UNEP

Waste and Climate Change

Global Trends and Strategy Framework

United Nations Environment Programme

Waste and Climate Change:

Global trends and strategy framework

Compiled by

UNEP
Division of Technology, Industry and Economics
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Acknowledgements

The Executive Director of UNEP has been enthusiastically following up on UNEP Governing Council Decision 25/8 on Waste to build capacity on waste management. UNEP, based on its successful and continuous support on waste management, has received a lot of requests from national governments and other entities to develop a strategy for co-benefits of waste management in the context of climate change. To develop this strategy, UNEP carried out an intensive review of linkages between waste management and climate change. Accordingly a draft paper to highlight the linkages and draft strategy was prepared and presented during a keynote presentation at ISWA/DAKOFA Conference on Waste as a pre COP event in Copenhagen during 2009. This draft paper attracted a lot of interest and technical feedback. A revised version, based on the feedback was prepared and presented at a Co-Benefits Workshop in Thailand and at Mayor of London's Conference on Waste and Climate Change under C40 Leadership Initiative. The governments and local authorities, in addition to experts, provided good inputs as well as technical and political feedback. Based on that feedback, third draft was prepared and uploaded at UNEP IETC website (www.unep.or.jp) in July 2010 for further comments and feedback.

Taking this opportunity, we would like to thank all those experts and government officials, who provided valuable feedback to realize this publication and future path for our activities on waste in the context of climate change. We are also very grateful to Dr. Jessica North of Hyder Consulting Pty Ltd. (Australia) for her work and patience to work with different stakeholders on this publication.

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Executive summary

At a global scale, the waste management sector makes a relatively minor contribution to greenhouse gas (GHG) emissions, estimated at approximately 3-5% of total anthropogenic emissions in 2005. However, the waste sector is in a unique position to move from being a minor source of global emissions to becoming a major saver of emissions. Although minor levels of emissions are released through waste treatment and disposal, the prevention and recovery of wastes (i.e. as secondary materials or energy) avoids emissions in all other sectors of the economy. A holistic approach to waste management has positive consequences for GHG emissions from the energy, forestry, agriculture, mining, transport, and manufacturing sectors.

The Governing Council of the United Nations Environment Programme (UNEP) has directed its International Environmental Technology Centre (IETC) branch to take action in the area of waste management. There are substantial co-benefits of waste management in the context of climate change. As a first step to realize these co-benefits, this paper seeks (a) to examine the potential climate impacts and benefits of different waste management activities, and (b) to present a UNEP-led framework strategy to assist member countries in prioritising their resources and efforts for waste management and climate change mitigation. The framework strategy is intended to align with the internationally recognised waste management hierarchy, in which waste prevention receives the highest priority, to optimise the co-benefits for climate change mitigation.

Every waste management practice generates GHG, both directly (i.e. emissions from the process itself) and indirectly (i.e. through energy consumption). However, the overall climate impact or benefit of the waste management system will depend on net GHGs, accounting for both emissions and indirect, downstream GHG savings. The actual magnitude of these emissions is difficult to determine because of poor data on worldwide waste generation, composition and management and inaccuracies in emissions models. Although currently OECD countries generate the highest levels of methane, those of developing nations are anticipated to increase significantly as better waste management practices lead to more anaerobic, methane-producing conditions in landfills.

Estimates of GHG emissions from waste management practices tend to be based on life-cycle assessment (LCA) methods. LCA studies have provided extremely useful analyses of the potential climate impacts and benefits of various waste management options. However, due to data availability and resources, LCA studies are primarily focussed on scenarios appropriate for developed countries. Due to the key, underlying assumptions on which these assessments are based (such as local/regional waste composition, country-specific energy mix, technology performance, etc) the results are not necessarily transferable to other countries. This makes it generally impossible to make global comparisons regarding the GHG performance of different waste management technologies.

The climate benefits of waste practices result from avoided landfill emissions, reduced raw material extraction and manufacturing, recovered materials and energy replacing virgin materials and fossil-fuel energy sources, carbon bound in soil through compost application, and carbon storage due to recalcitrant materials in landfills. In particular, there is general global consensus that the climate benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology, even where energy is recovered during the process. Although waste prevention is found at the top of the 'waste management hierarchy' it generally receives the least allocation of resources and effort. The informal waste sector makes a significant, but typically ignored, contribution to resource recovery and GHG savings in cities of developing nations.

A range of activities focussed on waste and climate change are currently being led by international organisations, including UNEP. There is clear recognition of the considerable climate benefit that could be achieved through improved management of wastes. UNEP is involved in a variety of relevant partnerships and programmes, such as Integrated Waste Management, Cleaner Production, and Sustainable Consumption and Production. There is also strong interest in Clean Development Mechanism (CDM) projects in the waste sector. CDM activity has focussed mainly on landfill gas capture (where gas is flared or used to generate energy) due to the reduction in methane emissions that can be achieved.

However, there is a lack of a cohesive approach, which has resulted in gaps, duplication, and regional disparity is programmes offered. A central mechanism is needed to collaborate with existing organisations to ensure accessibility to and dissemination of relevant information across the globe, effective use of resources to achieve climate benefit through integrated waste management, promotion of best practice, and rapid transfer of simple, effective, proven technologies and knowledge to developing countries.

UNEP is clearly positioned to help catalyse enhanced action for climate change mitigation within the waste sector, collaborating with existing organisations to ensure more effective delivery of initiatives across the globe. As the designated authority of the United Nations system in environmental issues, UNEP has a key role to play in providing leadership and encouraging partnerships in the fields of waste management and climate change. The development of a framework strategy to implement the proposed mechanism requires input from a range of stakeholders. To this end, the current report is intended as a further step in a global dialogue to engage the international waste community, identify the key issues, and create a strategy that will deliver significant climate benefit in the waste sector.

Abbreviations

BAU	Business as usual
CDM	Clean development mechanism
CER	Certified emission reduction
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	CO_2 equivalent
DAKOFA	Danish Waste Management Association (eng.)
DOC	Degradable organic carbon
DTIE	Division of Technology, Industry and Economics (UNEP)
EIT	Economies in transition
EPR	Extended producer responsibility
FOD	First order decay
GDP	Gross domestic product
GEF	Global Environment Fund
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISWA	International Solid Waste Association
JI	Joint implementation
LFG	Landfill gas
MBT	Mechanical biological treatment
MSW	Municipal solid waste
N_2O	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
RDF	Refuse derived fuel
SBC	Secretariat of the Basel Convention
SCP	Sustainable Consumption and Production
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Waste electrical and electronic equipment

1 Introduction

The waste management sector is in a unique position to move from being a comparatively minor source of global greenhouse gas (GHG) emissions[1] to becoming a major contributor to reducing GHG emissions. Although minor levels of emissions are released through waste treatment and disposal, the prevention and recovery of wastes (i.e. as secondary materials or energy) avoids emissions in other sectors of the economy. A holistic approach to waste management has positive consequences for GHG emissions from the energy, agriculture, transport, and manufacturing sectors. A recent report by the US EPA estimates that 42% of total GHG emissions in the US are associated with the management of materials (US EPA 2009).

A number of international organisations include waste and climate change initiatives in their portfolio of activities, recognising the considerable climate benefit that could be achieved through improved management of wastes. UNEP is clearly positioned to help catalyse enhanced action for climate change mitigation within the waste sector, collaborating with existing organisations to ensure more effective delivery of initiatives across the globe. As the designated authority of the United Nations system in environmental issues, UNEP has a key role to play in providing leadership and encouraging partnerships in the fields of waste management and climate change.

1.1 Context

Waste generation does not result in positive impacts on climate. Waste treatment and disposal can have both positive and negative climate impacts. Therefore, an increasingly key focus of waste management activities is to reduce GHG emissions. To strengthen waste management activities in the context of climate change, UNEP is preparing to develop a full scale programme based on its activities on waste management.

UNEP, through the International Environmental Technology Centre (IETC) and Sustainable Consumption and Production (SCP) branches of the Division of Technology, Industry and Economics (DTIE), and through the Secretariat of the Basel Convention (SCB), is supporting the implementation of UNEP Government Council decision (GC 25/8) on Waste Management and the Bali Declaration by Conference of Parties (COP) of the Basel Convention on Waste Management for Human Health.[2] These two pivotal UNEP decisions direct DTIE to take action in the area of waste and climate change.

UNEP is already undertaking various programmes and projects to assist its member countries to achieve improved waste management. These programmes and projects include Integrated Solid Waste Management (ISWM) based on the 3R (reduce, recycle, and reuse) approach, Sustainable Consumption and Production, E-waste management, converting waste agriculture biomass and waste plastics into useful energy and/or material resources, and management of hazardous waste. ISWM is a central theme of the current paper, which aims to look at the climate impact and benefit of the full range of waste practices, from waste avoidance to disposal, and develop the framework for a cohesive international strategy. UNEP is simultaneously proposing a ‘Global Platform for Waste Management’ (GPWM) to facilitate coherent delivery of international support for waste management – there would be clear

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[1] Waste sector emissions were estimated to account for 3-5% of total global anthropogenic emissions in 2005 (Bogner et al 2007).

[2] GC 25/8 is presented in more detail in Appendix A – UNEP Decision. The Bali Declaration is presented in detail in Appendix B – Bali Declaration.

synergies between a GPWM mechanism and an international strategy for waste and climate change.

UNEP's initiatives, including the current report, endeavour to align with the prioritisation of activities presented in the waste management hierarchy (see Figure 1). As described by the International Solid Waste Association (ISWA 2009):

> *'…the waste hierarchy is a valuable conceptual and political prioritisation tool which can assist in developing waste management strategies aimed at limiting resource consumption and protecting the environment'.*

As a result, priority is given in order to waste minimisation, re-use, recycling, waste-to-energy, and finally landfill.

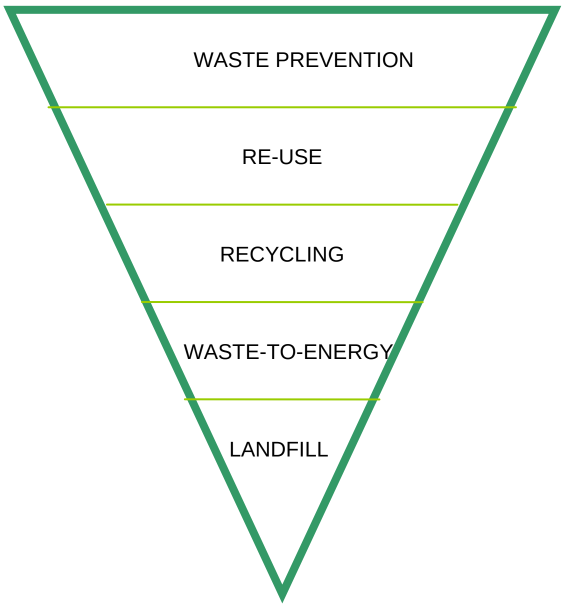

Figure 1: The waste hierarchy

The present paper presents examples of the potential benefits of different waste management activities for climate change abatement, discusses the relationships between waste and climate change, and identifies specific impacts of waste management on climate change. The objective of the paper is to identify the potential impacts and benefits of different waste management systems in terms of climate impact, derived from information presented in the literature. Based on these findings, a framework is proposed for developing a UNEP-led international strategy targeting waste and climate change initiatives.

There is a considerable body of literature regarding waste and climate change. The present report does not purport to make a further scientific contribution, or to make an exhaustive assessment of all existing publications, but rather demonstrates the wide range of issues taken into consideration by UNEP in development of the framework strategy. The intention is not to derive conclusions regarding the climate performance of one waste management approach versus another – sustainable solid waste management requires consideration of a range of systems and methods, appropriate to local conditions. Instead, the present report attempts to guide the strategy framework towards allocation of limited resources to priority actions, aligned with both climate change mitigation and the waste hierarchy.

1.2 Scope of work

This paper examines the climate impact of management systems for municipal solid waste (MSW), commercial and industrial (C&I) waste (excluding mining and munitions), construction and demolition (C&D) waste, agricultural waste, and hazardous waste (where data is available), at a global scale. Wastewater management is not addressed within the scope of the present report.

The classification of waste streams varies from country to country and often makes it difficult to discern separate waste streams in international reports. In Europe, for example, MSW is often defined as all waste arising within a municipal boundary, including any commercial, industrial, construction, and hazardous waste. In Australia, MSW refers to household waste and commercial waste collected with household waste. Construction and demolition waste may also be counted as commercial waste. Although climate impacts from wastewater and sewage treatment are not specifically discussed in the present report, these issues are significant, and certainly deserve detailed assessment. In some countries, bio-solids from wastewater treatment plants are included in totals of solid waste, and may therefore be included in reports of solid waste. Indeed, the two are occasionally treated at the same facility. The term 'biowaste' is used in the current paper in the European sense to mean biodegradable material, such as food and garden wastes.

Parameters of this paper are restricted to GHG emissions and GHG benefits associated with fossil fuel savings and material substitution, since its focus is the climate impact of waste management practices. Discussions focus on the GHG of particular relevance to waste management, notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The majority of waste and climate change studies adopt a time-horizon of 100 years over which to consider the consolidated impact of GHG. Whether or not this arbitrary time-frame is appropriate is not a focus of the current paper.

For the majority of waste management scenarios examined, the climate impact is considered from the point of waste generation to the point of material reuse, recovery, or final disposal – the embodied resources and energy in wasted materials are not considered. However, in the case of recycling and waste prevention, a climate benefit is examined in terms of avoided primary manufacture of materials (i.e. avoided inputs of resources and energy). The climate impact of the production of a marketable product from recovered materials, and the replacement of raw materials with recovered product, is included.

The focus is primarily on the climate impacts of direct and indirect emissions from waste treatment, recovery, and disposal processes. A complete discussion of the climate change impacts of waste management requires discussion of upstream, direct, and downstream GHG contributions. Upstream contributions arise from inputs of energy and ancillary materials; direct emissions are from system operations; and downstream contributions and savings relate to energy and material substitution and carbon storage/sequestration (Gentil et al 2009). Typically, not all GHG contributions are accounted for in emissions reports (see Table 1). Some contributions are minor – for example, waste collection usually represents only a small fraction of the overall GHG balance of waste management systems (e.g. less than 5% (Smith et al 2001; Dehoust et al 2005)).

Table 1: A generalised description of 'accounted' and 'not accounted' indirect and direct GHG emissions and savings (adapted from Gentil et al 2009)

	Upstream (indirect)	Direct (operating)	Downstream (indirect)
Accounted	Production of fuel, electricity, heat, and ancillary materials	Collection and transport, intermediate facilities, recycling, aerobic / anaerobic biological treatment, thermal treatment, landfill	Emissions and savings of energy / material substitution, carbon sequestration / storage
Not accounted	Unaccounted GHGs, construction, maintenance, decommissioning, import-export, embedded energy in waste	Unaccounted GHGs, unaccounted waste streams, historical waste (in landfill), staff commuting and travel	Unaccounted GHGs, decommissioning (end-of-life)

The current report assumes a basic understanding of waste management systems, processes and policy.

The limitations of a report that focuses solely on the climate impacts of waste management should be emphasised. The generation, treatment, and disposal of waste create myriad additional environmental, social, and economic impacts – many of them adverse. Clearly, there is some danger in considering only the climate aspects of an activity. Although the background report highlights the climate impacts of waste activities, any strategy in this field must necessarily be part of a wider, more holistic, integrated approach to global resource use and management.

Minimal reference is made to costs in the following sections – a financial assessment of waste management systems is beyond the scope of the current report. This can be seen as a major limitation given that financial resources in this area are scarce, and an international framework strategy must necessarily address the distribution of those resources to best address waste and climate change.

2 Waste management and GHG

2.1 Background

GHG emissions and savings (credits) are attributable to various stages of a waste management system. Figure 2 shows a simplified schematic of a municipal waste management system with the predominant climate impact sources. The general suite of activities – collection, separation, treatment, transfer, and disposal – applies to all waste types (i.e. MSW, C&I, C&D, hazardous), with varying levels of sophistication, with the possible exception of agricultural waste. In many rural areas, agricultural waste is dealt with in-situ, through uncontrolled burning, burial, or simple land dumping.

Evidently, not all sources of emissions are indicated in the diagram: there are further environmental burdens associated with manufacture of waste receptacles, vehicles, and treatment facilities, as well as the transfer of residual waste materials from intermediate stations and treatment facilities to landfill.

