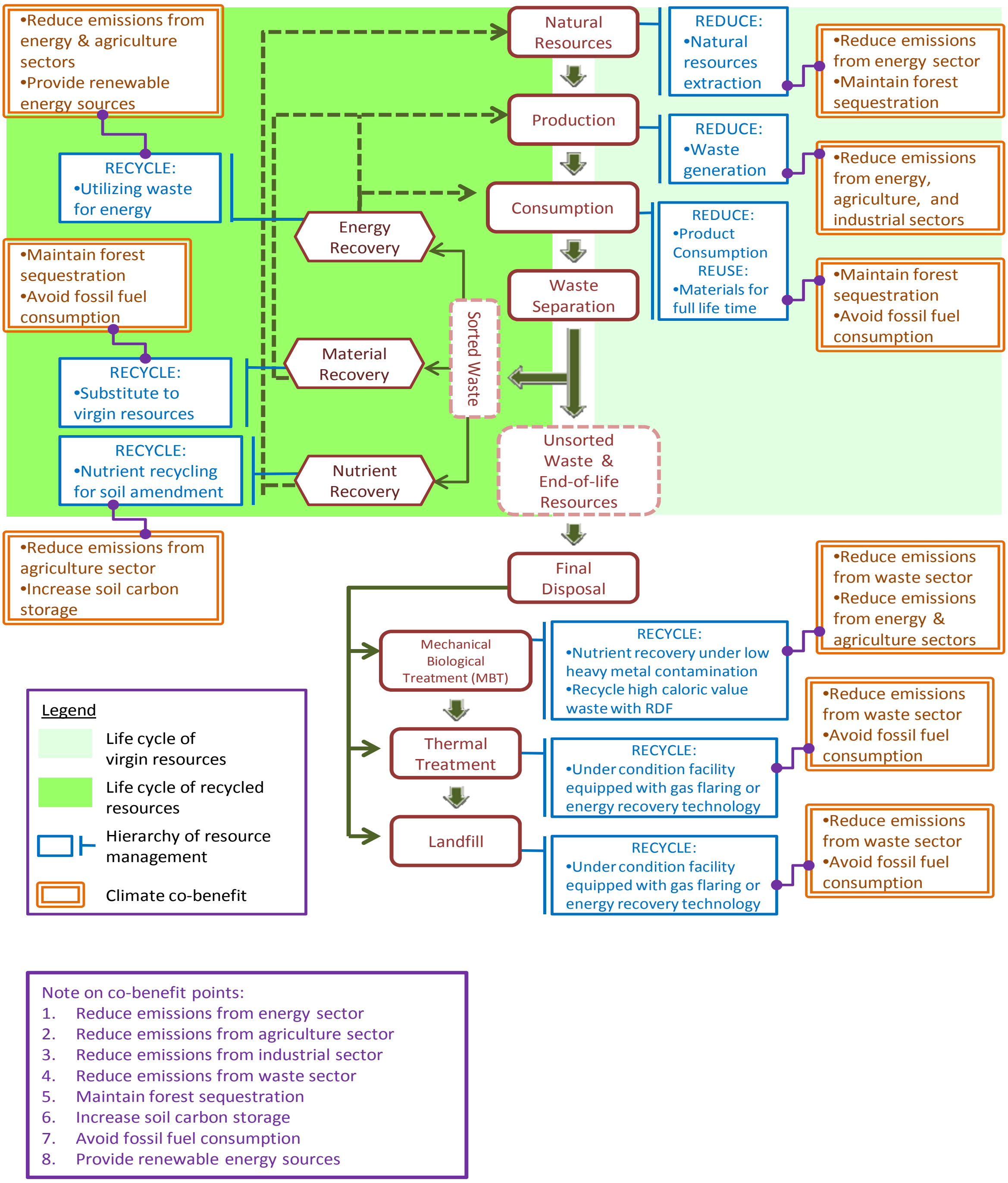

Fig. 2 3Rs practices at different life-cycle stages and their climate co-benefits

However, if separation at source is not practiced, there are other technical solutions available for recovering valuable nutrients and energy from organic waste, including aerobic biological treatment, landfill gas recovery, and thermal recovery (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 6)***. However, when regarded from a life-cycle perspective, when composted municipal solid waste is applied for soil fertilization, it can reduce GHG emissions from the agriculture sector, by reducing nitrous oxide emissions from the use of chemical fertilizer 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 fertilizer (Favoino and Hogg, 2008).

Table 7 presents calculations of potential GHG emissions from landfill disposal of food and paper wastes in the studied countries. Potential GHG emissions are generally depend on quantity of waste dumped, depth of landfill, and landfill management system. For this estimation, we use minimum and maximum default value for landfill depth which varied from unmanaged shallow landfill to well managed sanitary landfill (see ***Box 2***). Based on this estimation, the emissions from China were higher than those from other countries, followed by India, Indonesia, Viet Nam, Thailand, Philippines, Malaysia and Bangladesh. Practically, it is difficult to apply 3Rs to reduce all waste generated in the city. With great effort from the government and stakeholders, 30% reduction can be achieved which would result in reducing 15.5-39.0 $MtCO_2eq$/yr from food waste and 9.8-24.5 $MtCO_2eq$/yr from paper waste generated in the studied countries.

In addition, we estimated potential GHG emissions from waste reduction (compared to landfill), composting, and anaerobic digestion using default value from the 2006 IPCC Guidelines (See ***Box 3***). It was found that reducing one kilogram of food waste can reduce methane emissions from landfill by 0.42 $kgCO_2eq$ compared to shallow landfill and 1.05 $kgCO_2eq$ compared to deep landfill without gas recovery practice (***Table 8***). Paper and grass contain more degradable organic carbon per unit of weight than food waste, and thus their potential GHGs emission reduction potentials are higher than that of food waste (see ***Box 2 for reference***).

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 under a non-recycling scenario. Based on the 2006 IPCC guidelines on calculation of GHG emissions from biological treatment, composting and anaerobic digestion can reduce net GHG emissions (***Table 8***). 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 3** for details*). This calculation shows wide ranges of potential emissions reduction from waste reduction, composting and anaerobic digestion. The efficiency of GHG emissions from composting and anaerobic digestion depends on technology and management efforts. As shown in ***Table 8***, unmanaged composting of grass may contribute larger amount of net GHG emissions compared to landfill due to high global warming potential of nitrous oxide[3].

Table 6 Climate co-benefits of 3Rs application for organic waste management in main sectors.