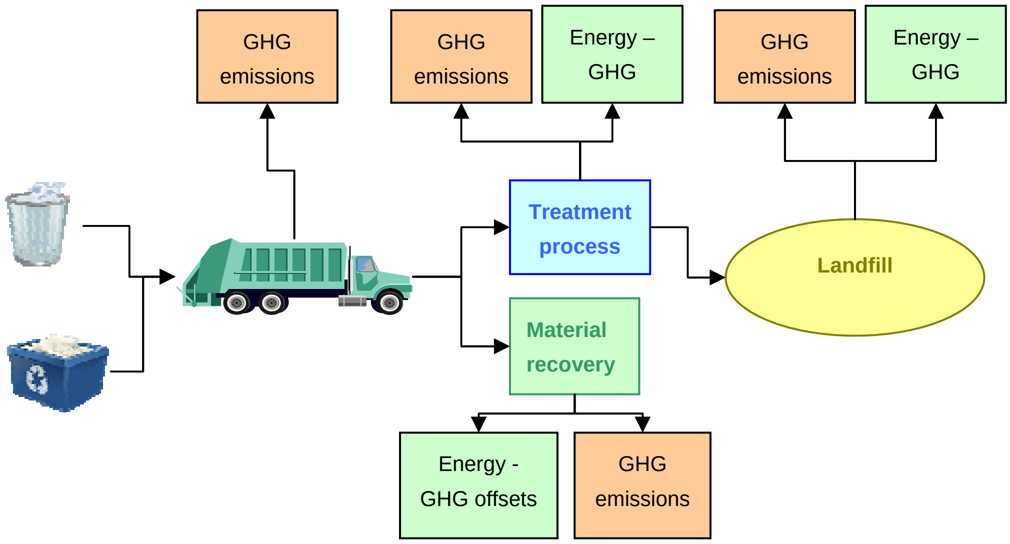

Figure 2 Simplified schematic of waste management system and GHG emissions (applicable to urban waste management)

2.2 Sources of GHG

Methane emissions from landfill are generally considered to represent the major source of climate impact in the waste sector (this impact is quantified in later sections). It is worth noting that, if a broader view of waste management were taken, which included materials management, landfill methane would no longer be the largest source of GHG in the sector. The potential to save GHG through improved materials management (i.e. preventing material waste) is discussed in later sections.

Waste contains organic material, such as food, paper, wood, and garden trimmings. Once waste is deposited in a landfill, microbes begin to consume the carbon in organic material, which causes decomposition. Under the anaerobic conditions prevalent in landfills, the microbial communities contain methane-producing bacteria. As the microbes gradually decompose organic matter over time, methane (approximately 50%), carbon dioxide (approximately 50%), and other trace amounts of gaseous compounds (< 1%) are generated and form landfill gas. In controlled landfills, the process of burying waste and regularly covering deposits with a low-permeability material creates an internal environment that favours methane-producing bacteria. As with any ecological system, optimum conditions of temperature, moisture, and nutrient source (i.e. organic waste) result in greater biochemical activity and hence greater generation of landfill gas.

The gradual decay of the carbon stock in a landfill generates emissions even after waste disposal has ceased. This is because the chemical and biochemical reactions take time to progress and only a small amount of the carbon contained in waste is emitted in the year this waste is disposed. Most is emitted gradually over a period of years.

Methane and carbon dioxide (CO_2) are greenhouse gases (GHG), whose presence in the atmosphere contribute to global warming and climate change. Methane is a particularly potent GHG, and is currently considered to have a global warming potential (GWP) 25 times that of CO_2 when a time horizon of 100 years is considered; the GWP is much higher (i.e. 72) when a 20-year time horizon is applied (see Table 2). Evidently, the choice of time horizon can have a dramatic effect on the estimated climate impact of methane emissions. Ideally, and in-line with IPCC guidance (1995), the choice of time horizon should reflect climate policy, or the climate effect of most concern. For example if the aim of a policy is to reduce the immediate or near-future levels of GHG, or minimise the rate of climate change, then a 20-year horizon is most appropriate. However, if the focus is on minimising the 'risk of long-term, quasi-irreversible climate or climate-related changes', then a 100 or 500 year time horizon is most suitable (Fuglestveldt et al 2001). However, as noted by an IPCC scientist: 'the time horizons tend to be misused or even abused. Industries tend to pick the horizon that puts their 'product' in the best light' (Fuglestveldt et al 2001).

In terms of reporting landfill emissions, the Intergovernmental Panel on Climate Change (IPCC) has set an international convention to not report CO_2 released due to the landfill decomposition or incineration of biogenic sources of carbon – biogenic carbon is accounted for under the 'land use / land use change and forestry' (LULUCF) sector (see discussion below, and refer to IPCC (2006) for accounting methodologies). Therefore, where landfill is concerned, only methane emissions are reported, expressed as tonnes of CO_2 equivalent (i.e. 1 tonne of methane is expressed as 25 tonnes of CO_2-e). In practice, methane emissions from landfill are rarely measured, but rather estimated for reporting.

Table 2 Global warming potential (GWP) for a given time horizon (Forster et al 2007)

Greenhouse gas	GWP 20-yr (kg CO_2-e)	GWP (IPCC 2007) 100-yr (kg CO_2-e)	GWP 500-yr (kg CO_2-e)
Carbon dioxide CO_2	1	1	1
Methane CH_4	72	25	7.6
Nitrous oxide N_2O	289	298	153

Estimates of methane emissions from landfill are generally made using a first order decay (FOD) model, which calculates the rate of methane generation as proportional to waste input. The IPCC Tier 1 and Tier 2 FOD (IPCC 2006) model is used by most countries to produce national GHG inventories, and tends to also form the basis for in-country reporting and regulations. EMCON Associates originally developed the FOD model to estimate methane generation and recovery from landfills in 1980 to assist LFG capture projects. The model was not intended for use as a tool to calculate 'fugitive' emissions, and has been shown to vary in how accurately it can predict emissions (compared to direct measurements using static chambers) (Bogner et al 2009).

A key piece of information to input to the model is the quantity and composition of waste deposited in landfills. These parameters vary enormously between and within individual sites, regions, and countries, and reliable data is costly and time-consuming to obtain. For these reasons, the IPCC provides a set of default values, which can be used where data is unavailable to calculate national GHG emissions from landfill. However, it should be noted that the use of default values could cause the FOD model to significantly underestimate or overestimate methane emissions (see discussions regarding uncertainty of estimates in the following literature review).

Where landfill gas is captured and used to generate electricity, it should be recognised that fugitive methane leaks from the system also contribute to total landfill GHG emissions. The climate benefit of this energy generation is discussed in the following sections.

Methane from wastewater management is the second largest source of GHG emissions from the waste sector as a whole, according to IPCC inventories (Bogner et al 2008). As previously stated, wastewater is not discussed within the scope of the present report, but certainly merits global attention. Additional, comparatively minor sources of GHG from the waste sector at the global scale include combustion of waste, and biological treatment. Uncontrolled burning of waste is largely obsolete in developed countries, but continues to be practiced in developing regions, causing release of CO_2.[3] Some landfills in developing countries, such as the Smokey Mountain site in Manila, smoulder continuously.

Controlled burning, in waste incinerators, also generates CO_2 emissions. Where incinerators generate energy, GHG may also be credited – this is discussed in the following section. Where incinerators do not generate energy, they will be net energy users, which will also contribute to their total GHG emissions. Advanced thermal treatment technologies, such as gasification and pyrolysis, may emit fewer emissions compared to mass-burn incineration. However, these are emerging technologies and cannot be considered ‘established’ technologies for the treatment of bulk mixed waste.

Aerobic composting processes directly emit varying levels of methane and nitrous oxide, depending on how the process is managed in practice. Closed systems, such as enclosed maturation bays or housed windrows, reduce emissions through use of air filters (often bio-filters) to treat air exiting the facility. Compost plants require varying, but usually small, amounts of energy input (with associated ‘upstream’ GHG emissions). Further GHG emissions occur ‘downstream’, depending on the application of the compost product – CO_2 will be gradually released as the compost further degrades and becomes integrated with soil-plant systems.

Anaerobic digestion (AD) systems are enclosed in order to capture and contain the biogas generated by the digestion process. GHG emissions from AD facilities are generally limited to system leaks from gas engines used to generate power from biogas, fugitive emissions from system leaks and maintenance, and possible trace amounts of methane emitted during maturation of the solid organic output. Such systems also consume energy, however plants are generally self-sustaining if appropriately operated (i.e. a portion of the biogas output generates energy for use in-plant). ‘Downstream’ GHG emissions will depend on the application of the matured digestate (as per aerobic compost product).

[3] Numerous other air pollutants are released during open, uncontrolled burning – the scope of the present paper is limited to GHG emissions.

Mechanical biological treatment (MBT) encompasses mechanical sorting of the mixed residual waste fraction, with some recovery of recyclable materials (limited due to contamination), and separation of a fine, organic fraction for subsequent biological treatment. The biological component may include anaerobic digestion with recovery of biogas for energy/heat generation, or aerobic composting to produce a biologically stable product for either land application (limited applicability) or use as refuse-derived fuel (RDF) to substitute fuel in industrial furnaces (i.e. co-incineration in cement kilns). MBT facilities vary considerably in terms of sophistication, configuration, scale, and outputs. GHG emissions associated with MBT are due to energy inputs (although AD systems may be self-sustaining), direct process emissions (this will depend on the air protection control system, such as a biofilter, attached to the aerobic composting component), gas engine emissions (for AD), and use of the composted organic output (disposed of to landfill or applied to land). There is some use of composted MBT output to remediate contaminated land, however most OECD countries strictly regulate the use of compost derived from mixed waste, and the majority is disposed of in landfill, or used as cover material for landfill operations.

2.3 GHG savings

In the context of the current report, the waste sector can save or reduce GHG emissions through several activities:

- Avoiding the use of primary materials for manufacturing through waste avoidance and material recovery (i.e. the GHG emissions associated with the use of primary materials – mostly energy-related – are avoided)
- Producing energy that substitutes or replaces energy derived from fossil fuels (i.e. the emissions arising from the use of waste as a source of energy are generally lower than those produced from fossil fuels).
- Storing carbon in landfills (i.e. carbon-rich materials that are largely recalcitrant in anaerobic landfill conditions, such as plastics and wood) and through application of compost to soils[4].

Indeed, depending on which GHG accounting convention is used[5], the waste sector is capable of generating a net GHG benefit through waste avoidance, material recovery, and energy recovery.

Waste minimisation refers to waste avoidance, through various mechanisms such as Cleaner Production and material light-weighting, and waste reduction. Reduction of waste post-generation is achieved through re-use and recycling. Indefinite re-use may be assumed for certain items in the waste stream, and closed-loop recycling may be assumed for certain types of materials (i.e. aluminium, steel, HDPE, PET, glass). Open-loop recycling, ‘down-cycling’, and industrial symbiosis are additional recycling methods. From a climate perspective, the benefits of both re-use and recycling are realised in avoided GHG emissions from waste treatment and disposal, and a GHG benefit in avoided resource extraction and manufacture of new products.

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[4] The IPCC methodology for reporting national GHG inventories does not credit the waste sector with GHG savings due to long-term carbon storage in landfills, but rather requests that this detail is reported as an ‘information item’ in the waste sector. The methodology also does not credit GHG savings to long-term carbon storage due to compost application to land (IPCC 2007).

[5] There is no universally accepted method for accounting for GHG emissions in the waste sector. Some conventions may not consider ‘material avoidance’ to generate a GHG saving with respect to waste – the saving may be credited to the industrial/manufacturing sector, or considered outside the boundaries of waste management. It is important to note nevertheless that the waste sector delivers this saving.

Recycling processes also vary between developed and developing nations. For example, there may be significant GHG emissions associated with poorly regulated, low-technology paper recycling plants in a developing country, which may reduce the net climate benefit associated with paper recycling. However, it may be reasonable to expect improvement in facility performance across the globe as standards progress into the future. The informal recycling sector often plays a significant, yet largely unrecognised role in waste management of developing nation cities. For example, Delhi waste pickers collect and recycle 15-20% of the city's MSW (Chintan 2009).

The compost output (from facilities that accept source-separated organic wastes) is typically assumed to substitute for the primary production of mineral fertilisers and/or peat – in either case, there is an associated GHG saving from avoided primary production. There are additional GHG benefits from reduced use of irrigation, pesticides, and tillage where compost is regularly applied to agricultural land.

AD systems and thermal treatments equipped with energy recovery systems generate power (electricity or heat) that can be assumed to replace a fossil-fuel based power source, with a consequent GHG benefit. This is also the case for landfill gas capture systems, which collect a portion of the gas (CO_2 and CH_4) generated in a landfill and use it to produce energy (usually electricity through gas engines). The GHG credit will vary depending on the source of fossil fuel that is assumed to be replaced – for example, substituting a coal power-source results in a much higher credit than substituting power derived from natural gas. These benefits are likely to decrease in most countries as the carbon intensity of national energy supplies declines. Where renewable sources of energy predominate, such as hydro, wind and solar, there may be no GHG savings associated with energy derived from waste.

It is effectively impossible to identify a 'true' level of GHG savings associated with the substitution of conventional energy sources. The GHG results presented in a given study will depend on a number of factors, including:

- Whether the energy is assumed to be produced as electricity, heat, or a combination;
- Whether the energy produced is substituting the country average mix of power sources (i.e. % coal, % gas, % wind/solar/hydro) or marginal sources (i.e. the source(s) most likely to be replaced by the additional contribution of energy-derived waste) (see Fruergaard et al (2009) for a detailed discussion of average and marginal energy, and the implications for GHG studies);
- Assumed efficiencies of different energy-producing technologies;
- How the provision of fuel has been accounted for (i.e. GHG emissions from extraction of raw materials, processing, storage, and transportation) (Fruergaard et al 2009); and
- How the provision of electricity and/or heat has been accounted for (i.e. GHG emissions from combustion of fuels, construction/demolition of the facilities themselves, and management of wastes) (Fruergaard et al 2009).

The GHG savings attributed to energy recovery in waste management systems often represent a significant portion of the estimated GHG balance. The factors noted above are not always clearly or transparently presented in studies, and will also vary considerably between countries and regions, which make useful comparisons difficult to achieve.

Further discussions of the assumptions and implications of GHG savings are found in the following literature review.

2.4 Biogenic carbon

Many studies that examine the linkages between waste and climate change adopt the current IPCC convention for national GHG inventories of ignoring the contribution of CO_2 emitted from biogenic materials where these materials are grown on a sustainable basis. The argument is that during the growth of the plants, carbon has been taken-up and incorporated, and that same amount of carbon is emitted when burnt or aerobically decomposed – the carbon equation is effectively 'neutral'. There are several points to this argument that are worth considering:

- Climate change is time-critical – it is widely accepted that immediate reductions in global GHG emissions are essential to reduce the impact of climate change. The atmosphere does not differentiate between a molecule of biogenic CO_2 and a molecule of fossil - derived CO_2; therefore it appears logical that immediate efforts should be made to minimise emissions of all CO_2, regardless of source.
- Plant growth – particularly of trees and longer-lived species – does not occur evenly over years and seasons, and the initial up-take of carbon by a seedling is far less than the uptake of carbon by a mature plant. Therefore it could be several years before a flux of biogenic CO_2 emitted instantaneously from a process (i.e. combustion of biogenic carbon) is re-captured through plant growth.
- The majority of wood, paper, and agricultural materials that enter the waste stream have not been produced through sustainable forestry/land practices – unsustainable practices deplete the carbon stored in forests and soil over time. According to IPCC methodologies for reporting national GHG inventories, if any factor '…is causing long-term decline in the total carbon embodied in living biomass (e.g., forests), this net release of carbon should be evident in the calculation of CO2 emissions described in the Agriculture, Forestry and Other Land Use (AFOLU) Volume of the *2006 Guidelines*'. However, it is unclear how and whether this information is being recorded in all cases.
- In a national GHG inventory for IPCC purposes, where deforestation and re-growth is accounted for in the land-use category (LULUCF), there may be an argument for ignoring biogenic carbon. However, in an examination of the GHG impact of waste management systems, where solutions are being sought to reduce emissions in the waste sector, there is justification for including all sources of GHG.
- The benefits that accrue from a reduction in total CO_2, irrespective of the source, would seem to be the best indicator of the consequences of the different options. The key theme is climate change and how to mitigate it, not differentiation of carbon sources.

The majority of literature referred to in the current report presents climate impacts following the IPCC convention. However, the reader is urged to keep in mind the relevance of excluding biogenic carbon from the climate change equation[6].

[6] Further discussion of biogenic carbon can be found in, for example: Eunomia (2008a), Rabl et al 2008, and Christensen et al (2009).

3 Climate impact of waste

3.1 Waste and climate change studies

The international literature on linkages between waste and climate change is largely focussed on MSW in developed countries, and there is limited reference or comparison to the impact of other waste streams or waste management in developing nations. The national studies rely on availability of extensive waste data sources, which is generally not the case in developing countries.

A large body of work takes a life-cycle assessment (LCA) approach to evaluating the current and potential future climate impact of waste scenarios. Although LCA is recognised as a valuable method for assessing direct and indirect impacts of waste systems (Bogner et al 2007), there is still considerable debate over methodology in this type of assessment, as well as inherent uncertainty. A key guideline for LCA results is that they should not be taken out of the context of the originating study (which tends to be very localised), should not be regarded as absolute values, and should only be considered for comparative purposes within the study (i.e. to compare the relative performance of different waste management options for a given city or defined region).

Furthermore, national studies are based on domestic production, consumption, transportation, recovery and disposal processes. However, waste streams may include considerable quantities of imported products, and many countries export secondary materials to foreign recycling markets. The climate impact attributed to a domestic process may be very different to that of a foreign process.

For these reasons, the current report does not endeavour to derive ‘global’ values for the GHG impacts and benefits of different waste management approaches – this would be impossible. Rather, the report attempts to indicate where potential impacts and benefits may be found within the waste management sector. Where specific examples are provided, the country or regional context for which they were originally developed is presented. The magnitude of impacts and benefits will vary for any given waste management method, depending on local conditions and specific study assumptions. Disparities between conditions in developed and developing nations make comparisons unfeasible. Therefore, it cannot be concluded that one waste management approach in particular has, universally, a better climate impact than any other approach.

3.2 Global trends in waste generation and management

Waste generation and waste composition varies between and also within countries (see Table 5), primarily due to differences in population, urbanisation and affluence. However, as already noted above, this type of information tends to be compromised (where used for comparative purposes) by the variance in definition of waste. Waste generation rates have been positively correlated to per capita energy consumption, GDP and final private consumption (Bogner et al 2008). Europe and the United States are the main producers of MSW in absolute terms (Lacoste and Chalmin, 2006).