Sectors	Climate co-benefits
Waste	• Reduced methane emissions from landfill. • Reduce carbon dioxide emissions from burning or incineration of plastic waste. Once organic waste is separated, it could improve cleanliness of plastic and other recyclable materials (Schouw et al, 2002), and thus increase reuse and recycling of plastic. Therefore, it can reduce the volume of plastic waste to incineration or open burning.
Energy and transport	• Reduced quantity of organic waste sent to landfills and incineration, and thus reduced emissions from energy use for waste transportation and treatment. This benefit would be obvious when community based and decentralized organic waste management is implemented. • Decrease the demand for new products and therefore also reduced emissions from energy use for production and distribution. • Reduced demand for agricultural and agro-industrial products can reduce energy use for agriculture, transportation and processing of those resources, and thus reduce emissions from energy use. • Energy recovered from organic waste can replace fossil fuels, and thus reduce emissions from energy sector • The use of compost and sludge of anaerobic digestion instead of chemical fertilizer can reduce emissions from chemical fertilizer production (Favoino and Hogg, 2008). • Compost reduces soil compaction and improves water infiltration rate (Shelton, 1991), thus could reduce energy used for tilling.
Industry	• Reduced demand for virgin materials and new products (e.g. instant and processed food, chemical fertilizer), and thus reduced emissions from industrial processes.
Agriculture	• The use of compost and sludge of anaerobic digestion instead of chemical fertilizer can avoid nitrous oxide emissions from farmland (Favoino and Hogg, 2008). • The use of compost can increase soil carbon sequestration which could reduce GHG emissions and also improve soil quality for plant growth (Favoino and Hogg, 2008).
Land use change and forestry	• Reduced demand for virgin resources can reduce mining activity in forest areas and logging, and thus reduce emissions from mining and deforestation. • Use of organic waste for soil improvement can preserve or enhance land productivity and thus reduce deforestation. • The 3Rs applied to paper and wood products can reduce deforestation.

Remark: The baseline for this comparison is that the waste would be either disposed in a landfill without gas recovery or incinerated without energy recovery and ineffective flue-gas cleaning.

[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 methane is 298 times stronger climate impact than carbon dioxide (Forster et al, 2007).

Table 7 Potential GHG emissions from landfill of food and paper wastes in developing Asian countries

Country	Type municipal solid wastes (Mt/yr)*			Potential GHG emissions from landfill of food and paper wastes ($MtCO_2eq/yr$)			
	Total	Food	Paper	100% landfill		70% landfill (30% reduction)	
				Food	Paper	Food	Paper
China	120	60	18	25.2-63.0	20.2-50.4	17.6-44.1	14.1-35.3
India	42	16.8	2.1	7.1-17.6	2.4-5.9	4.9-12.3	1.6-4.1
Indonesia	22.5	16.6	2.2	7.0-17.5	2.5-6.3	4.9-12.2	1.8-4.4
Thailand	14.7	9.4	1.2	4.0-9.9	1.3-3.3	2.8-6.9	0.9-2.3
Viet Nam	12.8	7.7	1.9	3.2-8.1	2.1-5.2	2.3-5.6	1.5-3.6
Philippines	11	5.0	1.8	2.1-5.2	2.0-4.9	1.5-3.6	1.4-3.5
Malaysia	8.7	4.3	1.5	1.8-4.5	1.7-4.2	1.3-3.2	1.2-2.9
Bangladesh	4.9	3.3	0.5	1.4-3.5	0.5-1.4	1.0-2.4	0.4-1.0
Sum	236.6	123.1	29.1	51.8-129.3	32.7-81.6	36.3-90.3	22.9-57.1

** See Table 3 for references.*

Box 2: Estimation of methane emissions based on the mass-balance approach

The IPCC guidelines provide two methods for 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 which reflects time factor for annual emissions estimation. Therefore, the FOD method provides 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 reduction from waste management. The equation of this method is as follows:

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

MSW_T = Total municipal 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)

Table 8 Potential GHG emissions from reduction, reuse and recycling of organic waste

Organic waste	Potential net GHG emissions reduction compared to landfill ($KgCO_2eq$ / kg of organic waste)		
	Waste reduction	Composting	Anaerobic digestion
Food waste	0.42-1.05	0.07-1.03	0.25-1.05
Paper	1.12-2.80	0.20-2.74	0.70-2.80
Grass	0.48-1.19	-0.44-1.13	0.06-1.19

Remarks: Minimum value stand for emissions reduction compared to shallow landfill (<5m depth),

: Maximum value stand for emissions reduction compared to deep sanitary landfill (>5m depth).

: High emissions in CO_2eq of composting, especially of grass, is caused by high global warming potential of nitrous oxide emitted from composting process, particularly vermin-composting.

Box 3: Default value for GHG emissions from biological waste treatment

GHG emissions from composting and anaerobic digestion depend on factors such as type of waste composted, temperature, moisture content and aeration during the process (IPCC, 2006). In this study, the default range of value provided by the 2006 IPCC guideline 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% DOC in dry matter - 2% nitrogen in dry matter - 60% moisture content
Anaerobic digestion	2 (0 – 20)	1 (0 – 8)	Assumed negligible	Assumed negligible	

As shown in ***Box 3***, waste reduction is the best option since there is no need to make any investment to achieve GHG emissions reduction. Anaerobic digestion has lower potential GHG emissions than composting. It could also provide co-benefits of energy and nutrient recovery. Therefore, anaerobic digestion is more attractive than composting in term of climate change mitigation and resource circulation.

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 food source for bacteria and pests. The Indian national action plan on climate change has also emphasized that increase organic waste separation for composting could also increase recycling of inorganic materials. Recycling of inorganic materials can sometimes reduce GHG emissions by up to 80-95% (***Box 4***) if virgin resources can be replaced. Effective recycling systems for these materials can therefore be very important for climate protection.

Box 4: Climate co-benefit of recycling of inorganic materials

The use of recycled materials can decrease GHG emissions from using virgin material. As shown in 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 material with virgin material.

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

IV.

3Rs 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, so are adaptation and mitigation actions to deal with GHG emissions from such waste. alternatively it can be viewed as an asset; for example, its recycling can provide local employment, its nutrients can contribute to soil fertilization, 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 recycling (including nutrient and energy recovery) are explained. The technology limitation and examples of actual implementation are also identified (***Table 9***). A few successful and failure stories are presented.

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

- Food waste discussed in this study is generated by households, restaurants, supermarket, fresh market, schools, organizations, 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 organizations 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, for example, saw mills and large-scale furniture factories.
- Grass waste includes garden waste, bush residues and fallen leaves from the municipal area. This report does not cover waste generated in agricultural areas, since collection and treatment of this 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.

4.1 Reduction

Reduction 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 reduction. This is because of the increase of waste generation due to modern materialistic lifestyles which are rapidly emerging in Asian developing countries. Through reduction 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, waste treatment), and waste (emissions from biological degradation and burning).

Food waste is a major component of municipal solid waste and it contributes the largest share of GHG emissions from the waste sector. The best way to reduce food waste is to calculate the 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 contribute to reducing GHG emissions through reducing food waste during food production and waste disposal. Reduction of conspicuous food consumption would also reduce household expenditure.

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 (mixed soup) and northern Thai people (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 as contributions to reduce burden on local government and decrease risk of GHG emissions from waste management. 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 organizations. 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.

Urban wood waste from furniture and construction sites is often reported as a part of “other” waste or sometimes as ‘wood and leaves’ in the waste statistics. It is therefore assumed that wood waste in developing countries is a small share of municipal solid waste. However, ‘wood and leaves’ may in some cases share a quite significant percent of municipal solid waste, for example at a dumping site in Bangkok which is estimated to consist of 13% ‘wood and leave’ (Nitikul, 2007).