Although developed countries are striving to decouple waste generation from economic growth, overall reduction in waste generation remains a challenge, particularly where populations are increasing.

In non-OECD regions, as countries progress towards achieving a higher standard of living, waste generation per capita and overall national waste production is set to increase accordingly if current production/consumption patterns persist. Although average annual per capita waste generation in developing nations is estimated at 10-20% that of developed nations, this figure is constantly rising in response to economic growth. Globally, waste generation is increasing.

In non-OECD countries there is a shift in waste management practices from open dumping or burning to waste disposal in controlled landfills, and to a higher proportion of the urban population receiving waste collection services. A number of OECD countries (i.e. Australia, Canada, the US, and New Zealand) continue to rely on controlled landfilling while European Union (EU) member states, under the pressure of the European Landfill Directive (1999), are seeking alternative solutions in order to minimise disposal of biodegradable municipal waste. Figure 3 indicates that as of 2007 Germany, Austria, Denmark and the Netherlands have made considerable progress in reducing per capita waste to landfill. More recently, the UK has also introduced more stringent regulations that have resulted in a coordinated effort aimed at minimising organics landfilled. Note that reduced landfilling does not equate to reduced overall waste generation: EU member states have increased recycling and biological treatment of organic wastes, and have tended to either favour MBT or incineration to treat residual waste prior to landfill disposal. Australia is rapidly developing a strong MBT industry.

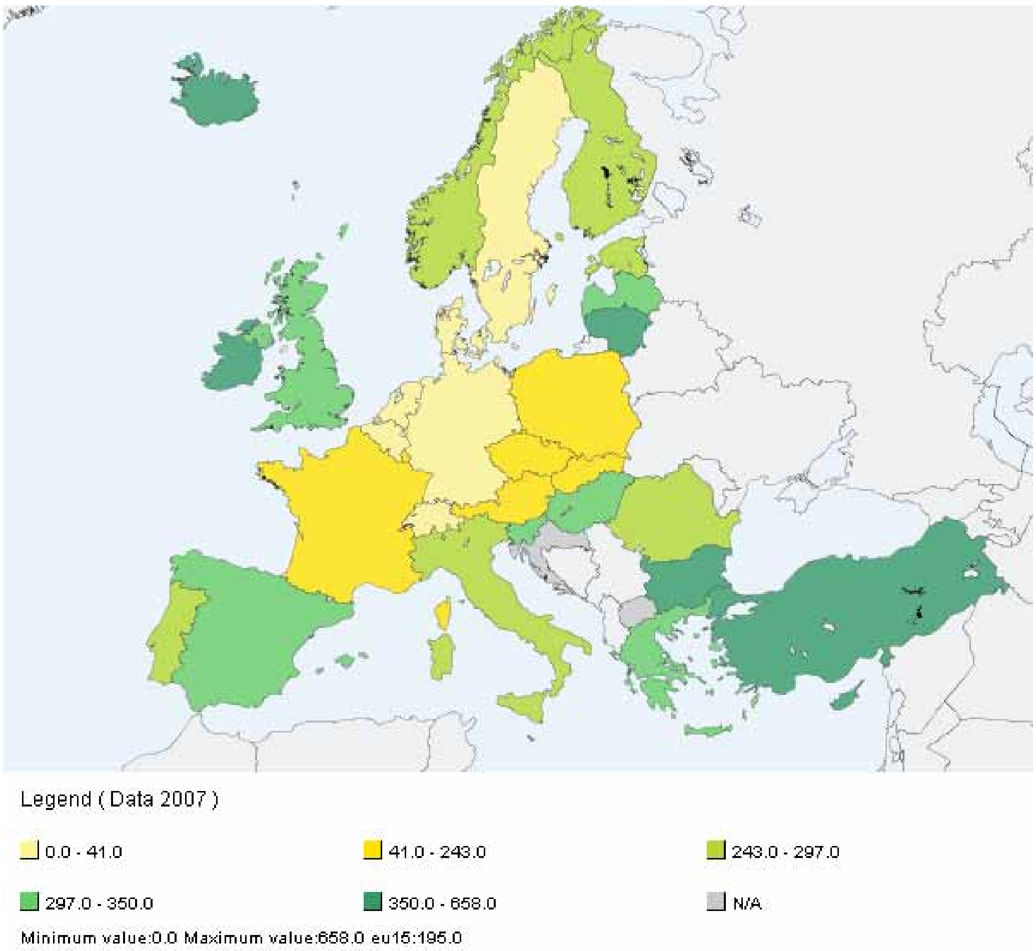

Figure 3: Per capita amount of waste (kg) landfilled annually in Europe (map generated by Eurostat (Eurostat, 2006)).

3.2.1 Decoupling waste generation from GDP

Decoupling waste generation from GDP is essential to ensure sustainable use of the world's resources, with consequent climate benefits. Unfortunately, there are limited examples of such de-linking in the world, and no examples of decoupling per capita GDP from per capita waste generation were found in the course of the present investigation. In developing nations, increasing GDP is strongly linked to increasing waste generation in urban areas. For example, India experienced an average GDP growth of 7% between 1997 and 2007, and estimated municipal waste arisings have increased from 48 million tonnes to 70 million tonnes during the same period (Chintan 2009, Sharholy 2008).

Several EU member states have to some extent managed to decouple waste generation from economic factors such as GDP (European Communities, 2003; OECD, 2005). However, in absolute terms, waste generation is increasing in the OECD. Germany appeared to have decoupled national waste generation from total GDP between 2000 and 2005; however waste generation increased between 2005 and 2006 due largely to a flux of construction and demolition waste (see Figure 4). A strong regulatory environment, driven largely by EU waste directives, caused the sharp decrease in waste generation in Germany.

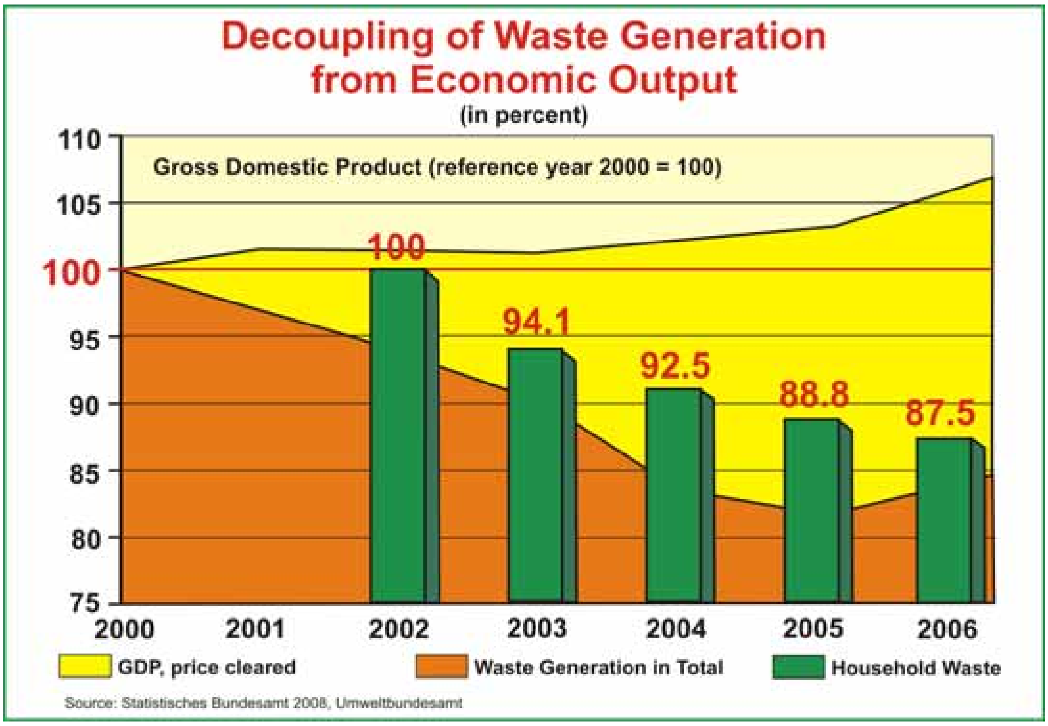

Figure 4: German waste generation and GDP data, 2000 - 2006 (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2008)

3.2.2 Global landfill emissions and data quality

Two independent studies have compiled global waste emissions data and trends – these are effectively reports of landfill emissions, since landfill methane is generally considered to represent the major source of emissions from the waste sector (this is elaborated on later in the current document). The US EPA study presents annual emissions from landfill for almost 100 countries as well as for geographical regions and international entities (US EPA, 2006). The data includes historical and projected emissions from national inventories as reported by countries as National Communications to the UNFCC while data gaps were addressed by utilising IPCC Tier 1 methodology[7] and defaults for calculating emissions. In the second study, Monni et al applied the IPCC FOD model (the Tier 2 method previously described), in order to calculate global emissions (Monni et al 2006). Using the model and default factors, landfill methane generation was calculated for past, present and future key years.

Table 3 presents the global landfill emissions calculated by these two studies. As US EPA assumes instantaneous emissions after deposition, the findings are not directly comparable. Moreover, this assumption is unrealistic as it is well documented that decomposition of waste in landfills is a gradual process that can take decades to complete. As a result Monni *et al* calculations are lower than US EPA for the first few covered years as initial emission growth is slower than the corresponding growth in waste quantities, while future emissions are higher due to the gradual decomposition of waste deposited prior to the introduction of waste minimisation measures such as the EU Landfill Directive. In both studies however, there is a trend for emissions from waste to increase.

Table 3: GHG emissions from waste as calculated by US EPA (2006) and Monni et al (2006) ($MtCO_2$-e, rounded) (Data sourced from Bogner *et al* 2007).

Source	1990	1995	2000	2005	2010	2015	2020	2030	2050
US EPA (2006)	760	770	730	750	760	790	820		
Monni *et al* (2006)	340	400	450	520	640	800	1000	1500	2900

As reported by Bogner et al (2007), availability and quality of annual data are major problems for the waste sector. This uncertainty extends to data on waste type and mix, quantity, and management practices. In addition to considerable variation in data quality and unavailability of any kind of data for a number of countries, non harmonised national definitions of waste make comparisons between countries difficult (Monni et al 2004).

The 2006 IPCC Guidelines (IPCC, 2006) indicate that uncertainties for global emissions from waste can be as high as 10-30% for developed countries (with good data sets) to 60+% for developing countries that do not have annual data. Examining the 2001 Finnish GHG emissions inventory, Monni et al (2004) calculated a -28% to +30% uncertainty with respect to emissions arising from waste disposal. Monni et al also noted that if alternative, but equally defensible, assumptions were adopted for future waste generation, their results for total methane emissions from landfills worldwide could be 40-50% lower, or 20-25% higher than those actually presented.

Furthermore, calculations for estimating emissions from decomposition of waste in landfill are also subject to high levels of uncertainty. An accepted method for direct measurement of emissions is not currently available and therefore all estimates are based on theoretical models such as the IPCC First Order Decay model (IPCC, 2006). All available models are based on a number of underlying assumptions. Even accepting that data on waste quantities and composition are accurate, subsequent assumptions on decomposition rates, methane generation rates and oxidation rates amongst others, all add error and uncertainty to the calculations.

In summary, it is extremely difficult to gauge the accuracy of current estimates of the climate impact of waste activities, either at a national or global scale, due to data limitations. Results of projections of GHG emissions from waste are highly dependent on the assumed rates of waste

[7] At the time of the study, Tier 1 methods assumed that all potential methane is released in the year the waste is disposed of. Since 2006, IPCC uses a Tier 1 method based on the FOD model.

generation. There are already uncertainties at the national level, and this is exacerbated when global predictions are made. Although a concerted international effort could be mobilised to address these limitations and produce robust waste databases, it would seem more logical and worthwhile to direct limited global resources towards minimising GHG emissions from waste activities.

3.3 Climate impact of waste management practices

Every waste management practice generates GHG, both directly (i.e. emissions from the process itself) and indirectly (i.e. through energy consumption). However, the overall climate impact or benefit of the waste management system will depend on net GHGs, accounting for both emissions and GHG savings.

The following discussion is not intended to represent an exhaustive investigation of the climate impact of each waste management approach, but rather explores the range of potential benefits and impacts of the major management practices, supported by examples from the literature. The discussion is organised in reverse order of the waste management hierarchy, beginning with landfill and ending with waste prevention.

3.3.1 Landfill

In the majority of countries around the world, controlled and uncontrolled landfilling of untreated waste is the primary disposal method. Methane emissions from landfill represent the largest source of GHG emissions from the waste sector, contributing around 700 Mt CO_2-e (estimate for 2009) (Bogner et al 2007). In comparison, the next largest source of GHG emissions from the management of solid wastes is incineration[8], estimated to contribute around 40 Mt CO_2-e (2009 data estimated in Bogner et al (2007)). Landfills may also be a source of nitrous oxide; however the contribution to global GHG emissions is believed to be negligible, and related to the management of both wastewater biosolids disposed at landfills and landfill leachate (Bogner et al 2008).

Table 4 provides a qualitative summary of the indirect and direct GHG emissions and savings associated with landfilling. To provide a complete picture, all GHGs are noted, including biogenic CO_2.

[8] To reiterate, the second largest source of emissions from the waste sector as a whole is wastewater. The current report addresses emissions from solid waste management.

Table 4: Summary of indirect and direct GHG emissions and savings from landfills (adapted from Scheutz et al 2009)

Upstream (indirect)	Direct (operating)	Downstream (indirect)
CO_2, CH_4, and N_2O emissions from: production of fuel used on site, electricity consumption, and production of materials (i.e. liner material, soils)	Fugitive emissions of CH_4, trace NMVOC[9], N_2O and halogen-containing gases; biogenic CO_2 from waste decomposition; CO_2, CH_4, N_2O, trace CO and NMVOC from fuel combustion in equipment; biogenic CO_2, CO_2, CH_4, and N_2O from leachate treatment	Energy produced from combustion of captured LF CH_4 substitutes fossil energy: avoided CO_2 Long-term carbon stored in landfill (organic materials largely recalcitrant in anaerobic conditions): avoided CH_4 and biogenic CO_2

There are several general points worth noting regarding landfills and GHG emissions in the non-OECD region:

- Where landfill practices are informal and do not extend to site compaction and cover, the optimum anaerobic conditions for methane-production do not develop. Therefore less methane is produced per tonne of organic waste (compared to controlled sites). Degradation processes proceed under more aerobic conditions, generating larger quantities of biogenic CO_2.
- There is a trend towards more managed landfill practices in developing nations, which will somewhat ironically lead to enhanced anaerobic conditions and therefore generation of greater quantities of methane in the future. However, higher methane generation does mean that landfill gas capture systems become more economically viable.

For a specific site, the quantity of methane emissions will depend on waste composition, landfill management, LFG management, cover material (for optimal methane oxidation) and climate. Various authors have used IPCC regional defaults for quantities and composition of waste landfilled in conjunction with the IPCC FOD model to produce a global estimate of landfill methane emissions (i.e. Monni et al 2006; US EPA 2006a). As discussed in previous sections, the assumptions and uncertainties inherent in the FOD model for predicting landfill emissions are considerable. Monni et al (2006) adjusted the estimate to account for OECD countries where there has been a measurable decrease in landfilling, largely due to EU member states reaching early compliance with the European Landfill Directive, which requires a significant reduction in the quantity of biodegradable municipal waste landfilled. For example, from 1990 to 2005, Germany gradually banned the practice of landfilling untreated organic waste. By 2012, this ban is anticipated to result in a saving of approximately 28.4 million tonnes of CO_2-e due to avoided methane emissions from landfill (Dehoust et al 2005).

Monni et al (2006) projected emissions from the waste sector to 2050, assuming continuation of current trends in waste management (a business as usual (BAU) scenario). Results of the emissions projected for each region under BAU assumptions are shown in Figure 5. Due to diversion of waste from landfilling and recovery of LFG, emissions of landfill methane from OECD countries are predicted to remain relatively stable if current trends continue. EIT countries contribute only a small portion to global landfill methane – there are fewer nations that are categorised as EIT, and there will presumably be some activity in waste diversion and gas capture. The disturbing trend is the exponential increase in methane emissions from non-OECD

[9] NMVOC refers to non-methane volatile organic compounds.

landfills due to growth in population and affluence, expansion of waste collection services to more of the population, and improved landfill practices. In this scenario, non-OECD countries will have a relative share of 64% of global landfill methane emissions by 2030. Evidently, improved landfill management in non-OECD regions has many public health and environmental benefits; hence, care and planning is needed to avoid the associated dis-benefit of increased methane emissions.