4.2 Reuse

Reuse here refers to two activities: i) distribution of one's used product to other persons which they can then use either for its original purpose or for a new purpose with little or no processing. For example, old wooden furniture of a wealthy man reused by a poorer family; and ii) using a product that cannot function in its original purposes to serve as a new type of product with little or no processing. For example, paper that originally produced for writing or printing. once both sides are used it cannot be used for its original purposes anymore. However, it can be used as a wrapping material or reshaped as a paper bag, which is typical in developing Asian countries.

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 wastes, though it should be noted that 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, if advanced processing is involved, such as in the production of pelletized feed, it may be more adequate to consider it as recycling. Production of feed pellets can increase use of food waste in a larger scale because the feed can be stored and distributed over a long distance. 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 fowls are raised at home. In some urban areas, 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. Food waste from restaurants in Cambodia is collected for pig feed.

Due to 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).

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 animal health.

The use of organic waste for animal feed requires collection and transportation, which adds to costs, and the system will not be workable if it is not cost-effective. Therefore, reusing food waste for animal feed is mainly applied to large sources of waste such as markets, restaurants, cafeterias and hotels, as it is economically viable for collectors. 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 Nonthaburi Municipality were sold to duck farms. A similar practice was also found in Phitsanulok Municipality.

Also, as a strategy to prevent 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 the cold season[4] (Pichittoday, 2008). Therefore, it can be expected that the collection of organic waste from the vegetable and fruit markets, and restaurants and cafeterias for duck feed will increase.

Plant residues such as trimmings, leaves, and grass can be applied directly for soil mulching. This practice requires low labor input and low investment. Use of plant residues 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 either by donation or by selling (***Fig. 3***). 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 wood.

Fig. 3 Separation of wood furniture for reuse in Wat Suankaew, Nonthaburi, Thailand (photo by Dr. Yasuhiko Hotta, IGES)

[4] Wild birds migrate from China and Siberia to Thailand during November to February

4.3 Recycle

Recycling involve a complex set of activities in a process to recover resource from waste. Recycling requires more time, labour inputs, higher investment, and may produce more GHG emissions during the process than reuse and reduce. A product from recycling 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 in general these can be expected to be smaller than the GHG emissions that would occur as a result of landfill disposal.

Objectives of recycling organic waste are to recover valuable nutrients and energy. Nutrient recovery includes composting and biological extraction; energy recovery is such as fuel briquette. Some technologies enable anaerobic digestion (biogas and nutrient), pyrolysis (heat and biochar) while mechanical biological treatment of mixed waste could recover nutrients for soil improvement and other inorganic materials (e.g. plastic and metals) for recycling.

4.3.1 Recycle of sorted organic waste

i) Composting

Composting is based on microbial degradation of food, vegetables, fruits, leaves, grasses, and crop residues - sometimes mixed with tissue paper, nappies and paper.

Composting is a traditional practice for agricultural waste; however it is also applicable to municipal organic waste. The composting of MSW is practiced in the studied countries, particularly in China, Thailand, Cambodia, Bangladesh, Indonesia, Philippines, India, and Viet Nam. However, the average composting of MSW in the studied countries, as reported by several researchers, ranged only from 5-15%.

Composting techniques include very simple ones, such as windrow composting (***Fig. 4***) and in-basket composting (***Fig. 5***) to more complicated ones, such as in-vessel system. Composting requires regular management, such as waste separation and plant operation. 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 cost is 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 sources. Therefore, many large-scale composting plants fail (Zurbrugg 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 term 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 fertilizer.

Therefore, compost should be fortified with chemical fertilizer, as is already practiced in Bangladesh.

Fig 4. Windrow composting of municipal organic waste

Fig 5. In-basket composting of municipal organic waste
(Photo by Toshizo Maeda, IGES)

Composting can reduce the GHG emissions from the waste sector, but some researchers reported that composting also releases nitrous oxide and methane. Vermin-composting releases nitrous oxide, which is a more potent GHG than methane. Nitrous oxide emissions are positively correlated with the number of earthworms (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 aerobic conditions of the pile. Composting should be accelerated through the management of the wet and dry ratio of the waste pile. Dried plant residues, leaves, sawdust, and rice husk can be added to increase the dry ratio of the pile.

Box 5: Successful case: Decentralized composting in Surabaya, Indonesia

In Surabaya community based composting has been successfully introduced utilizing local resources, and low-cost and low-tech compost technologies. The initiative was taken in 2000 by Pusdakota, a university-based NGO, which conducted 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 10% waste reduction from 1,500 ton/day in 2005 to 1,300 ton/day in 2007. Compost baskets were distributed for free to 16,000 households and active participation from householders could reduce 16 ton/day of organic waste (Maeda, 2009). In addition, 12 composting centres were developed to treat market and household wastes and thus resulted in reduction of organic waste by 40 ton/day (Prapti, 2009).

A market for produced compost is provided by the Surabaya city government which purchases it for city parks use. In order to extend Surabaya's achievements, in cooperation with Kitakyushu City, the KI Secretariat has developed Surabaya's Solid Waste Management Model as a compost replication model aiming for 10% of waste reductions 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, the Philippines and Thailand.

Based on preliminary estimation, 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.

Box 6: 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 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 scales received subsidies of 1.58 million USD (1 USD ≈ 10,256 Indonesian Rupiah). From 2002 to 2004, increased subsidy was provided to compost producers to meet production quota targets and to fulfil administrative and technical requirements. Retroactive subsidy was provided by paying 10% of total production cost to producers (Prapti, 2009). It was estimated that 216.5 tons of compost per day were produced, with estimated reduced emission of 50.5-743.7 tCO_2eq/day.

Unfortunately, almost 50% of co-producers of WJEMP become stagnant compost producers. Prapti (2009) notes that this project mainly relies on subsidy. The market was also driven by subsidy from government and lack of involvement of concerned stakeholders including compost users (e.g. farmers, plantation, City Park and forestry), the related department of the local government and related agencies at national level (e.g. Department of Forestry, Department of Trade, Department of Industry and the Ministry of Small and Medium Enterprise). At the end of the project there was no clear mechanism for producers to proceed and no market for produced compost.

ii) Anaerobic digestion

Biogas can be generated using anaerobic digestion systems. It is typically manufactured using cow and pig manure. The biogas can be used for cooking and electricity generation. However, this technology is quite new for municipal solid waste and the operation systems are more complicated because, unlike manure, municipal organic waste is not homogenous.

Anaerobic digestion for biogas generation has some advantages over composting, bio-extraction and landfill gas recovery. For example, anaerobic digestion requires a smaller area for operation and the gas collection is easier and more effective than landfill gas recovery. Solid residues from the digestion that contain low quantities of heavy metals can be applied as organic fertilizer (Sripanomthanakorn and Polprasert, 2002). The time required for anaerobic digestion is also shorter than for general composting techniques.