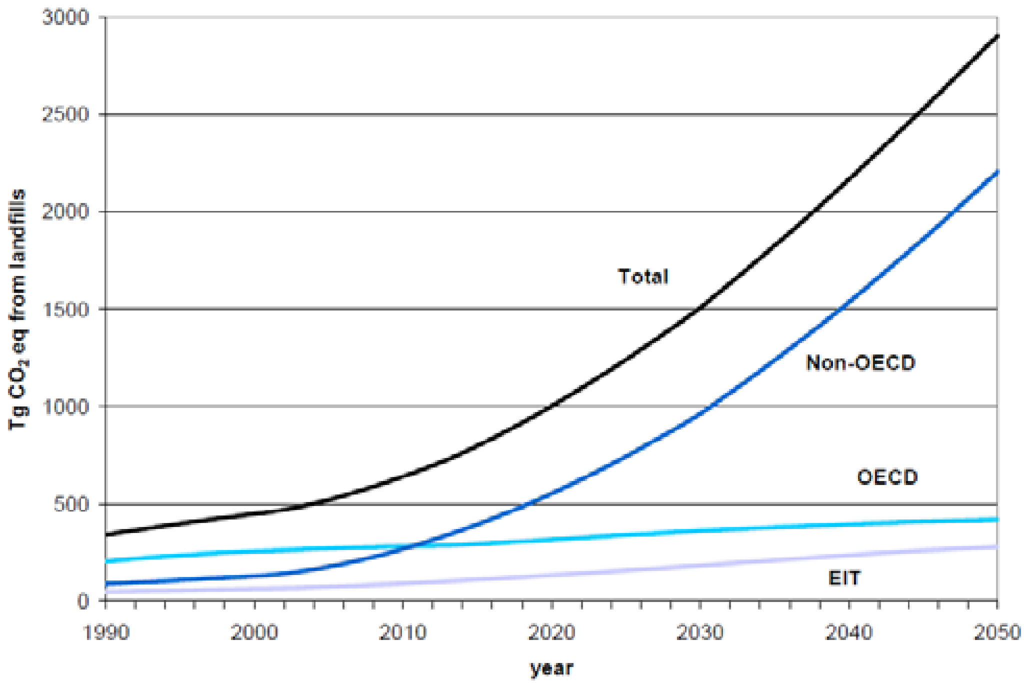

Figure 5 Methane emissions from different regions - BAU scenario (source: Monni et al 2006)

Landfills reduce GHG emissions where LFG recovery systems generate energy that substitutes for fossil-fuel energy sources, or where carbon storage is taken into account. In terms of energy savings, the climate benefit calculated for a specific site will largely depend on the type of fuel source of the energy that is assumed to be replaced. Monni et al (2006) compared potential emissions savings on a global scale for landfill methane projections in 2030, and estimated 56 Tg CO_2-e where coal-derived energy is assumed to be replaced and 22 Tg CO_2-e where natural gas-derived energy is replaced (natural gas is a 'cleaner' fuel than coal, therefore there is less climate benefit in replacing natural gas).

A key assumption in terms of global projections of landfill climate impact is the assumed rate of LFG capture. Even at a national level, there is often enormous variation in estimated capture rates. Capture rates for individual sites will also vary with time as methane yield changes with the development of the site – an instantaneous rate of capture does not represent a 'whole-of-life' capture rate. Over a 100-year period, managed landfills of the type seen in developed countries may capture around 50 – 80% of methane generated (Manfredi et al 2009, Bahor et al 2009). Landfills in EIT regions are estimated to capture around 35% of methane generated (Bahor et al 2009).

Certain waste materials are largely recalcitrant in landfills – non-biodegradable materials (i.e. plastics), lignin and some lignin-bound cellulose and hemi-cellulose undergo minimal decomposition in the anaerobic conditions within managed landfills (Barlaz 2006). A high proportion of wood waste, for example, may be considered as carbon stored in landfills while anaerobic conditions prevail. Landfills may calculate a GHG benefit for long-term storage of recalcitrant materials in landfill (usually estimated based on wood waste). For example, over a 100-year time horizon, Manfredi et al (2009) suggest GHG savings of 132 to 185 kg CO_2-e per tonne of wet, mixed MSW input for carbon stored in well-managed, European landfills. Landfill carbon storage may be reported in IPCC national GHG inventories, but the carbon is credited to the harvested wood products (HWP) sector (IPCC 2006). It must be emphasised that, purely from a climate change perspective, burying wood in landfills may be part of the solution; however, there are myriad other reasons (i.e. ecological, resource use, land use) for not doing this.

European studies emphasise the climate benefit of diverting biodegradable waste from landfills (e.g. Dehoust et al 2005; Smith et al 2001; Eunomia, 2002). Smith et al (2001) suggest that diverting food, garden, and paper waste to composting or recycling reduces net GHG emissions by 260 kg CO_2-e per tonne of MSW (assuming landfills meet average EU standards for LFG management). Diversion of organic wastes from landfill and implementation of active systems for landfill gas extraction are complimentary to an extent: due to the gradual release of methane over many years, even if a ban on landfilling organic waste were implemented at a site today, there would still be an existing store of organic material releasing methane, that could be extracted into the future. The considerable impact of these measures is evident in the EC-15 (as discussed above). In addition, organic waste diversion and LFG capture are feasible options for implementation in non-OECD regions. However, detailed, site-specific analysis is necessary to determine the effectiveness (including cost implications) of installing LFG capture systems on landfills with active organic waste diversion programs.

CDM landfill projects

The Clean Development Mechanism (CDM), under the Kyoto Protocol, provides an opportunity for developing nations to implement landfill gas capture schemes, thereby improving waste management practices and addressing climate change. CDM is discussed in more detail in later sections. Several points are worth noting regarding LFG capture projects:

- Landfill gas management should be promoted in all countries as a required practice; however, under the current terms of CDM, such regulation would no longer enable landfill gas projects to meet the ‘additionality’ criteria for CDM approval;
- The availability of ‘cheap’ credits obtained through CDM landfill gas projects might undermine the drivers, which carbon trading schemes hope to provide;
- There are difficulties in assessing the portion of methane actually being captured from a site (as discussed previously).

LFG capture projects represent a large portion of registered CDM projects (these are discussed later in the report). The CDM is applicable during the first commitment period of the Kyoto Protocol (2008 – 2012), however after that its continuation is uncertain.

CDM projects recovered a reported 30 Mt CO_2-e of landfill methane in 2008 (Monni et al 2006). Monni et al (2006) compared several different waste management scenarios, at a global scale (see Figure 6 – note that the study does not take into account GHG credits, such as material savings, energy savings associated with LFG recovery, or carbon storage). In the ‘CDM ending in 2012’ scenario, 30 Mt CO_2-e has been assumed as annual recovery from 2008-2012, after which no further installation of gas recovery is assumed in non-OECD countries. The High Recovery (‘HR’) scenario assumes an annual increase in LFG recovery of 15% in all regions (in non-OECD from 2013 onwards). This is a very ambitious assumption, and although theoretically possible, it does not represent a conservative approach. Due to the high assumed recovery rate, the HR scenario performs extremely well compared to other scenarios, and is particularly effective in the non-OECD region. The modelling highlights the potential benefits of LFG capture at the global scale.

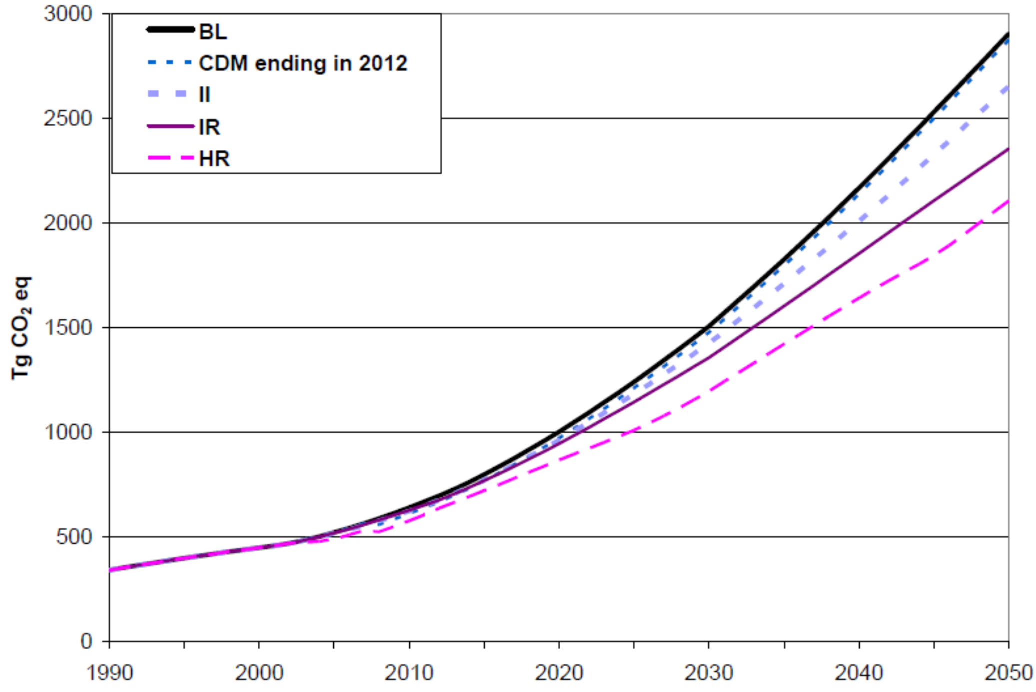

Figure 6 Global methane emissions from landfills in the BAU and four mitigation scenarios (source: Monni et al 2006)

Landfills may currently represent the largest source of GHG emissions from the waste sector, but the options for reducing this climate impact are available and achievable: divert biodegradable waste from landfill disposal and maximise landfill gas capture. Neither option is technically complex, and there is a body of knowledge and experience in OECD regions that could be transferred to non-OECD countries.

3.3.2 Thermal treatment

Thermal waste treatment refers to mass-burn incineration, co-incineration (i.e. replacing fossil fuels with refuse-derived fuel (RDF) in conventional industrial processes, such as cement kilns), pyrolysis and gasification. Mass-burn incineration is the most commonly applied thermal treatment. Pyrolysis and gasification may be considered as emerging technologies, with limited success in treating mixed waste streams. The majority of studies assume that energy is recovered from the thermal treatment of waste, either as heat or electricity, which can equate to a considerable GHG saving (depending on the type of energy displaced). Metals are also recovered from incinerator ash, and this contributes to further GHG benefits. The present review focuses on the climate impact of incineration, particularly given the limited data available for pyrolysis and gasification processes and performance.

Approximately 130 million tonnes of waste are currently incinerated across 35 countries (Bogner et al 2007). Japan, Denmark, and Luxembourg treat >50% of the waste stream through incineration. France, Sweden, the Netherlands and Switzerland also have high rates of incineration (Bogner et al 2007). Incineration is only applied in a limited capacity in the remainder of the OECD countries. There is no incineration of mixed waste practiced in either Australia or New Zealand, largely due to public opposition. Australia, New Zealand, Canada and the US do not have legislation in place that limits landfilling (i.e. as is the case with the EU Landfill Directive); therefore landfill remains the cheapest and thus preferred disposal option.

Incineration of mixed wastes is a largely unfeasible option in non-OECD countries due to cost and often unsuitable waste composition (as discussed below). Thermal treatment with energy recovery may be eligible for CDM funding. The CDM methodology for ‘avoided emissions from organic waste through alternative waste treatment processes’ (AM0025) is applicable to projects that derive energy from waste. Much of the waste in the non-OECD region is characterised by a high percentage of putrescible waste (see Table 5) with consequent high moisture and low calorific value, making it unsuitable for incineration without considerable pre-treatment, such as pressing or drying (Lacoste and Chalmin 2006; UNEP 2009).

Table 5 Characteristics of MSW in low, medium, and high GDP countries (source: Lacoste and Chalmin, 2006)

	Low-GDP countries	Medium-GDP countries	High GDP countries
Example country	India	Argentina	EU-15
GDP US$/capita/year	<$5,000	$5,000 - $15,000	>$20,000
MSW kg/capita/year	150 - 250	250 – 550	350 – 750
MSW collection rate	<70%	70% – 95%	>95%
% putrescible waste in MSW	50% - 80%	20% - 65%	20% - 40%
Heating value kcal/kg	800 – 1,100	1,100 – 1,300	1,500 – 2,700

China, despite its non-ideal waste composition, has vigorously embraced incineration: the proportion of MSW incinerated has risen from 1.7% in 2000 to 5% in 2005, with the construction of 67 incinerators (Bogner et al 2007). A 2005 World Bank report noted:

> *Shanghai, which has the most ‘internationally standard’ waste stream (i.e. higher fraction of plastics and papers and less moisture) in China still has a waste composition that is barely autogenic (a high enough heating value to burn on its own). Most Chinese cities would have to use supplemental fuel in order to burn their solid waste, and thus there would be no net energy generation to offset the high costs of incineration (World Bank 2005).*

India has had limited success with thermal treatment projects, which tend to focus on turning MSW into refuse derived fuel (RDF), or ‘fluff’, to combust for energy production or to supplement fuel for cement kilns. The informal recycling sector in Indian cities recovers much of the dry, high calorific material from MSW, leaving a moist residue with high green waste content unsuitable for production of combustible ‘fluff’ without considerable pre-treatment (i.e. drying). For example, these difficulties have been reported at facilities in Chandigarh and Hyderabad (Yadav 2009, Joseph 2007). India, like many developing nations, also lacks laboratory facilities to appropriately monitor the performance of thermal facilities (i.e. testing substance levels in emissions and ash). Similar problems have been experienced at incinerators in Thailand.

At the global level, the climate impact of incineration is minor compared to that of landfilling, contributing around 40 Mt CO_2-e in the current year (Bogner et al 2007)[10]. Direct emissions from facilities are predominantly fossil and biogenic CO_2. The amounts of fossil and biogenic carbon in the waste input will vary significantly between countries, regions, and even facilities (Astrup et al 2009). Typically only fossil CO_2 is counted as a GHG emission from incineration; therefore,

[10] Municipal waste may contain 40-60% biogenic carbon, which is also emitted during incineration. This same portion of biogenic carbon (apart from the largely recalcitrant wood fraction) also contributes to biogenic CO_2 emissions from landfill. It is worth considering the relevance of time, in the context of the time-critical nature of climate change (i.e. immediate mitigation action is necessary): the biogenic CO_2 from incineration is released instantaneously to the atmosphere, whereas the biogenic CO_2 from landfill is released gradually over a period of years. This comment is not intended to suggest a preference for one waste management system over another, but rather seeks to highlight an important discussion.

the overall climate impact of incineration will be highly influenced by the fossil carbon content of the input waste. Downstream, indirect GHG savings due to energy generation may dominate an estimate of emissions from incineration, depending on the energy assumed to be replaced. Table 6 provides a qualitative summary of the indirect and direct GHG emissions and savings associated with incineration. To provide a complete picture, all GHGs are noted, including biogenic CO_2.

Table 6: Summary of indirect and direct GHG emissions and savings from incineration (adapted from Scheutz et al 2009)

Upstream (indirect)	Direct (operating)	Downstream (indirect)
CO_2, CH_4, and N_2O emissions from: production of fuel used in facility, heat and electricity consumption, production of materials (i.e. air pollution control (APC) systems) and infrastructure	CO_2 and biogenic CO_2 from waste combustion; trace CH_4, N_2O, CO, and NMVOC	Heat and/or electricity produced from combustion of waste substitutes fossil energy: avoided CO_2 Recovery of metals from ash substitutes raw materials: avoided GHG emissions from material production Use of bottom ash to substitute aggregate: avoided GHG emissions from producing virgin aggregate CO_2, CH_4, N_2O, and trace CO, and NMVOC from transport of APC residues and fly ash

The estimated GHG impact of thermal waste treatment processes, such as incineration, gasification, and pyrolysis, depends in large part on the energy source(s) assumed to be replaced by energy generated through the process. The Dehoust et al (2005) study examined the impact of changing the energy source from natural gas (i.e. combined cycle gas turbine (CCGT)) to coal, and found that the GHG saving doubled: if coal is assumed to be replaced, thermal treatment receives double the carbon credit for energy produced than if natural gas is assumed to be replaced. The choice of both baseline and marginal energy mix is a key element of waste and climate change studies, and is often a point of debate. Many developed countries are moving towards more sustainable national energy supply, with conventional coal-powered stations being phased-out in favour of less GHG-emitting alternatives. Therefore, at least in developed countries, the climate benefit of energy derived from waste incineration may lessen in the future.

Estimations of the climate impact of incineration with energy recovery also depend on whether electricity, heat or combined heat and power (CHP) are assumed to be produced. European waste incinerators are reported to have conversion efficiencies of 15-30% for electricity and 60-85% for heat, with efficiency based on the % conversion of the lower heating value of the waste into energy (Astrup et al 2009). In Northern Europe it is fairly common to find district heating networks powered by waste incinerators. Areas of Central and Eastern Europe also have the necessary infrastructure to utilise heat. The UK has examples of incinerators providing heat to adjacent industries (i.e. a latex plant) – industrial heat usage is in many cases more attractive than district heating. However, in many parts of the world, the infrastructure necessary to usefully apply the heat is often not in place and prohibits building CHP plants. An alternative use of heat energy may be for absorption refrigeration in situations where cooling is more desirable than heating; however this is not yet a common practice. The location of thermal technologies is therefore a crucial consideration when assessing energy efficiency and the potential for thermal treatment to mitigate climate impact.

The GHG impact of thermal treatment of waste biomass – such as crop residue – may be very different to that of incineration of mixed wastes. The assessment will depend on a number of factors, including:

- Alternative life-cycle for the biomass – in the case of crop residues, an important consideration is whether they would be left in-situ, or mulched on-site, to contribute nutrients and structure to soils, or burnt (uncontrolled)
- Suitability of the biomass for anaerobic digestion – if the waste biomass has a composition suitable for AD (i.e. minimal lignin content) then the climate benefit of AD with energy recovery outweighs that of thermal processing with energy recovery (and typically presents a less expensive option)[11]
- Whether biogenic CO_2 is considered relevant, particularly given the time-relevance of climate change

An important, but often overlooked point is that crop residues, although not useful from the perspective of human consumption or production, contain an often significant portion of the original nutrient input to the crop. In combusting residues, there is the danger that these nutrients are removed from the agricultural ecosystem, and result in a net depletion of essential building blocks for future crops. This may perpetuate the use of 'imported' fertilisers and soil amenders, with ensuing climate impact from manufacturing and transporting soil additives. A portion of crop residues may potentially be removed in a sustainable manner (Kim and Dale 2004); therefore individual cropping systems should be carefully assessed before waste biomass is removed to fuel power plants – even where residues are currently burnt in-situ, this may not be the most sustainable alternative.