Anaerobic digestion for municipal solid waste is implemented in several of the studied countries, however, the rate of implementation is still low as the investment, maintenance costs and technical skills required are much higher than for composting. In 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.

This review found that the studied countries mainly focus on large-scale anaerobic digestion and most projects fail because of over-capacity (e.g. Müller, 2007) and because they are not adapted to local conditions. Therefore, it can be concluded that large-scale anaerobic digestion is unsuited to developing countries especially where organic waste separation at sources is not common. Small- to medium-scale (less than 50 tons of waste per day) projects that generate biogas from municipal organic waste are best suited to developing countries because they require less investment, are easier to operate, and a better fit to the types and volumes of municipal waste.

Box 7: Successful case: Decentralized anaerobic digestion in Kerala, India

Kerala is located in southern India. Waste generation is 137 ton/day. Most waste is dumped into landfills (ENVIS centre-Kerala, 2009). Around 1999, a NGO, BIOTECH, started to run a household level biogas plant for kitchen waste treatment and production of gas for cooking. The cost of one cubic meter capacity household biogas plant ranged from 219 – 365 USD. Approximately 15,000 units of household biogas plants were installed. The produced gas is used for cooking which possible to replace one third of household cooking energy. The digester effluent can be used for soil fertilization (Heeb, 2009). Through continuous development, BIOTECH has installed many anaerobic digestion plants for kitchen waste treatment in various scales.

- 170 toilet-linked biogas plants. These plants could be equipped with additional inlet for kitchen waste input. The size is 2 m^3. The gas produced is used for cooking.
- 200 biogas plants in hotels, schools, hospitals and other institutions with the size of 4-10 m^3. The biogas produced is used for cooking. Biogas generation from a large size digester (50 m^3) could be assisted with an electric generator.
- 28 market level plants have already been built and 22 more are under construction or in planning. The size is 25 m^3 which is possible to treat 250 kg of waste per day.

BIOTECH is very successful in implementing decentralized anaerobic digestion for kitchen waste treatment in Kerala. Heeb (2009) found that the success factors of this case are i) awareness of individual politicians of the importance and benefit of 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 8: Failure case: Anaerobic digestion in Lucknow, India

Lucknow has one of the largest biomethanation plants for 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. 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 sufficient regular supply of organic waste and the waste input to this facility was highly mixed with non-degradable wastes (Kurian, 2007).

iii) Biological extraction

Biological extract is a form of organic liquid fertilizer which contains various types of beneficial microorganisms. It is also referred to as Effective Microorganism (EM), bio-extract or biological liquid fertilizer. Biological extraction is achieved by fermenting waste, EM and sugar sources under anaerobic condition for 5-7 days. 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.

Biological extract is used as organic fertilizer, toilet and wastewater deodorant, composting starter, cleaning detergent for toilets and pets' 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 chemical from vegetables and fruit, reducing smell from fish, controlling mosquitoes, ants and houseflies, and cleaning accessories.

Biological extraction requires less time than composting and anaerobic digestion. It also requires lower labor input than composting. The disadvantage of biological extraction is that the product is more difficult to store than compost. The liquid contains high concentration of EMs 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 Pathumthani Municipality, Nonthaburi Municipality and Bangkok Metropolitan Administration, Thailand. A pilot project in Pathumthani Municipality produced biological extract from December 2006 to September 2007 and the municipality was able to reduce waste flow to landfill by 9.24 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 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.

iv) Pyrolysis

Pyrolysis is a very new technology for urban organic waste treatment and is mainly still under laboratory research. Pyrolysis is a 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 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 it 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.

v) Fuel briquettes

The briquette technique has been known to the developing countries of Africa and Asia-Pacific since the 1970s. Fuel briquettes can be produced from the high calorific value organic wastes such as paper, sawdust, wood and plant residues.

Briquettes can be used as an alternative to fuel wood, charcoal and kerosene. Briquettes are promoted to reduce the use of fuel wood in Africa, Cambodia and in Nepal.

Briquette use is suited to urban fringe areas where residents practice agriculture and do not have sufficient electricity and gas supply, such as in Laos, Nepal and Cambodia. It is also possible that fuel briquettes could have market value in the Asia-Pacific region as there is a common belief that food cooked using wood fuel is more delicious than dishes cooked using gas or electricity. Further, 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 a concern that hazardous materials such as printed paper contaminating lead should not be mixed for briquettes production.

3.3.2 Recycle of unsorted wastes

i) Mechanical Biological Pre-Treatment

It is recognised that careful separation at source is hard to achieve for any significant amounts of organic waste. Some practitioners are of the opinion that around 30% of organic waste separation can be achieved, but that this requires significant efforts. The rest, unsorted and containing high portion of organic waste should be treated properly to avoid GHG emissions.

Mechanical biological pre-treatment (MBT) under aerobic condition is an alternative to recover valuable resources from mixed urban waste. It is carried out in two main steps: i) fermenting mixed waste under aerobic condition for approximately nine months, thereby avoiding methane emissions from landfill disposal and ii) segregating valuable waste such as compost-like products, plastic, and others before dumping inert wastes into landfill or incineration. By this practice, 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.

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

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

The segregated plastic waste can be sold as a refuse derived fuel if it is not contaminated with chlorine (such as polyvinyl chloride). Other valuable materials can be segregated and sold in the recycling market.

MBT is being successfully practiced in Phitsanulok Municipality of Thailand. There is no problem of leachate and very less of waste volume is dumped into the landfill. This practice has a high potential to be replicated in other province.

ii) Landfill gas recovery

Landfill disaposal is an end-of-pipe solution for waste disposal. It is practiced by the burial of mixed municipal solid waste into a designated area and cover with soil. Landfills can be classified as uncontrolled landfill, controlled landfill, and sanitary landfill. Improper management of landfills may cause public nuisance, contamination of water resources and soils, as well as release GHG emissions in the form of methane to the atmosphere.

Generally, over half of waste dumped into landfills in developing Asian countries is organic waste, which could convert to methane gas under anaerobic conditions. This can be recovered for energy use in forms of gas and electricity (SCS Engineers, 1994). Unfortunately, most landfills in this region are not equipped with gas recovery systems.

Sanitary landfill should be constructed for disposal of non-recyclable materials such as plastic and mixed wastes that cannot be separated for recycling efficiently.

Unsorted food waste may be dumped into sanitary landfill if a gas recovery system is installed. However, it should be regarded as the last option due to the high investment needs, difficulty in collection of methane gas and rising trend of social resistance to landfill siting. Further, some researchers report that achievement of methane emissions reduction from landfill gas recovery projects is relatively low, one project only managed to achieve 34% of estimated emissions reductions (Plöchl et al, 2008). Additionally, the landfill gas utilization for power generation is often not economically attractive on its own. Feed-in tariff[5] and CDM financial mechanism is required to associate the project (Plöchl et al, 2008).

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

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

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

Table 9 Examples of 3Rs practices for municipal organic wastes

Management option	Reducing over consumption	Human food	Animal feed	Compost	Biogas	Biological extract	Soil mulching	Biochar	Fuel briquettes
3Rs category	Reduce	Reuse	Reuse	Recycling	Recycling	Recycling	Reuse	Recycling	Recycling
Suitable type of organic waste	Food, paper; wooden furniture and construction	Food	Food, vegetables, fruits, grass leaves	Food, vegetables, fruits and plant residues	Food, vegetables and fruits	Food, vegetables and fruits	Plant residues	Paper, plant residues, wood waste	Paper, plant residues, wood waste
Required waste quality	-	Very high	High	Medium (Low heavy metal)	Medium (Low heavy metal)	Medium (Low heavy metal)	Medium	Low (Low heavy metal, if the charcoal is applied for soil conditioning)	Low (No dioxin emitting waste)
GHG reduction in other sectors	Agriculture, Energy, industry, land use change & forestry, Food industry	Agriculture, Energy, industry, land use change & forestry, Food industry	Feed industry	Agriculture, Synthetic fertilizer industry	Energy, Agriculture, Synthetic fertilizer industry	Agriculture, Industries	Energy, agriculture, synthetic fertilizer industry	Energy, agriculture, synthetic fertilizer industry	Energy, land use change & forestry
Potential project scale	Household to large scale	Household	Household to community	Household to large	Household to large	Household to large	Household to large scale	Medium to large scale	Household to large scale
Investment	None	Almost none	Very low	Low to medium	Medium to high	Medium	Very low	High to very high	Low to medium
Example of practicing countries	Thailand	China, Thailand	Cambodia, China, Thailand	Bangladesh, Cambodia, Indonesia, etc.	India, Thailand	Thailand	Thailand	-	Cambodia, Nepal

V.

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 anaerobic fermentation of organic waste in landfills and GHG emissions in other non-waste sectors. Each technology has its specific strengths and weaknesses, therefore, in implementation, the local government should consider the local contexts prior to selection of technology: waste quantity, waste characteristic, waste generation behavior, land available, investment capacity, personnel, scale of implementation, beneficiary from technology, interest of local residents, stakeholders participation and negative impact of technology. Preliminary study and public hearing should be carried out prior to decision making. Whatever the case, successful implementation of the 3Rs cannot be achieved without 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 (landfill and incineration). The 3Rs are therefore highly important to solve the said problems.

In this section, appropriate organic waste management hierarchies for 3R implementation based on climate co-benefit, resource efficiency and energy balance are presented. The hierarchies presented indicate what can be regarded as the most appropriate options for the main types of organic waste. Alternative options are provided for unsorted organic waste. A decision diagram is provided to guide the decision making of local governments. However, 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 food source for animal and microorganism. Paper and wood wastes are stable forms of organic waste which 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 10**. For the municipality which takes full responsibility for disposal of waste generated in the municipal area, the promotion of waste reduction and reuse is required to reduce waste flows to final disposal site. Current waste management practices in most areas do not meet the environmental standard 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 large amount of methane emissions from landfill and open dumping of organic waste where methane collection are not practiced. For social need, we considered food and energy security, poverty reduction and income distribution as a factor. For technology aspects, higher priority is given to technology that could utilize the resource efficiently, contribute least GHG emissions, and require low energy and monetary input. The preferable technology should also be possible to be handled by the local government with little external supports.

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

Table 10 Significant factors for development of organic waste management hierarchy

Municipality need	**Social need**	**Preferable technology**
• Reduce waste flows to final disposal site • Collection and safe treatment of waste • Reduce cost for waste collection and disposal • Reduce environmental impact from waste treatment • Simple and easy to handle	• Food security • Energy security • Poverty reduction/job creation • Income distribution	• Low GHG emissions • Efficient resource recovery • Low energy input • Low monetary investment • Low environmental impact

5.1 Food waste

In the studied countries, food, fruit and vegetables are the largest source of organic wastes, and they can account for more than 80% of municipal organic waste generation. 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.

Food waste has high moisture content, low calorific value, high nutrient value, and degrades rapidly. Taking into account climate co-benefits, resource recovery, and energy input, an integrated management hierarchy is identified as shown in ***Fig. 6***.

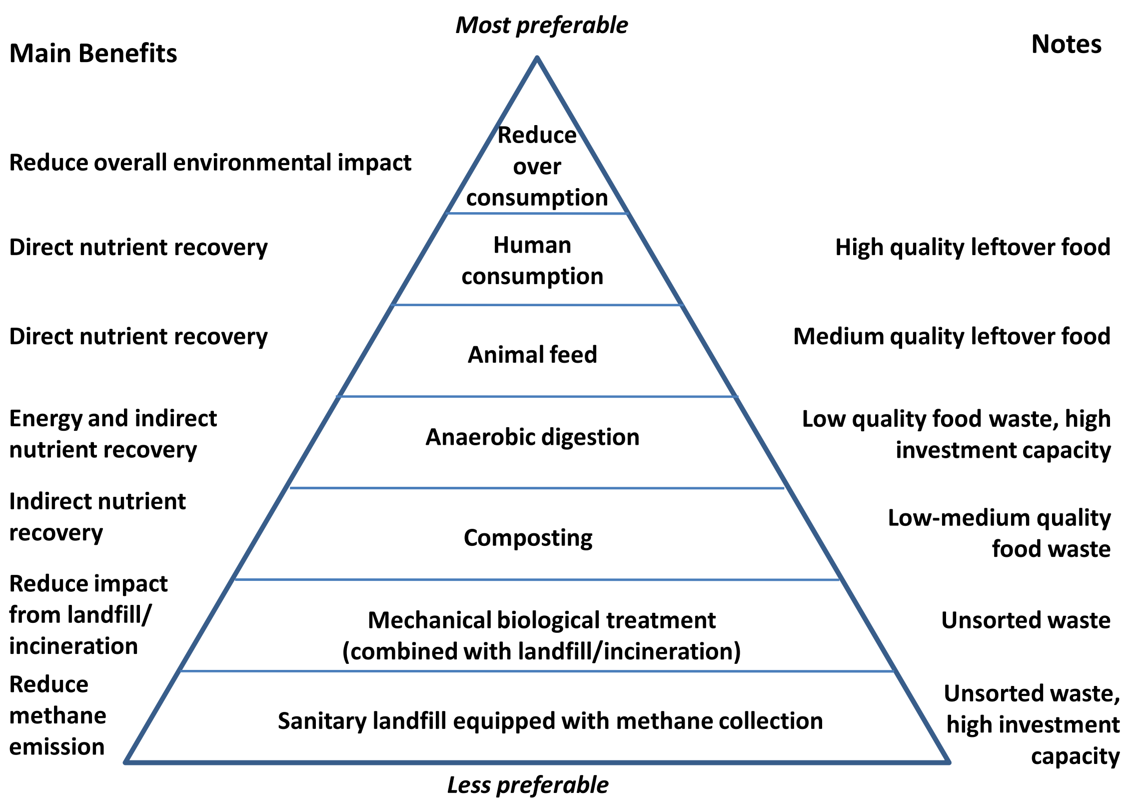

Fig. 6 Recommended integrated food waste management hierarchy for developing Asian countries

Taking account of Asian behavior on food consumption, reduction of over demand of food leading to waste needed to be highlighted. Very high quality of 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. However, the investment is higher than composting.