Pyrolysis and gasification of biomass may offer higher efficiencies (of conversion of waste to energy) than mass-burn incineration, especially if operated in heat only or CHP mode, if the low-emissions claims of technology suppliers are accepted. However, both gasification and pyrolysis should be considered conservatively as emerging technologies, still under development, and with variable track records. For a number of years, centralised gasification of wood (or other high-lignin content) biomass has been trialled primarily in Japan and Europe. Independent emissions data is difficult to obtain from Japanese facilities to ascertain GHG performance, and European plants have met with mixed success. Tars produced during wood pyrolysis appear to be a major problem for gas engines attached to furnaces, causing low generating efficiencies and down-time for maintenance, and require sophisticated technical solutions to avoid. Pyrolysis and gasification should not be ruled-out as potential future technologies to produce relatively clean energy from biomass waste.

Assessments of the potential GHG benefits of the thermal conversion of biomass waste to energy should be treated with caution. Although various methods can be used to estimate the total calorific value of the biomass ('total biomass energy') there is no thermal process that will convert 100% of that calorific value into energy. Assuming 100% efficiency can lead to highly erroneous estimations of the scale of potential energy production (and GHG benefit through fossil fuel replacement) of waste biomass.

Thermal technologies could have a valuable role to play in the treatment of specific streams of wastes, or carefully prepared mixed residual wastes (i.e. RDF), as part of an integrated and

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[11] For example, see analysis in: Eunomia Research & Consulting (2008). *Greenhouse Gas Balances of Waste Management Scenarios – Report for the Greater London Authority*. Although this study assessed MSW, similar assumptions and technologies would apply to agricultural waste biomass. See also Smith et al (2001).

future-thinking waste management system. In many countries, thermal treatment plants require long lead-times (i.e. >10 years) to meet planning approval, financing, construction, and commissioning. In addition, facilities will last for at least 25 years with limited flexibility for changing waste supply, which suggests that capacity needs to be planned for carefully. This suggests that such facilities may be part of a longer-term strategy for climate abatement.

3.3.3 Mechanical biological treatment

MBT refers to a wide range of technologies that separate incoming waste into recyclable materials for recovery and an organic fraction for biological treatment (stabilisation). In Europe, facilities tend to produce a refuse-derived fuel (RDF) for subsequent thermal treatment; this is not the case in other regions (i.e. Australia). MBT – in all its various configurations – has a strong track record in Europe, and the UK and Australia are increasingly embracing MBT as the cost of landfilling increases in these countries. MBT is relatively scarce in the rest of the world, therefore the majority of LCA-type studies that estimate GHG emissions from MBT are based on European, UK, and Australian conditions.

The downstream, indirect GHG emissions/savings from MBT generally outweigh both upstream and direct process emissions. Table 7 provides a qualitative summary of the indirect and direct GHG emissions and savings associated with MBT. To provide a complete picture, all GHGs are noted, including biogenic CO_2.

Table 7: Summary of indirect and direct GHG emissions and savings from MBT (adapted from data provided in Scheutz et al 2009)

Upstream (indirect)	Direct (operating)	Downstream (indirect)
CO_2, CH_4, and N_2O emissions from: production of fuel used in facility, heat and electricity consumption, and infrastructure	CO_2, CH_4, N_2O, trace CO and NMVOC from fuel combustion in equipment Biogenic CO_2, CH_4, and N_2O from windrows Biogenic CO_2, CH_4 (leakages) and trace N_2O from reactors, and biofilters (MBT AD)	Heat and/or electricity produced from combustion of biogas substitutes fossil energy (MBT AD): avoided CO_2 Front-end recovery of materials substitutes raw materials: avoided GHG emissions from material production Use of organic compost output to substitute soil growth media: avoided GHG emissions from producing virgin growth media Long-term carbon stored in landfill (organic materials largely recalcitrant in anaerobic conditions):avoided CH_4 and biogenic CO_2

The overall climate impact of a particular MBT technology will depend on:

- The efficiency of front-end sorting processes – recovered materials contribute to potentially significant downstream GHG savings

- Energy consumption of system – more automated, sophisticated systems have a higher energy demand
- Energy generation – in the case of anaerobic digestion (AD)-type MBT facilities, energy produced from biogas – either heat or electricity – will account for a GHG saving
- Control of emissions during the maturation phase – best-practice for MBT involves the use of air pollution control systems, such as scrubbers and biofilters, to prevent emissions of nitrous oxide and methane
- Carbon storage potential – compost derived from mixed waste is usually restricted in application (i.e. remediation of contaminated land or landfill), but may be credited with a GHG benefit from carbon storage
- Biodegradability of final output – the biodegradability of the final composted output will decrease with increased maturation time, and the lower the biodegradability, the less potential for the material to generate methane (if landfilled)

The main gains in terms of climate benefit are from separation and recovery of recyclable materials and through reduction of the amount of biodegradable waste landfilled (or medium-long term binding of carbon where composted output is applied to soils). Less organic material to landfill equates to fewer methane emissions. Where MBT outputs are landfilled rather than applied to land (the use of MBT compost outputs tends to be highly regulated in OECD countries), some methane will still be generated. Theoretically, an MBT process could reduce methane generation by 90%, compared to landfilling the equivalent quantity of waste (Bogner et al 2007). GHG emissions and savings associated with recycling, composting, and AD are discussed in greater detail in the relevant sections below, although the composting and AD discussions relate to source-separated organic waste, rather than the organic fraction derived from mixed MSW.

MBT, with simple aerobic composting of the organic portion of the mixed waste stream, may offer an easy, relatively inexpensive solution to reduce the climate impact of landfilling waste. This may also be seen as an interim solution to gain rapid GHG benefit while waste management systems are improved (i.e. to increase source separation and recovery).

The dried organic outputs from MBT may also be used as refuse-derived fuel (RDF) for incineration with energy recovery or co-combustion in industrial furnaces, typically cement kilns, paper pulp mills, and coal-fired power plants. RDF generally does not replace conventional fossil fuel on a 1:1 ratio by weight – more RDF may be required to achieve the same energy output. Conventional furnaces will have a limit to the amount of fuel calorific value they can substitute with RDF (Eunomia, 2008b) and not all industrial processes can be easily adapted to use RDF. Emissions control at industrial plants may be less stringent than at waste incinerators – the EU has addressed this concern through the Waste Incineration Directive (WID) that stipulates emissions requirements for any plant combusting significant quantities of waste. The climate impacts from burning RDF in industrial furnaces depend in part on the conventional fuel displaced.

MBT-AD technology for mixed residual waste is largely found in Europe. Many European plants are small-scale, treating less than 20,000 tonnes per year (Kelleher, 2007). The EU Landfill Directive creates the necessary cost and regulatory incentives to support development of both MBT-AD and MBT-composting facilities. The performance of MBT-AD requires careful preparation and pre-sorting of incoming waste in order to ensure a suitable mixture is introduced to the digestion micro-organisms. European plants are equipped with sophisticated front-end sorting equipment, which makes MBT-AD a less affordable and viable solution for developing countries, or countries where landfilling is cheap.

3.3.4 Composting and anaerobic digestion (of source-separated organic wastes)

Composting systems treat biodegradable material such as food, animal industry wastes, green waste, wood, and agricultural residues and produce a range of organic soil amendment products that can replace manufactured fertilisers and/or peat, reduce the need for pesticides, improve soil structure, reduce erosion, and reduce the need for irrigation. Around 2,000 composting facilities currently treat source-separated household organic waste in Europe (Boldrin 2009). Composting and anaerobic digestion of source-separated wastes requires significant investment in local community education (both households and commercial enterprises) and public awareness – this is essential to ensure proper source-separation, high-quality compost products, and secure end-use markets.

Simple composting systems are an effective, low-tech solution for developing countries to reduce waste quantities and generate a valuable compost product for application to agriculture. Both composting and AD systems are found throughout non-OECD regions. For example, the UN Economic and Social Commission for Asia and the Pacific (ESCAP) has assisted cities in Bangladesh, Pakistan, Sri Lanka, and Viet Nam to set-up simple local composting facilities for organic wastes (UN ESCAP, 2009). There are approved methodologies for composting projects under the CDM, such as the methodology for 'avoided emissions from organic waste through alternative waste treatment processes' (AM0025). In India, the informal waste sector feeds into both small and large-scale composting facilities. In the Defense Colony neighbourhood of Delhi, waste pickers collect material from 1,000 households and compost it in a series of neighbourhood composting pits. Also in Delhi, a large-scale composting plant processes 200 tonnes of separated organic waste per day (Chintan 2009). An estimated 9% of MSW in India is composted, and compost is a valuable and marketable product for Indian agriculture (Sharholy 2008).

The climate impact of composting and AD systems is due to both direct process emissions and indirect upstream and downstream emissions. Table 8 provides a qualitative summary of the indirect and direct GHG emissions and savings associated with composting and AD processes. To provide a complete picture, all GHGs are noted, including biogenic CO_2.

Table 8: Summary of indirect and direct GHG emissions and savings from composting and AD processes (adapted from data provided in Scheutz et al 2009)

Upstream (indirect)	Direct (operating)	Downstream (indirect)
CO_2, CH_4, and N_2O emissions from: production of fuel used in facility, heat and electricity consumption, and infrastructure	CO_2, CH_4, N_2O, trace CO and NMVOC from fuel combustion in equipment **Compost processes**: Biogenic CO_2, CH_4, and N_2O from windrows **AD processes**: Biogenic CO_2, CH_4 (leakages) and trace N_2O from reactors, and biofilters	Heat and/or electricity produced from combustion of biogas substitutes fossil energy (**AD processes only**): avoided CO_2 Use of organic compost output to substitute soil growth media: avoided GHG emissions from producing virgin growth media

Direct emissions from composting facilities result from fuel combustion in equipment (i.e. front-loaders) and from decomposition of the organic material. As composting produces CO_2 from biogenic carbon sources, it does not contribute to national GHG inventories for the waste sector under IPCC accounting methods (IPCC 2006). CH_4 and N_2O emissions will depend on the type of organic waste input, the technology used (in particular, whether the process is open or enclosed), and how the process is managed (Boldrin et al 2009). The IPCC default values for reporting emissions from biological treatment processes in national GHG inventories provide an indicative range of emissions levels (see Table 9), which are also comparable to the range of values presented for open and enclosed composting systems in Boldrin et al (2009).

Table 9: Default emissions factors for CH_4 and N_2O emissions from biological treatment of waste (reproduced from IPCC 2006)

Type of biological treatment	CH_4 Emissions Factors (g CH_4/kg waste treated)		N_2O Emissions Factors (g N_2O/kg waste treated)		Remarks
	On a dry weight basis	On a wet weight basis	On a dry weight basis	On a wet weight basis	
Composting	10 (0.08 – 20)	4 (0.03 – 8)	0.6 (0.2 – 1.6)	0.3 (0.06 – 0.6)	Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%.
Anaerobic digestion at biogas facilities	2 (0 – 20)	1 (1 – 8)	Assumed negligible	Assumed negligible	The emission factors for dry waste are estimated from those for wet waste assuming a moisture content of 60% in wet waste

Once compost is applied to land, further, minimal emissions will be generated as organic compounds are gradually mineralised to biogenic CO_2. Therefore, compost applied to soil has a medium or long-term potential to store carbon; however, it does not represent a permanent solution for 'locking-up' carbon (Smith et al 2001; Favoino and Hogg, 2008). Quantifying the climate benefit of carbon storage is extremely difficult and will largely depend on how the soil landscape is managed (cropping, tillage, irrigation, compost application rate, etc), climate, and original carbon content of the compost and soil. Estimates of GHG savings range from 2 kg CO_2-e to 79 kg CO_2-e per tonne of composted waste applied to land (Smith et al 2001; Boldrin et al 2009; ROU, 2006). Compost applications to land may also result in emissions of N_2O, depending on the nitrogen content of the compost, and when the compost is applied (i.e. N_2O releases are likely if vegetation is not taking up nitrogen at the time of application) (Boldrin et al 2009). However, compared to synthetic fertilisers, compost may in fact reduce overall N_2O emissions from agricultural land by providing a more slowly released source of nitrogen (Favoino and Hogg, 2008).

Compost applied to land replaces synthetic fertilisers and soil improvers (i.e. peat) and reduces the need for pesticides, tillage, and irrigation (Favoino and Hogg 2008, Boldrin et al 2009, US EPA 2006, Smith et al 2001). The manufacture of synthetic fertilisers is energy-intensive (e.g. extraction of phosphate rock), as is the extraction of peat for use as a soil amender (note that peat extraction also generates methane emissions). Peat use is not widespread in certain parts of the world, including developing regions and Australasia. Where compost replaces either synthetic fertiliser or peat, there will be a GHG benefit due to avoided energy use. GHGs are also released during the manufacture of synthetic fertilisers: studies have reported values of 4-13 kg CO_2 per kg synthetic N, 0.5-3 kg CO_2 per kg synthetic P, and 0.4-1.5 kg CO_2 per kg synthetic K (ROU 2006, Boldrin 2009). Substitution of fertiliser has been estimated to save around 8 kg CO_2-e per tonne of composted waste applied to land, and substitution of peat has been estimated to save between 4 and 81 kg CO_2-e per tonne of composted waste (PROGNOS 2008, Boldrin 2009).

Estimates of the net climate impact of both open and enclosed composting systems in Europe are savings of around 35 kg CO_2-e per tonne of wet organic waste input (Smith et al 2001, Boldrin et al 2009), taking into consideration fertiliser and peat substitution, and carbon storage in soil.

Anaerobic digestion (AD) of source-separated organic wastes is an alternative to aerobic composting systems, although AD tends to accept a smaller range of materials (i.e. materials with a high lignin content, such as woody garden wastes, are generally not suitable for AD in large quantities). The biogas produced by AD tends to have a high methane content (around 60%, although it will depend on the process parameters) and therefore high energy content.

Energy consumption at the AD plant results in indirect, upstream GHG emissions, although the plant's energy requirements may be partially met through heat generated 'in-house' (see below). Diesel and electricity are the main energy sources – diesel use is minimal (i.e. 1.6 L per tonne of waste) and electricity use varies with the process. The climate impact associated with electricity use will depend on the local mix of fuels, with coal-power resulting in a higher impact than, say, natural gas. Møller et al (2009) suggest a range of values from 2-45 kg CO_2-e per tonne of waste. Small quantities of fugitive emissions from leaks in the system and during maintenance account for direct process GHG emissions – the majority of biogas is contained and used to generate energy. Møller et al (2009) estimated the climate impact of fugitive emissions at 0-48 kg CO_2-e per tonne of waste received at typical AD facilities, which is generally in line with IPCC indicative values (see Table 9).

Indirect, downstream emissions are due to energy generation and use of the digestate/compost output. Typical electricity production efficiencies of 35% are assumed for biogas in LCA-type studies (Eunomia, 2002; Christensen et al 2009), and plants often operate in CHP mode, using the heat 'in-house' to reach the necessary AD process temperatures. This of course assumes sophisticated AD facilities, as are common in Europe – the climate impacts of simple, small-scale AD systems that may be more applicable to developing regions are difficult to assess due to lack of data. Biogenic CO_2 emissions from the combustion of biogas range from 154-250 kg CO_2-e per tonne waste (Møller et al 2009). Climate impact due to the release of small quantities of unburned methane and nitrous oxide during the combustion process result in GHG emissions of 15-24 kg CO_2-e and 0.3-0.5 kg CO_2-e per tonne of waste, respectively (Møller et al 2009). Biogas can also be cleaned and either a) used in transport, b) used to power equipment, c) used in local 'sour' (i.e. impure) gas networks, or d) piped into a gas distribution network, subject to local regulation.

Depending on facility performance, assumptions regarding energy, the end-use of energy generated, and assumptions regarding use of digestate, an advanced, European-style AD facility may have a net climate impact ranging from -375 to 111 kg CO2-e per tonne of wet organic waste input (Møller et al 2009). Higher levels of biogas production, a high-CO_2-e energy mix, and use of heat rather than electricity would all contribute to greater GHG savings.

3.3.5 Recycling

After waste prevention, recycling has been shown to result in the highest climate benefit compared to other waste management approaches. This appears to be the case not only in the OECD (i.e. ISWA 2009, Christensen et al 2009, US EPA 2006) but also in developing countries (i.e. Pimenteira et al 2004, Chintan 2009), although limited data is available. For example, in the US, recycling materials found in MSW resulted in the avoidance of around 183 Mt CO_2-e in 2006 (US EPA, 2009). Estimates of GHG savings are generally based on the premise that recycled materials replace an equal – or almost equal[12] – quantity of virgin materials in a closed-

[12] Process losses will occur during material reprocessing, and will depend in part on the individual facility. For example, Merrild et al (2009) refer to an approximate material loss for paper reprocessing of 2.4% on a weight basis.

loop recycling system (i.e. where material is reprocessed back into the same or a similar product).