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

In the area where separation at source for food waste is not well practiced, mechanical biological treatment (MBT) should be applied prior to landfill disposal and incineration. Direct incineration of food waste is not recommended as it requires high energy input.

5.2 Paper waste

Paper has high calorific value and low moisture content. Therefore paper 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. 7***). The paper that is still in good quality should be reused, for example using both sides of the paper, and then using the used paper for wrapping. The non-reusable paper can be mixed to produce other kinds of product such as bricks or pots which would produce less environmental impact compared to recycled paper production. The use of paper for fuel briquette is given next preferable as we considered that the end-of-life of those products can be used as a soil conditioner.

Thermal treatment such as pyrolysis, controlled combustion and incineration of paper is preferable to landfill disposal due to its high calorific value which make it consume less energy for incineration. Further incineration of paper can avoid methane emissions from landfill. Biochar and ash from these thermal treatments can be used for soil improvement, once heavy metal contamination is lower than required standard.

However, if paper is mixed with other high moisture and low calorific value content, other options such as MBT and landfill gas recovery should be applied.

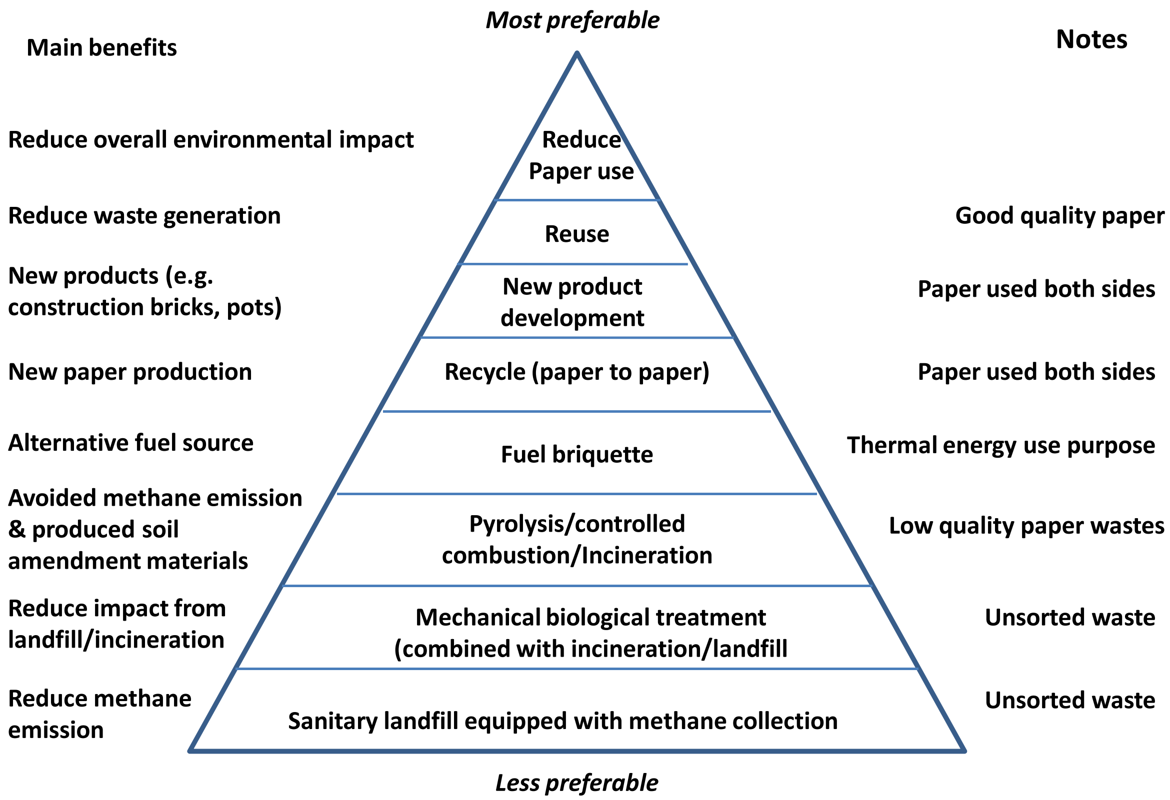

Fig. 7 Recommended integrated paper waste management hierarchy for developing Asian countries

5.3 Wood waste

Wood waste from furniture and construction sites has high calorific value and is large in size. A recommended management hierarchy starts from reuse and repair of wood products (***Fig. 8***). Used wood products can be distributed to other people who want it or be reused as construction material without processing. Repair is second preferred as some additional materials is required. Products that cannot be repaired or reused can be used as fire wood.

Crushed or ground wood can be used as a medium for mushroom production and fuel briquettes. Residues of fire woods and fuel briquettes can be applied as a soil conditioner. The mushroom medium can later be used as material for composting. As mentioned in 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 vermin-composting should not be practiced.

Controlled open dumping of wood waste is considered a better option than landfill disposal. The degradation of wood waste in a controlled open dumping site does not produce methane. However, the dumping site should be organized and available to access by the public in order to enhancing utilization of this waste. Generally, old furniture and wood wastes thrown away by wealthy people are often reusable to others.