Recycling activities are not limited to closed-loop systems, but encompass open-loop recycling, down-cycling, and industrial symbiosis. Open-loop recycling occurs where recycled material is used to make a new, different product, often with a loss of material quality (which may be referred to as ‘down-cycling’). Industrial symbiosis involves the exchange of resources including by-products among industrial enterprises, which may form ‘recycling clusters’ to facilitate sharing resources. Case studies of industrial symbiosis in both developed and developing regions have shown measurable environmental and economic benefits with respect to air, water, and waste (Chertow and Lombardi 2005, Ashton et al 2009, Harris 2007). GHG savings may be associated with reduced use of raw materials, reduced transportation (i.e. of wastes to landfill), and fossil fuel substitution in CHP facilities (i.e. where there is an industrial use for the heat) (Ashton 2009, Harris 2007). Since 2005, the UK’s National Industrial Symbiosis Programme has diverted more than five million tonnes of waste from landfill and eliminated more than five million tonnes of carbon emissions through its activities (Chertow 2009).

Table 10 provides a qualitative summary of the indirect and direct GHG emissions and savings associated with recycling processes. To provide a complete picture, all GHGs are noted, including biogenic CO_2. Generally, emissions relating to the indirect downstream processes far outweigh the combined operating and upstream emissions in recycling processes (for example, see analyses in Merrild et al (2009), Larsen et al (2009), Astrup et al (2009), and Damgaard et al (2009)).

Table 10: Summary of indirect and direct GHG emissions and savings from recycling processes (adapted from data provided in Scheutz et al 2009)

Upstream (indirect)	Direct (operating)	Downstream (indirect)
CO_2, CH_4, and N_2O emissions from: production of fuel used in facilities (i.e. material recycling facilities and reprocessing plants), heat and electricity consumption, and infrastructure	CO_2, CH_4, N_2O, trace CO and NMVOC from fuel combustion in equipment	Recovery of materials substitutes raw materials: avoided GHG emissions from material production Recovery of paper avoids use of harvested wood: wood biomass replaces fossil fuel as energy source (biogenic CO_2 emissions replace fossil CO_2) or unharvested wood sequesters carbon

The GHG benefits of recycling specific materials, such as metals, plastics, glass, and paper products, are well documented (Smith et al 2001; WRAP, 2006; US EPA 2006), and are shown to vary with material, recovery rates, and the type of fossil fuel avoided (where energy savings are calculated). In particular, the magnitude of estimated GHG savings from recycling is highly dependent on the energy assumptions applied to both reprocessing facilities and substituted virgin material plants. Recycling GHG savings have been estimated for countries and/or regions using LCA - Table 11 compares values applied in Northern European, Australian and US studies. The variations in the amounts of GHG credited to the materials shown in the table will largely be due to the energy assumptions of the individual LCA studies.

Table 11 CO2-e savings for materials recycled in N Europe, Australia, and USA (ISWA 2009; RMIT 2009; US EPA 2006).

Material	Kg CO_2-e saved per tonne of material recycled – Northern Europe	Kg CO_2-e saved per tonne of material recycled – Australia	Kg CO_2-e saved per tonne of material recycled – USA
Paper	600 - 2,500	670 – 740	838 – 937
Aluminium	10,000	17,720	4,079
Steel	2,000	400 – 440	540
Glass	500	560 – 620	88
Plastic	0 -1,000	0 – 1,180	0 – 507

The range of values for paper presented in Table 11 also reflects different paper types, and each study's assumptions regarding unharvested wood stocks. For example, paper recycling reduces the demand for wood – some studies assume that this 'saved' wood would be used as an energy source (and therefore generate energy GHG savings), whereas others assume that the wood remains unharvested, and thus has a carbon sequestration benefit. Merrild et al (2009) estimate that the downstream GHG impact of paper recycling in Northern Europe could range from +1,500 kg CO_2-e/tonne paper waste (i.e. emissions) to -4,400 kg CO_2-e/tonne paper waste (i.e. savings), depending on whether recycled paper is assumed to replace virgin or recycled paper stocks, the energy assumptions, and the choice of what happens to the unharvested wood.

The range of values for plastic (Table 11) reflects a number of possible factors, such as: different types of plastic polymers, direct substitution of virgin plastic versus a mixed plastic product replacing the use timber or concrete (i.e. for garden furniture and fences), assumptions regarding energy, and reprocessing techniques. Astrup et al (2009) found that the substitution of virgin plastic generated greater climate benefit (i.e. savings of 700 – 1,500 kg CO_2-e/tonne plastic waste) than either the substitution of wood (i.e. emissions of 70 – 500 kg CO_2-e/tonne plastic waste) or production of energy (i.e. savings of 1,200 – emissions of 50 kg CO_2-e/tonne plastic waste) using plastic recycled in Europe.

A recent investigation by the UK Waste and Resources Action Programme (WRAP) of 55 LCA studies found that '*across the board, most studies show that recycling offers more environmental benefits and lower environmental impacts than other waste management options*' (WRAP, 2006). The report's main GHG-related conclusions for specific materials included:

- On average, virgin production of paper followed by incineration with energy recovery consumes twice as much energy as paper recycling; however, the GHG benefit of recycling paper depends largely on the system boundaries adopted by the individual LCA studies (in particular, whether the GHG 'cost' of using timber to produce paper is accounted for)
- Closed-loop recycling of glass results in net climate benefits compared to incineration. There is insufficient data on open-loop recycling (i.e. glass recycled into aggregate, insulation, or other secondary product) to determine the net GHG impact
- Where recycled plastic replaces virgin plastic of the same kind in ratio of 1:1 (by weight), recycling of plastic was found to have a net environmental benefit compared to incineration. For every kg of plastic recycled, around 1.5 – 2 kg CO_2-e is saved.

- Production of virgin aluminium requires 10-20 times more energy than recycling aluminium. Although regional differences in energy sources cause large variations in the extent of GHG savings, there is a universal climate benefit in recycling aluminium.
- Production of virgin steel requires around two times as much energy as production of steel from recycled scrap. As above, regional differences in energy sources may cause variations in the extent of GHG savings; however there is a universal climate benefit in recycling steel.

China has become the major global destination for recycled materials. 50% of the UK's recovered paper and 80% of recovered plastics are exported to China. The UK's WRAP recently commissioned an investigation into the carbon impact of exporting collected recycled materials to China in order to determine whether the climate impact of overseas transport (in container ships) outweighed the benefits of recycling (WRAP, 2008). For the UK, the impact of shipping was minimal, in part due to the fact that ships would otherwise return empty to China (the majority of the shipping movement is from China to the UK – transport of recycled materials back to China represents a marginal impact).

An alternative to recycling plastics that has received some interest recently is conversion of plastics to synthetic diesel. An investigation into GHG impacts of a variety of waste and energy management scenarios for London found that the climate benefits of recycling plastics from the city's MSW far outweighed conversion to diesel (Eunomia, 2008).

The role of the informal recycling sector should not be underestimated in developing nations. The World Bank estimates that around 1% of the urban population in developing countries (approximately 15 million people) earns their livelihood from waste-picking and the informal recycling sector (Medina 2008). Because these activities are not formally organised or often sanctioned by government, their contribution to waste management and resource recovery (and the economy) is often not recognised. However, there is growing appreciation of the role of 'waste pickers' in some countries. Governments in Brazil and Colombia now support the informal sector, which has enabled the formation of waste picker organisations with greater respect and ability to negotiate direct source-collection contracts (or informal agreements) with businesses, industries, and neighbourhood associations (Medina 2008).

A recent report on the climate impact of the informal waste sector in India estimates that activities in Delhi alone equate to savings of around 962,000 tonnes CO_2-e (Chintan 2009). This figure was calculated based on only paper, plastics, metals, and glass recovery, using material specific emissions factors developed for the US EPA's LCA model, WARM, in the absence of Indian LCA tools. However, the report authors note that, due to very conservative estimates of recycling rates and the much more coal-dependent energy mix in India, the values generated by WARM are likely to underestimate the contribution of the informal sector. Figure 7 compares the GHG savings attributed to the informal recycling sector with the estimated GHG reductions anticipated from several waste-to-energy projects and a composting plant currently registered as CDM projects for India (Chintan 2009). The comparison is highly relevant: waste-to-energy projects generally conflict with the informal sector, limiting waste pickers' access to recyclable materials and negatively impacting their livelihood (Chintan 2009, Global Alliance of Wastepickers/Recyclers and Allies 2009).

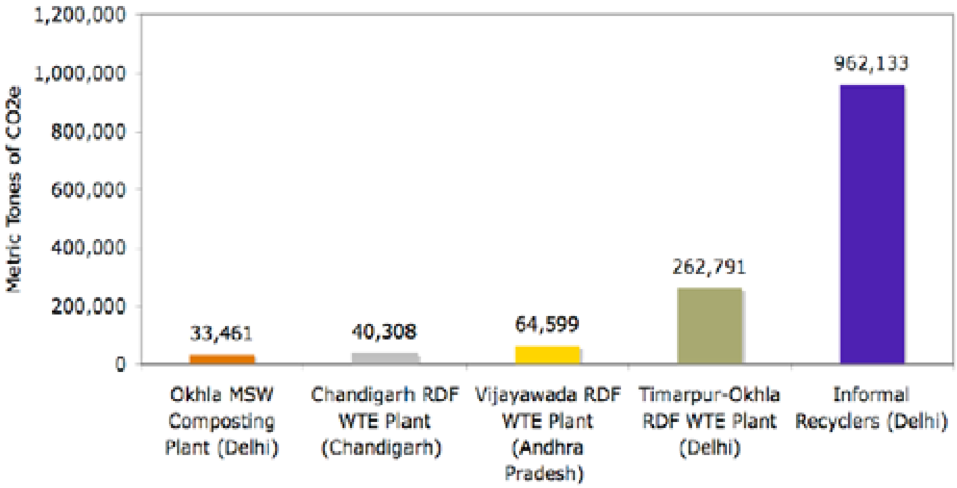

Figure 7: Estimated average annual GHG emissions reductions for waste management scenarios in India, based on assessment of informal recycling sector and data provided in UNFCCC CDM Project Design Documents (Chintan 2009).

The economic contribution of waste pickers should also not be overlooked. Informal recycling in Jakarta reduces the volume of waste by approximately 30%, thereby saving on collection and disposal costs, and extending the life of landfills (Medina 2008). In major Indian cities such as Delhi and Bangalore, waste pickers prevent at least 15% of MSW going to landfill, saving the government around US$13,700 per day in waste collection and disposal costs (Sharholy 2008). Mexican paper mills have strengthened relationships with waste picker associations in order to secure more supply of valuable waste paper.

3.3.6 Waste prevention

Waste prevention is considered the most important action in the waste hierarchy; however it often receives minimal priority in terms of resource allocation and effort. Waste avoidance is critical to decoupling waste generation from economic growth. Within waste prevention there exists a raft of mechanisms that can deliver climate benefit, such as cleaner production, extended producer responsibility, sustainable consumption and production, etc. The SCP Branch of UNEP is involved in a number of programmes targeting sustainable consumption and production, including collaborations with the International Solid Waste Association (ISWA) on waste minimisation. Various mechanisms have been developed and applied to prevent waste arising, with most relying on concerted efforts to educate waste generators. Table 12 provides examples of several waste prevention programmes.

A number of EU Directives, such as the Waste Electrical and Electronic Equipment (WEEE) Directive and the Directive on Packaging and Packaging Waste, have promoted extended producer responsibility (EPR) for specific materials in Europe. Parts of Canada and Australia also have EPR legislation in place that effectively reduces targeted waste streams, such as beverage containers, used tyres, and car batteries.

In terms of climate change impact, the benefits of waste prevention generally outweigh benefits derived from any other waste management practice: not only are net GHG emissions avoided from treatment and disposal of the waste, but there is also a noteworthy benefit in avoided GHG emissions from less raw resource extraction and manufacturing. LCA has been used to estimate the climate benefit of avoided resource use for a limited number of scenarios – it is difficult to quantify the impacts of a waste prevention measure. A US EPA study found that, generally, the net GHG emissions for a given material are lowest for source reduction and highest for landfilling (US EPA, 2006). This is especially true for prevention of paper waste where GHG savings are attributed to increases in forest carbon sequestration (i.e. less use of virgin forest materials to produce paper products equates to less deforestation).

Table 12 Examples of waste prevention initiatives across different waste streams

Targeted waste stream	Initiative	Comments
Commercial / Industrial waste	Cleaner Production	For example, manufacturing wastes are reduced through systems assessment and more effective use of raw materials
Municipal solid waste	Extended product life	Many products have limited lifetime for purely commercial reasons (i.e. built-in obsolescence) – increasing product durability and warranty has a direct impact on waste generation
Packaging waste	Light-weighting	Reducing the amount of material used to produce packaging (i.e. lighter plastic wrapping, lighter cardboard boxes)

A recent report produced by the US EPA Office of Solid Waste and Emergency Response (US EPA 2009) examines how GHG emissions could be prevented through alternative management of materials (US EPA, 2009). An estimated 42% of total US GHG emissions are due to materials management. Strategies discussed in the report include source reduction through improved product design and cleaner production, increasing product durability, and maximising the ease of product disassembly (for recycling). A number of scenarios were modelled to estimate the potential GHG reductions, assuming no economic, institutional, or technological barriers – results of several scenarios are shown in Table 13 and indicate the order-of-magnitude impact of various activities. The scenarios were modelled using the waste LCA tool developed by the US EPA (called WARM). The assumptions in WARM regarding LFG capture, incinerator efficiency, etc, will impact on results – these assumptions are not presented in the report. However, the key areas for action are clear: increasing recycling, maximising LFG capture, and reducing packaging result in significant GHG benefits.

Table 13 Summary of selected materials management scenarios for the US (source: US EPA, 2009)

Scenario	Estimated GHG emissions benefit (Mt CO_2-e/yr)
Reduce packaging use by 50%	40 – 105*
Reduce packaging use by 25%	20 – 50
Increase the national MSW recycling and composting rate from current (32.5%) to 50%	75
Combust 25% of currently landfilled MSW	20 – 30
Capture 50% of currently emitted methane at US landfills for electricity generation	70

*higher benefits include GHG credit for forest sequestration

3.4 Summary of GHG implications of waste management practices

Direct comparisons of the climate impacts of different waste management practices, based on GHG estimates presented in the literature, are not possible at the global scale. The current report does not propose to identify a single 'best' waste management approach, in terms of climate benefit, for global application. Rather, the preceding discussion is intended to inform the development of UNEP's international framework strategy to deliver and support initiatives in the field of waste and climate change.

Several general conclusions can, however, be drawn from the above discussion:

- The net GHG emissions estimated from any given waste management system will depend on regional conditions, such as waste composition and energy mix, and assumptions regarding technology performance, carbon storage/sequestration, etc. Where data is limited or unavailable, as is often the case in developing nations, accurate estimates of GHG emissions from waste practices are unlikely to be achievable.

- Although the current report was commissioned to examine the climate implications of waste management practices, an integrated approach to planning for waste management must also consider the economic, social, and wider environmental aspects of technologies and activities.

- There is general consensus across the global waste sector that the greatest climate benefit will be achieved through improved materials management leading to waste prevention. Recycling of most materials results in the 'next best' GHG savings. Globally, waste prevention and resource recovery represent the key activities by which the waste sector can significantly contribute to climate change mitigation.

- The climate benefits of composting and anaerobic digestion are attributable to carbon binding in soil, substitution of synthetic fertilisers (and peat), reduced use of pesticides, and improved soil structure (reduced erosion and less irrigation). These benefits are difficult to determine and generally only the GHG savings due to soil carbon binding and fertiliser (and peat) substitution are estimated.

- GHG savings can be achieved through incineration of waste with energy recovery, depending on waste composition, use of the generated energy (as heat and/or electricity), the substituted energy mix, and efficiency of the technology.

- Methane emissions from landfill represent the largest source of GHG emissions in the waste sector. Landfill remains the predominant waste disposal method in most parts of the world, and as landfill management improves in developing countries, methane emissions are anticipated to increase. LFG capture can considerably reduce methane emissions and, where the captured gas is used to generate energy, can lead to GHG savings.

During consultation on the draft version of the current report, numerous respondents requested a comparison of the GHG emissions of different waste management practices. As noted above, this is not possible at a global level. However, a series of recent publications provide comparable data in the European context (see relevant articles, as referenced below, in *Special issue: Applied Greenhouse Gas Accounting: methodologies and cases*. Waste Management & Research: 27: 9: November 2009). A synopsis of this data is presented in Table 14 and is intended to provide a general summary of GHG impacts of waste management practices, and to demonstrate the range of values estimated for the various management options, in the European environment. To reiterate, these values, and any comparison, are not transferable to other regions/countries.

Table 14: Summary of GHG emissions from waste management practices in Europe (negative values indicate GHG savings and positive values indicate GHG emissions; data sources are noted in table).