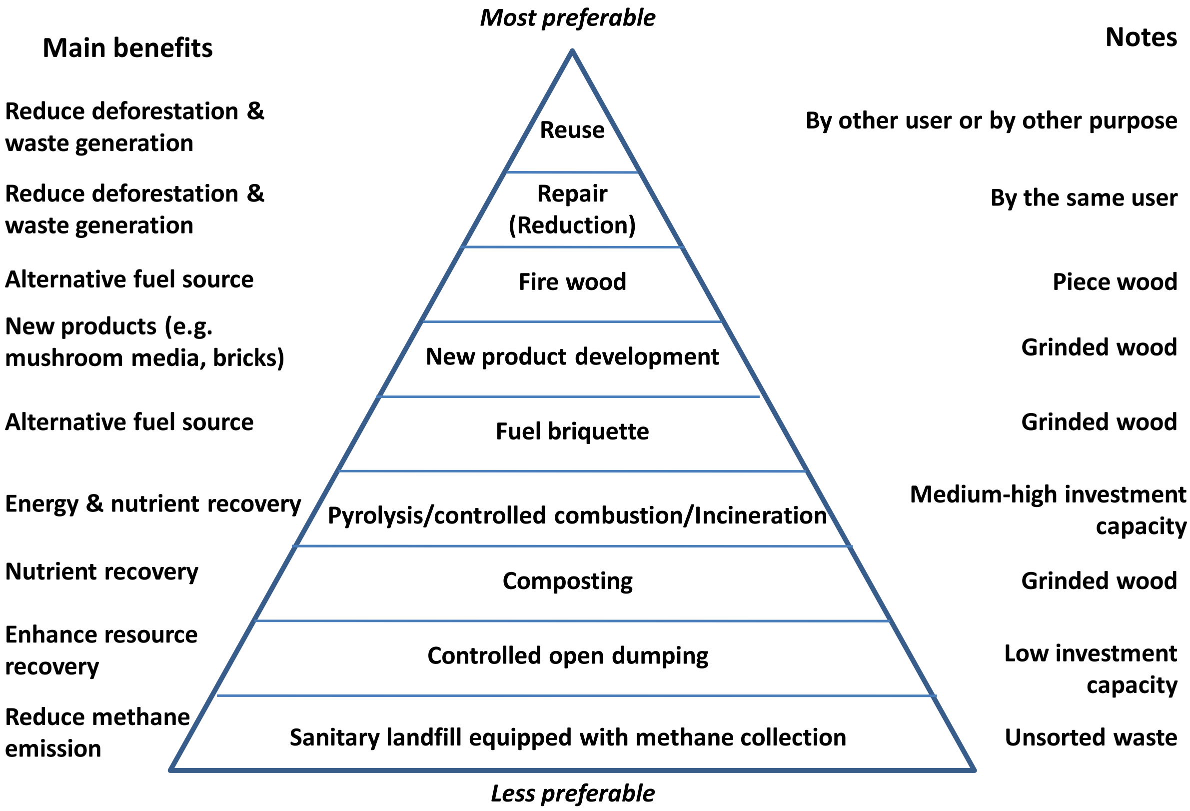

Fig. 8 Recommended integrated wood waste management hierarchy for developing Asian countries

5.4 Grass and garden wastes

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

Grass, leaves and small branches from gardens should be treated in different from wood waste as they are different in size and potential use (***Fig. 9***). Garden wastes can be left for soil mulching or making composting on the field. Also preferable is mixing the grass with food waste to improve the carbon and nitrogen (C/N) ratio of the composting pile.

The management hierarchy of grass should start with soil mulching, animal feed, composting, new product development, fuel briquette and use the residue of fuel briquette as a soil conditioner. Anaerobic digestion for grass may require longer time for digestion compared with food waste. Controlled combustion and incineration is preferable than sanitary landfill.

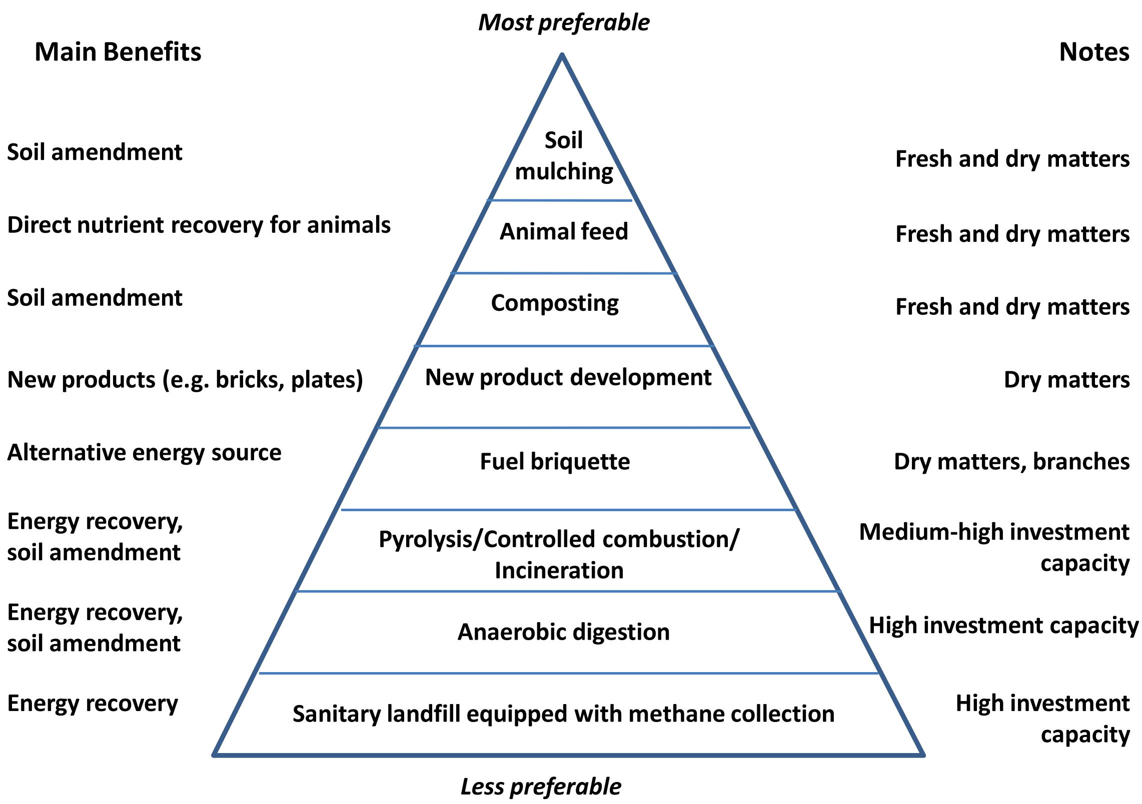

Fig. 9 Recommended integrated grass and garden waste management hierarchy for developing Asian countries

The aforementioned hierarchy is designed for separated organic waste. However, waste composition in municipalities is complicated. To help the local government in taking decision on appropriate organic waste management model in a given area, a supporting decision model is developed as presented in ***Fig. 10***. It is recommended that the authorities should promote waste separation at source, particularly for food waste, and further, if applicable, paper, wood and grass wastes respectively.

According to the diagram, the management of organic waste is divided into eight lines: unsorted waste and mixed organic waste (A), food waste (B), mixed non-food waste (C), paper (D), mixed wood and grass wastes (E), wood waste (F), and grass waste (G). In cities where waste separation at source is failed, MTB is highly recommended prior to landfill and incineration.

The local government is encouraged to select the organic waste management options based on its capacity (personnel and investment), quantity of waste generated in the city, and social needs.