Waste management activity	Upstream emissions (kg CO2-e/tonne input waste)	Direct emissions (kg CO2-e/tonne input waste)	Downstream emissions (kg CO2-e/tonne input waste)	Key assumptions	Energy data	Source
Recycling paper	1.3 to 29	2.7 to 9.4	488 to 1,464	Reprocessing of 976 kg recovered waste paper, substituting recycled paper stocks	Average electricity mixes for Nordic countries and Central Europe	Merrild et al 2009
			-1,269 to 390	Reprocessing of 976 kg recovered waste paper, substituting virgin paper stocks	Average electricity mixes for Nordic countries and Central Europe	Merrild et al 2009
			-1,854 to -4,392	Reprocessing of 976 kg recovered waste paper, substituting virgin paper stocks and energy from biomass	Average electricity mixes for Nordic countries and Central Europe	Merrild et al 2009
Recycling glass	1 to 19	0 to 10	-506 to -445	Recovered glass cullet substitutes 1 tonne of virgin glass	European average electricity mix	Larsen et al 2009
Recycling plastic	23 to 548	0 to 60	-1,574 to -108	Recovered plastic substitutes virgin plastic or timber	High carbon-intensity European average electricity mix	Astrup et al 2009
	2.5 to 68	1 to 60	-1,047 to -58	Recovered plastic substitutes virgin plastic or timber	Low carbon-intensity European average electricity mix	Astrup et al 2009
Recycling aluminium	6 to 45.8	6.8	-5,040 to -19,340	Reprocessing and avoided virgin production of 950 kg recovered aluminium scrap	Average electricity mixes for Nordic countries and Central Europe	Damgaard et al 2009
Recycling steel	6 to 45.8	6.8	-560 to -2,360	Reprocessing and avoided virgin production of 980 kg recovered steel scrap	Average electricity mixes for Nordic countries and Central Europe	Damgaard et al 2010

Waste management activity	Upstream emissions (kg CO2-e/tonne input waste)	Direct emissions (kg CO2-e/tonne input waste)	Downstream emissions (kg CO2-e/tonne input waste)	Key assumptions	Energy data	Source
Incineration of MSW with energy recovery	59 to 158	347 to 371	-811 to -1,373	Electricity and heat (for district heating system) produced	High carbon-intensity European average electricity mix	Astrup et al 2009b
	7 to 62	347 to 371	-480 to -712	Electricity and heat (for district heating system) produced; average European waste composition; efficiency of electricity conversion = 15-30% of LHV of waste; efficiency of heat conversion = 60-85% of LHV of waste	Low carbon-intensity European average electricity mix	Astrup et al 2009b
Open composting systems	0.2 to 20	3 to 242	-145 to 19	Compost applied to land, substituting mineral fertilizer, reducing N2O emissions, and binding carbon	Low and high European average electricity mixes	Boldrin et al 2009
			-880 to 44	Peat substitution	Low and high European average electricity mixes	Boldrin et al 2009
Enclosed composting systems	1 to 60	5 to 81	-145 to 19	Compost applied to land, substituting mineral fertilizer, reducing N2O emissions, and binding carbon	Low and high European average electricity mixes	Boldrin et al 2009
			-880 to 44	Peat substitution	Low and high European average electricity mixes	Boldrin et al 2009
Anaerobic digestion	3 to 46	20 to 76	-414 to -49	Sophisticated AD systems; combustion of biogas (substituting heat or electricity); land application of digestate substituting fertilizer and binding carbon in soil	Low and high European average electricity mixes	Moller et al 2009

Waste management activity	Upstream emissions (kg CO2-e/tonne input waste)	Direct emissions (kg CO2-e/tonne input waste)	Downstream emissions (kg CO2-e/tonne input waste)	Key assumptions	Energy data	Source
Dump (unmanaged landfill)	0	561 to 786	0	Average European waste composition; approx 46% of original biogenic C in waste assumed to remain as stored C and credited as GHG savings	n/a	Manfredi et al 2009
Landfill with flared LFG	2 to 12	-71 to 150	0	Average European waste composition; LFG capture efficiency over 100 yrs = 50-80%; 48% of original biogenic C assumed stored	n/a	Manfredi et al 2009
Landfill with LFG capture and utilisation	2 to 16	-71 to 150	-5 to -140	Average European waste composition; LFG capture efficiency over 100 yrs = 50-80%; 48% of original biogenic C assumed stored	Low and high European average electricity mixes	Manfredi et al 2009
Low organic waste landfill	2 to 10	-50 to -13	0	Low organic waste (30-40% biogenic C); LFG capture efficiency over 100 yrs = 30-50%	Low and high European average electricity mixes	Manfredi et al 2009

4 Development of international strategy framework

The following sections develop a framework for a UNEP-led strategy in the field of waste and climate change. UNEP is already active in a number of waste and climate change programmes, including collaborations with other UN and international organisations – these activities are summarised in Table 15. The goal of UNEP's strategy framework in this emerging field is to enhance existing initiatives, identify gaps in current global activity, and catalyse the direction of resources towards essential programmes and actions at the local, regional, and national level. There are clear synergies with the DTIE Branch's simultaneous proposal to launch a Global Platform for Waste Management (GPWM).

Table 15 Current UNEP activity, at various scales, relevant to waste and climate change

Nature of activity	Activity description
Technical Policy & regulation Institutional Social	Recycling initiatives Sustainable Consumption and Production (i.e. the Marrakech Process) International declaration on Cleaner Production National Cleaner Production Centres Resource-Efficient Cleaner Production Programme (RECP) (UNEP/UNIDO) Global e-Sustainability Initiative Integrated waste management International Panel for Sustainable Resource Management Life Cycle Initiative (UNEP/ Society of Environmental Toxicology and Chemistry (SETAC)) Green Economy Initiative Regional Seas Programme – marine litter Capacity Development for Clean Development Mechanism Project Global Platform for Waste Management (currently being launched)

4.1 Context – international conventions

The most relevant international conventions in the field of waste and climate change are the United Nations Framework Convention on Climate Change (UNFCCC) and the Basel Convention (BC). The pertinent articles of the UNFCCC are as follows[13]:

- Article 4.1(c) – reference to development, application, and transfer of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of GHG in the waste sector

[13] UNFCCC 1992 (FCCC/INFORMAL/84 GE.05-62220 (E) 200705)

- Article 4.3 – reference to providing financial resources to meet the full costs incurred by developing country Parties in complying with their obligations to communicate information related to implementing the Convention (i.e. national GHG inventories and reports)
- Article 4.5 – reference to the transfer of environmentally sound technology and knowledge from developed country Parties to developing country Parties to enable them to implement the provisions of the Convention
- Article 11 – reference to a mechanism for the provision of financial resources on a grant or concessional basis, including for the transfer of technology

Waste is further highlighted on the UNFCCC agenda in the Bali Action Plan (2008)[14], through the following sections, which directly impact on the waste sector:

- Paragraph 1(b) – reference to enhanced national/international action on mitigation of climate change through cooperative sectoral approaches and sector-specific actions
- Paragraph 1(d) – reference to enhanced action on technology development and transfer to support action on mitigation
- Paragraph 1(e) – reference to enhanced action on the provision of financial resources and investment to support action on mitigation and technology cooperation

The Basel Convention (BC) is the leading international agreement addressing both hazardous and other wastes. The focus of the Convention has historically been on the trans-boundary movement of hazardous wastes. However, the Convention’s definition of wastes is broad and covers “substances or objects which are disposed of or are intended to be disposed of or are required to be disposed” (Article 1). The Convention addresses both hazardous and “other” wastes. “Other” wastes are referred to extensively throughout the Convention and include those wastes that are referred to in Annex II (including household wastes).

The Convention calls on Parties to take “all practicable steps to ensure that hazardous and other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes” (Article 1). Climate change is necessarily included within this mandate. Indeed, the Basel Convention is arguably mandated to examine a broad range of issues relating to wastes and waste management, including those touching on climate issues.

The Convention’s focus on environmentally sound management provides an opportunity for efforts both to improve the contribution of waste management to climate goals, and to realize new and additional resources to enhance waste management and implement the Convention.

The Basel Convention also cooperates with the Stockholm Convention on Persistent Organic Pollutants and the Rotterdam Convention on Prior Informed Consent Procedures for Certain Hazardous Chemicals and Pesticides. The simultaneous extraordinary meetings of the conferences of the Parties to the Basel, Rotterdam and Stockholm conventions (ExCOPs) which were held at the Bali International Convention Centre in Bali, Indonesia, from 22 to 24 February 2010, back-to-back with the eleventh special session of the UNEP Governing Council/Global Ministerial Environment Forum adopted an omnibus decision which included among others joint activities on chemical and waste-related issues, joint managerial functions, joint services, the synchronization of budget cycles, joint audits and review arrangements..

[14] UNFCCC Decision 1/CP.13

4.1.1 Need for enhanced action

There is general agreement amongst the Parties to the UNFCCC that the current levels of action on mitigation, adaptation, technology transfer, and finance are not sufficient to meet the requirements of the UNFCCC. Parties have identified a pressing need to enhance technology transfer and finance.

Negotiations under the Bali Action Plan are expected to yield enhanced actions in a range of areas relevant to the nexus between climate change and waste management.

- In relation to enhanced action on mitigation, the Parties are discussing how “cooperative sectoral approaches and sector-specific actions” can enhance the development, application, and transfer of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of GHG in all relevant sectors, including the waste sector. Sectoral approaches to technology transfer provide one means for enhancing cooperation on waste and climate linkages.
- In relation to enhanced action on technology, the Parties are discussing technology action plans, a multilateral technology fund and new institutional arrangements to scale-up the development and transfer of technologies. New or enhanced arrangements may provide a useful vehicle for supporting cooperation to address shared challenges of climate change and waste management.

In relation to enhanced action on financing, the Parties are discussing the provision of substantially scaled-up financing for mitigation, adaptation and technology cooperation, an enhanced financial architecture and institutions to support national actions. Discussions are addressing both short-term and long-term financial needs. The waste sector is one area, among others, that should be eligible for scaled-up financing.

In the negotiations, a variety of proposals have been offered in each of these areas. Several recurring themes are evident in the proposals relevant to enhanced funding, which provide an indication of areas where additional efforts could be made, particularly from the perspective of developing countries[15]:

- Recognise, promote and strengthen engagement at the country level
- Ensure a country-driven approach and direct access to funding
- Enable a shift from a project-based approach to a programmatic approach to help optimize and scale up implementation
- Reduce fragmentation of funding by facilitating linkages between various funding sources and funds to promote access to a variety of available sources
- Ensure activities relevant to climate change undertaken outside the framework of the financial mechanism (including those related to funding) are consistent with the Convention and relevant Conference of Parties decisions

Closely linked with proposals to enhance financing are those to strengthen the development and transfer of technologies. In particular, there is strong support for a technology transfer mechanism. Currently, there is no single focal facility through which all the various mechanisms and programmes of the different agencies pass through. This has led to dispersed,

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[15] Important proposals on financing have also been offered by Mexico, Norway, Switzerland, China and the G77, the United States and other countries. For example, submissions from Parties recorded in FCCC/AWGLCA/2008/MISC.5 and FCCC/AWGLCA/2008/MISC.2/Add.1

uncoordinated efforts, and duplication[16]. Key elements of a technology transfer mechanism may include a new subsidiary body (established under Article 7.2(i) of the Convention) to enable implementation of the Convention's technology-related obligations to support action on mitigation and adaptation, as well as a dedicated Technology Fund to finance efforts relating to technology development and transfer. The mechanism would address current shortcomings in the transfer of technology, by supporting initiatives such as:

- Promotion, facilitation and implementation of activities along the entire technology cycle to accelerate the rate at which environmentally sound technologies are adopted.
- Support for research, development, manufacture, commercialization, deployment and diffusion of technologies for adaptation and mitigation, in accordance with the Bali Action Plan.
- *Adaptation technologies* to address the adverse effects of climate change and finance the removal of barriers to the large-scale transfer of technologies for adaptation.
- *Technologies to address the adverse impact of response measures*, and finance the removal of barriers to the large-scale transfer of technologies for reducing the adverse impact of response measures.
- *Capacity-building* to manage and generate technological change, enhance absorptive capacity, and create enabling conditions in developing countries. This would include costs relating to research, development and demonstration of new technologies; enhancing human and institutional capacity; and guarantees on foreign direct investment for environmentally sound technologies.
- *Commercialization of new and emerging technologies*. This would include venture capital, with public investment leveraging private capital markets for emerging technologies; research, development, and demonstration of new technologies, financed by venture capital and other sources; and joint technology development.
- *Creation of manufacturing facilities* for environmentally sound technologies, including low-GHG (greenhouse gas) emission technologies. This would include the costs of compulsory licensing and cost associated with patents, designs, and royalties; conversion of existing manufacturing facilities or of establishing new facilities; research and development activities, including joint research, development, design, and demonstration; technology adaptation; retraining and dissemination of know-how; operation (of facilities/technologies); and monitoring and verification.
- *Procurement of low-greenhouse gas emission technologies*, including software and hardware. This would include cost of premature modification or of replacement of existing equipment, as well as the cost of new equipment; cost of retraining and dissemination of know-how; cost of technical assistance for the design, installation and stable operation of the technology; cost of fuel and other operational costs; cost of technologies for fuel switching; and cost of monitoring and verification.

4.2 Current international activity – waste and climate change

The total number of current projects led by international organisations is difficult to ascertain as there is no central clearinghouse of information, and projects range in scale from local initiatives

[16] See also comments by Sarma, K. M. (2008). *Technology Transfer Mechanism for Climate Change*. Draft 24 March 2008. Available from the Institute for Governance & Sustainable Development.

with limited reporting to high-profile multi-national projects[17]. Comprehensive lists of international initiatives are provided in Appendix C –. Further input from the international waste and climate change community would help to expand this list and assist in a more thorough gap analysis. As previously mentioned, UNEP is already a key leader in the waste and climate change arena. The IETC Branch is particularly active in waste management and treatment, whereas the SCP Branch focuses on overall resource efficiency, with programmes on waste prevention.

4.2.1 Offsetting: CDM and JI

The CDM and JI are flexible mechanisms under the Kyoto Protocol, which assist Annex 1 countries to meet their emission reduction commitments through investment in projects initiated in either non-Annex 1 countries (in the case of CDM) or Annex 1 countries (JI projects). Details of the CDM and JI are available from the UNFCCC website[18]. In both mechanisms, Annex 1 countries offset their own emissions by reducing those of another country – at a global scale, offsetting does not equate to a reduction of emissions. Reductions are achieved through the caps placed on emissions from Annex 1 countries.

The issue of 'additionality' is critical in ensuring that CDM and JI projects deliver real climate benefit. CDM projects are only approved by the CDM Executive Board if they can demonstrate that the planned activities and consequent emissions reductions would not occur without the additional incentive provided by the CDM. This can be a difficult point to prove, and different interpretations of additionality have lead to some criticism of CDM projects.

At the time of writing there are 409 active registered CDM projects related to waste handling and disposal. This includes projects related to wastewater; however the majority deal with solid waste – examples are provided in Appendix D – CDM waste projects. Waste projects are predominantly involved in LFG capture and, usually, conversion to energy. Waste to energy (incineration) and composting projects are also receiving approval. A range of baseline and monitoring methodologies have been approved by the CDM Executive Board in order to establish the credibility of a project[19]. Alternatively, project participants can propose a new methodology. The process of developing and receiving approval for a CDM project takes 1-2 years, or longer if a new methodology is proposed (Norsk Energi 2008).

There are approved methodologies for LFG capture (i.e. ACM0001 'Consolidated baseline and monitoring methodology for landfill gas project activities**'**, sometimes in conjunction with ACM0002 'Consolidated methodology for grid-connected electricity generation from renewable sources'). Combustion of waste with energy recovery and organic waste composting projects both may use methodology AM0025 ('Avoided emissions from organic waste through alternative waste treatment processes'). Compost projects may also be eligible to use methodology AMS-111.F ('Avoidance of methane emissions through controlled biological treatment of biomass').

The waste related projects represent around 18% of all CDM projects (Figure 8). The 11 rejected or withdrawn waste-related CDM projects this year were related to landfill gas, although

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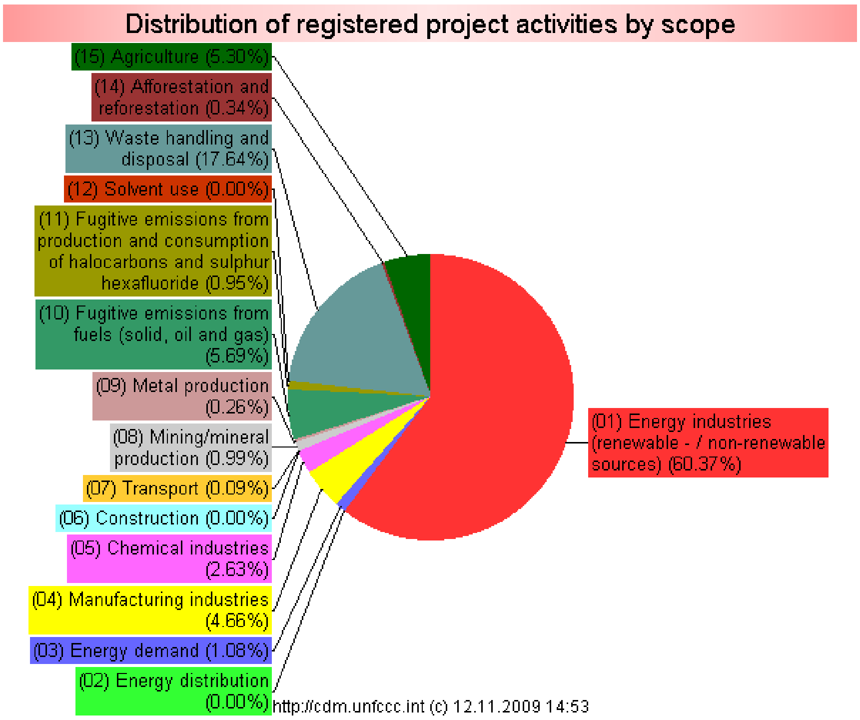
[17] Numerous national government organisations offer bilateral aid for waste and climate change initiatives, but are not within the scope of the present report.