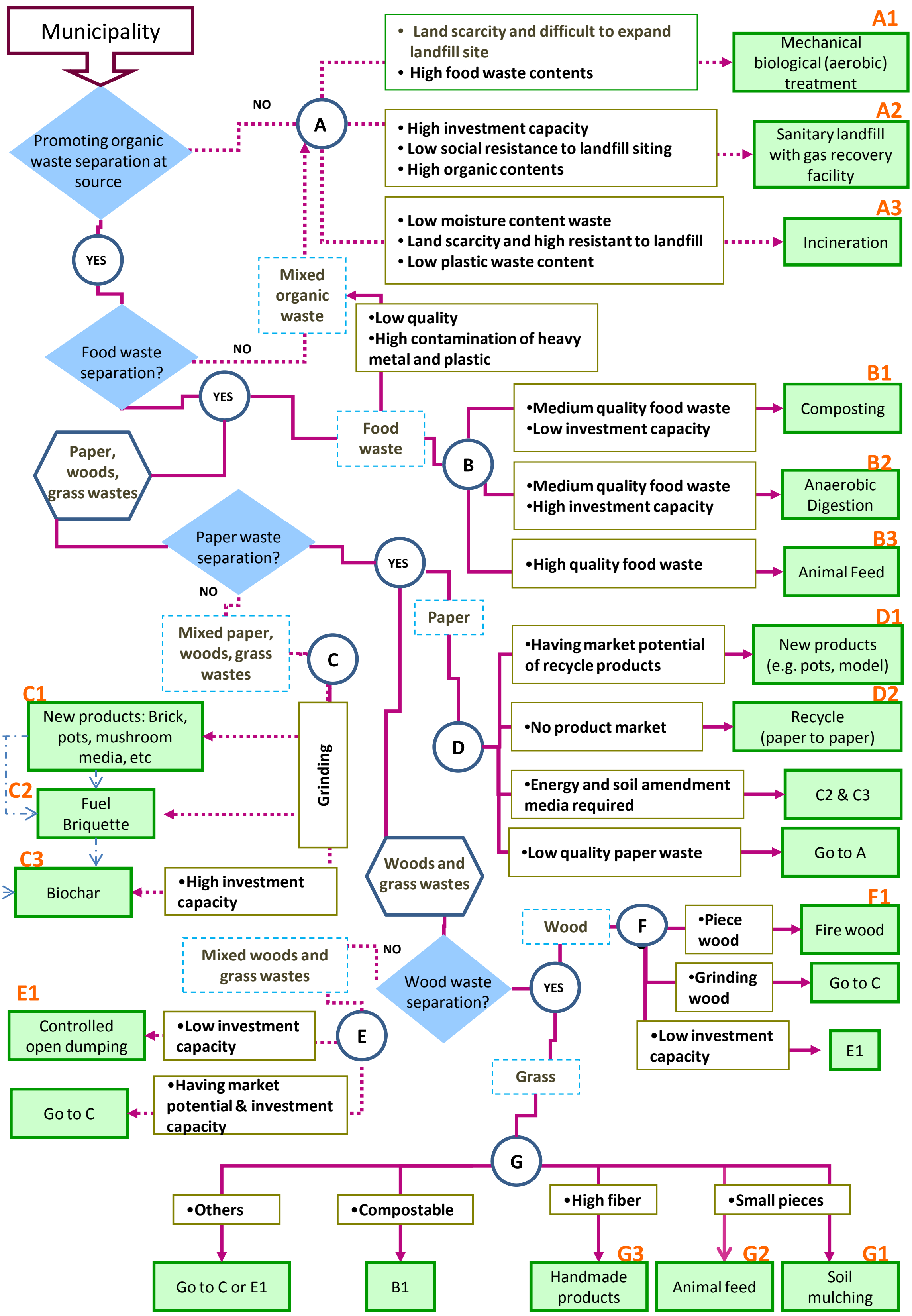

Fig. 10 A supporting model for decision making on integrated organic waste management

VI.

Conclusion

Waste generation in developing Asian countries is increasing, thus GHG emissions from the waste sector and the other sectors related with production and consumption (e.g. agriculture, industry, energy, and land use change and forestry sectors) are also increasing. Due to failure in waste management by government and evidence of environmental impacts from waste disposal sites, social resistance to construction of new landfills and incineration sites has increased. The 3Rs present an alternative to avoid the aforementioned problems. They are national concerns and 3Rs should be promoted widely in order to reduce resource consumption, decrease GHG emissions and reduce the need for landfills and associated land-use conflicts.

It is further recommended that the 3Rs should be promoted nationwide for waste separation at source and the application of technology that is appropriate to local contexts - in terms of waste quality and volume, costs, and technology. GHG emissions from, and investment in, landfill and incineration could be substantially decreased through the 3R approach. Governments should prioritize reducing, reusing and recycling according to their relative contribution to GHG emissions reductions and other national objectives such as food security, energy security, poverty reduction and income distribution.

Nevertheless, the local authorities should keep in mind that the 3Rs practice requires active participation of multi-stakeholders particularly from the residents and efforts of the government to handle waste efficiently after segregation. Additionally, rethinking for resource use and treatment is very important for implementation of 3R strategies. Therefore, government should put efforts on mainstreaming environmental education on multi-benefits of 3R practices, particularly quantitative information.

The 3Rs could provide climate co-benefits to the waste sector and other non-waste sectors. However, quantitative data presenting climate co-benefits of the 3Rs in developing countries are very rare. More research on the various benefits of the 3Rs and improved interaction between researchers and policy-makers are needed to enhance implementation.

Experience in the implementation of 3Rs in developed and developing Asian countries should be exchanged to enhance wide and successful implementation. Waste separation at source is the major constraint in the Asian countries and mostly the local governments are lack experience. A waste separation and collection model that has become widely applied in developed and developing countries could be a good example for other countries. Hence, strengthened international research cooperation and improved information sharing among countries in Asia are likely to be conducive towards that end.

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Appendix I: Summary of the national climate action plans in selected countries

i) China

China, which has the largest GHG emissions amongst the studies 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 program was detailed in China's National Climate Change Programme, which is 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. Further, over 1,500 large- and medium-scale biogas digesters have been 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 3Rs 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 recovery and utilization of construction rubbish and waste. China intends to promote the use of straw to produce plant fiber board 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 wastes from the source, recovery and utilization 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 utilization of waste at the source.

The development of waste disposal and comprehensive utilization technology will be accelerated for the small- and medium-cities as well as rural areas. Composting technology suited for China's circumstance and capacity will be promoted. Further, 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, feed-in tariff as well as 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 fertilizer in reasonable quantities and increase the use of organic fertilizer to improve soil fertility and to reduce nitrous oxide emissions from cropland.

ii) India

In India, the Prime Minister's Council on Climate Change developed the 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 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[6]. 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, aluminum 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 utilization and recycling options.

Indian 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 development of decentralized 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 wastes have not been successful and open dumping practices are still common. A factor for this delay in development because the waste management authorities in India have been transferred from the State Governments to the Urban Local Bodies since 1992 which has resulted in low capacity to handle the waste.

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 fertilizer.

[6] The recycling rate in India is 70%, but in Japan is only 53% (SME, 2007).

iii) Indonesia

In 2007, Indonesia announced the 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 utilization of clean energy from new or renewable energy sources.

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

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

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

iv) Thailand

Thailand approved its Strategic Plan on Climate Change in 2008, which extends from 2008-2012. The strategic on GHG reduction activities from the waste sector include 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 to reduce waste generation. In addition, waste separation at source is proposed to utilize the resource efficiently.

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

A policy to reduce use of agrochemical in agricultural sector is emphasized. Therefore, there is a potential that urban composting can fulfill the need of agriculture sector.

v) Bangladesh

Bangladesh announced its National Climate Change Strategy and Action Plan in 2008. The action plan mainly emphasizes 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.

For climate change mitigation, Bangladesh is attempting to reduce GHG emissions from energy sector by development of renewable energy sources such as biogas, promoting a low carbon growth pathway and GHG emissions reduction from agriculture and urban waste management. Bangladesh registered an urban composting project with the CDM, which is evidence of the government's efforts to reduce GHG emissions. However, there is no specific indication of the 3Rs being promoted for climate change mitigation in the national action plan.

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

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