[18] See: http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php

[19] Baseline methodologies guide the preparation of credible scenarios which present the net GHG emissions/reductions that would occur without the project; monitoring methodologies ensure the credibility of the GHG reductions resulting from the project.

there does not appear to be a single reason for project failure (issues included methodology and lack of additionality).



Sectoral Scope*	Registered Projects
(01) Energy industries (renewable - / non-renewable sources)	1400
(02) Energy distribution	0
(03) Energy demand	25
(04) Manufacturing industries	108
(05) Chemical industries	61
(06) Construction	0
(07) Transport	2
(08) Mining/mineral production	23
(09) Metal production	6
(10) Fugitive emissions from fuels (solid, oil and gas)	132
(11) Fugitive emissions from production and consumption of halocarbons and sulphur hexafluoride	22
(12) Solvent use	0
(13) Waste handling and disposal	409
(14) Afforestation and reforestation	8
(15) Agriculture	123

* Note that a project activity can be linked to more than one sectoral scope

Figure 8 Distribution of CDM projects (source: UNFCCC website)

Several trends in the regional distribution of CDM projects are worth noting (these trends refer to all CDM projects, not only waste-related activities). Donor countries are almost exclusively European, with the exception of Japan and Canada. Switzerland and the UK are almost the only countries that invest in Mexico. Most of the projects supported by Germany relate to composting. Major host countries include India, Brazil, China, Malaysia, Mexico; however some of the poorest regions have limited CDM projects. For example, Africa and the Middle East are comparatively under-represented (approximately 5% and 4% of total CDM, respectively – around one fourth of CDM projects in Africa are in South Africa).

There are significantly fewer JI projects than CDM. Of the current 243 JI initiatives, 32 (13%) relate to landfill gas capture, and additional projects may relate to energy produced from waste biomass. Russia and the Ukraine host 58% of all projects, and Eastern Europe hosts a further 36%. Germany, France and New Zealand host the remaining few projects. New Zealand is the only non-European country to host a JI initiative (of the six projects currently operating, two are LFG recovery, and the remainder are wind farms).

4.3 Gap analysis

Gaps exist in the current range of activities led by international organisations in the field of waste and climate change. However, it is also apparent that perhaps the most significant ‘gap’ is a cohesive, systematic approach to the global mobilisation of waste and climate change programmes. As described in the first part of this paper, the magnitude of the climate impact from waste management is largely guesswork – essential information regarding waste generation and management is simply not available in many cases, from both developed and developing regions. Even more important is the lack of waste sector information that would allow a more accurate assessment of the opportunities. In the waste sector, opportunities generally equate to net GHG savings.

Without a clear idea of the problem and opportunities in each country, national waste strategies and action plans cannot be realistically developed. And without national strategies, international assistance will necessarily be fragmented, potentially resulting in poorly allocated resources, lack of government support and commitment, and duplication. Fact-based national strategies, including clear goals and targets, are critical to guide international assistance. There are indeed evident synergies with the UNEP DTIE project ‘Waste Management: Converting Problems into Opportunities to Improve Resource Efficiency’, which aims to develop integrated waste management – including strategies – in developing nations.

The benefits of waste prevention, in terms of the potential to off-set GHG emissions, have not been fully explored or exploited at the global level. Further investigations for specific materials and at regional scales are needed to properly assess the opportunities. For example, useful studies may include identification of carbon-intensive materials to target in ‘lightweighting’ projects. Again, a cohesive effort would avoid duplication and ensure well-resourced, targeted, high quality studies. Results of studies must inform regional and national decisions, through government as well as industry associations. International best practice in waste prevention policy and practice needs to be both developed and disseminated. Synergies exist with UNEP’s SCP programme, and could be more fully explored and exploited.

The CDM and JI may offer opportunities to transfer best practice in waste prevention from Annex 1 countries, however assistance is needed to find or apply suitable methodologies. This is also the case for projects focussed on resource recovery. Currently, no methodologies exist under CDM/JI that specifically recognise the value of GHG savings associated with waste minimisation – this represents a serious gap. There are accepted methodologies appropriate for fuel-switching and fossil fuel avoidance, which could be applied to certain waste minimisation projects, if these projects are structured to fit the methodologies. A further shortcoming of the current spread of CDM projects across the globe is severe regional disparity: as shown above, many of the world’s poorest countries do not have CDM projects. UNEP’s ‘Capacity Development for Clean Development Mechanism” Project, launched in 2002, aims to improve understanding of CDM in potential host countries and develop the institutional and human capacity needed to develop and implement CDM projects. The effectiveness of this initiative and the possibility of further extending it need to be explored. In the event that the CDM is replaced or twinned by a non-offsetting mechanism, the capacity of the least-developed countries to access these sources of finance must still be addressed.

The role of the informal sector in resource recovery and associated climate change mitigation is largely overlooked in developing countries. Waste pickers require support to form co-operatives, access better equipment, negotiate direct access to waste sources, and generally improve their health, safety, and livelihood. Governments of developing nation cities need assistance to understand the value of the informal sector and to incorporate the informal sector in waste strategies.

From the previous analysis, there are clearly a number of waste management processes that effectively mitigate GHG emissions or offer a net benefit. These can be generally grouped into two categories: 1) processes that are technologically simple, rapidly deployed, and low-cost (in relative terms), and 2) processes that involve sophisticated, expensive technology and typically require > 5 years to deploy (i.e. due to financing, planning, and regulatory processes). Although various international programmes identified above provide technical and/or financial support for the development of waste processes within each category (i.e. GEF funds both LFG recovery and waste-to-energy projects), there is a lack of collaboration to focus resources on achieving rapid, effective emissions reductions and gains in the waste sector.

In summary, the following gaps in international activities are apparent:

- Collaborative, international focus on the rapid deployment of simple, proven waste practices and technologies.
- Development of marginal abatement cost curves to help inform funding priorities.
- Production of comprehensive waste reports and strategies for developing (and EIT) countries, with details of waste generation, management practices, and trends (UNEP-GC. These should link-in with the existing ISWM initiative led by UNEP, and ensure that information and goals with relevance to climate change are highlighted.
- Centralised collation and dissemination of global waste sector information of relevance to climate change.
- Support for targeted LCA and CBA-type studies at the local level, to support decision-making vis-à-vis waste prevention policy.
- Development and global dissemination of international best practice in policy and programmes relevant to waste prevention and sustainable production and consumption.
- Investigate development of new CDM and JI methodologies for waste prevention practices, and to account for GHG savings gained through resource recovery (i.e. recycling), and provide guidance on application of existing methodologies to recycling and waste prevention projects.
- Support for the informal recycling sector, including recognition of the sector's role in sustainable waste management and resource recovery, protection of waste-pickers' livelihood, and improvement of health, safety, and general quality of life.
- Capacity of the world's poorest countries to access finance sources and technology.
- Willingness of potential donor countries and organisations to fund projects in accordance with the priorities of the waste management hierarchy.

4.4 Strategy framework

UNEP is seeking to develop a strategy framework for discussion and for action. The waste sector, through sound resource management and resource and energy recovery, has the potential to become a net contributor to global GHG reductions. The overall aim of the strategy is therefore to promote sustainable waste management, in accordance with the waste management hierarchy, and reduce greenhouse gas emissions from the waste management sector. Objectives are intended to be achieved through cohesive delivery of projects focussed on bridging gaps between existing activities in the context of waste and climate change.

The structure and components of the framework are relatively generic, and applicable to the development of any organisational strategy. The vision, goals, approach, guiding principles, and strategic directions have evolved from UNEP's recognised leadership role in the area of waste and climate change. Actions have been identified through a gap analysis of existing international organisations and initiatives. Given the range of current activities and the lack of consolidated information regarding them, a critical review of the proposed actions by the international community will be essential to ensure resources are best applied.

4.4.1 Vision

A vision statement must be developed in consultation with key stakeholders to ensure ownership of the strategy. The following vision has evolved from input from the international waste management community:

To minimise climate impact through sustainable solid waste management, with actions prioritised according to the waste management hierarchy.

4.4.2 Goals

The strategic objectives noted above sit within three over-arching goals:

Goal 1: to minimise the impact of human activities on the climate

Goal 2: to promote waste prevention and resource recovery, thereby reducing the climate impact of raw material extraction and manufacturing processes

Goal 3: to support and promote sustainable solid waste management (SWM) practices

4.4.3 Guiding principles

'Build on existing initiatives and strengths' reflects that many existing initiatives and actions are under way, and the objective is to build on and strengthen these while identifying gaps and areas to add value. The objective is to support and augment these existing initiatives, to build on them wherever possible and to ensure that the whole becomes more than the sum of the parts. Building on existing strengths helps to ensure buy-in and build trust, while enabling scarce resources to be used efficiently and effectively. This principle applies equally to the existing informal recycling sector in developing countries.

'Partnerships and shared responsibilities' recognises that a large number of organisations at international, national, and regional levels are involved in the area of waste and climate change (as identified in previous sections of this report), and that responsibility must be shared between these organisations to ensure swift delivery of effective GHG prevention and mitigation measures in the waste sector.

'Best practice – best available technologies' is a key principle where assistance is extended to countries where uncontrolled landfilling is the predominant practice (i.e. EIT and non-OECD countries). Although controlled landfilling may be a better practice, there may be a 'best available technology' or system that avoids disposal of untreated waste and recovers materials and/or energy. The 'best practice' in terms of the waste hierarchy is decoupling of waste generation from GDP – this must be encouraged through sharing experiences in waste prevention and material recovery between nations.

'Recognise diversity – address disparity' means that the diversity of approaches to integrated waste management and climate protection will be embraced and built upon, and knowledge and technology will be transferred from developed to developing nations to address the considerable regional disparity in waste management capabilities.

4.4.4 Functions

The strategy could support a number of functions designed to achieve the vision and enhance action to minimize the impact of human activities on the climate and to support and promote sustainable SWM practices in-line with the waste management hierarchy. In accordance with its principles, the strategy would seek to build on existing initiatives and promote partnerships and best practices while recognizing diversity in approaches.

Some of the functions could be undertaken directly by the entities participating in the strategy (e.g. UNEP, SBC, others) while other functions would be catalysed or supported by the strategy. The functions could also be undertaken at different levels: international, national or sub-national. The final configuration would be developed through consultation with key stakeholders to gain feedback and ensure buy-in. Some key functions could include:

- *Strengthening national institutions*. The strategy will seek to identify relevant national focal points for waste and climate activities, enhance cooperation and strengthen capacity and knowledge through engagement of expertise within countries (e.g. national research institutions, universities, public and private-sector bodies) and cooperation at a bilateral, regional or international level. The informal waste sector in developing nations should not be overlooked as a key stakeholder and often critical focal point of waste activity.

- *Strengthening national networks*. The strategy will support the creation and/or strengthening of relevant national networks of individuals and institutions in the public, private and non-profit sectors with relevant expertise and knowledge. Networking can play a crucial role in identifying needs and solutions and sharing best practices.

- *Supporting preparation of country programmes*. The strategy can provide support to the development of national strategies on climate change, waste management and other areas to help identify linkages and synergies. Where appropriate, the strategy can help to identify experts with capacity to support the development of country-specific programmes that are consistent with domestic priorities and goals.

- *Building awareness and capacity.* The strategy can help to raise the awareness among policy- and decision-makers at the local, regional and national levels about interplay of waste management and climate change, as well as opportunities to benefit from financial assistance, technology transfer or other support arising from existing and emerging arrangements to address climate change. UNEP’s work in other areas (e.g. Green Customs initiative) provides useful models.

- *Supporting development of appropriate regulations and policies.* National regulations and policies shape public and business behaviour. The strategy can support the conversion of national programmes into regulations and policies. It can also enable the development of supportive policies in related areas. Cooperation could involve sharing of experiences and best practices at the local, regional or national levels and between countries. A focus of policy should be to promote decoupling of waste generation from economic indicators, such as GDP.

- *Technology identification and selection.* The strategy can enable the identification of needs, and matching of needs with appropriate technologies. It can also provide an opportunity for technology and service providers to identify un-met needs and develop appropriate solutions. Effective cooperation and communication can reduce the likelihood of inappropriate technology selection and lock-in. At the local level, it is important to preserve a range of strategies for waste management and not simply promote transfer of European, Australian, or other technologies without discussion of their affordability, overall sustainability, and adaptability – this is particularly true for developing nations.

- *Funding incremental costs of hardware and operations.* The strategy can support governments to identify appropriate funding for the incremental costs of sustainable waste management technologies and practices. This could involve identifying relevant multilateral, regional or private sector financing options and helping governments to match their projects with appropriate financial assistance. Funding support for developing nations should focus on providing or enhancing local financial resources for waste management, including mechanisms to enable local authorities to obtain and continue those resources into the future (i.e. administered waste disposal fee program, public-private partnerships, etc).

- *Supporting international networking and cooperation.* As well as supporting networking at the national level, the strategy can support networking and cooperation at the international level – both among governments and among stakeholders in various sectors of the waste management industry. More systematic cooperation and networking internationally has provided a key to success in other areas of environmental policy.

- *Enabling stakeholder involvement*. The strategy could encourage participation by all relevant stakeholders at appropriate levels, including local communities, non-governmental organizations, academics and researchers and the private sector. In many developing countries, the informal recycling sector is a key stakeholder group in the waste sector, and should be engaged in decision-making.

4.4.5 Actions

Based on the analysis of gaps in international activity, and input received from the international waste management community, a number of actions are proposed – the list is indicative only, and certainly not exhaustive. Selected actions would be delivered through an international entity, specifically tasked with the waste and climate change strategy. Within the limitations of available financial resources, actions would be implemented in priority according to the waste management hierarchy (i.e. actions pertaining to waste prevention and reduction would be implemented first).

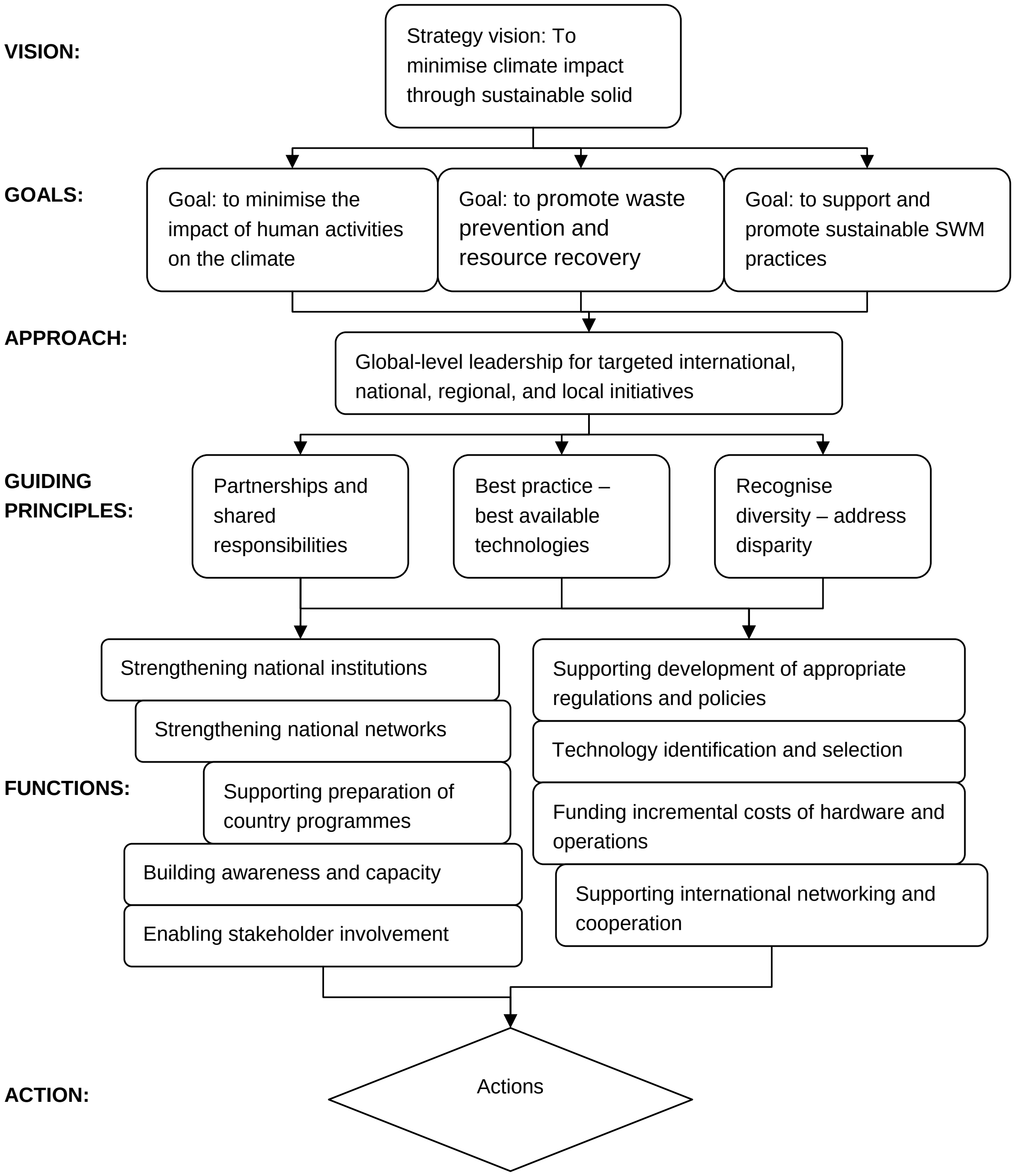
Identified gaps	Proposed actions
Development and global dissemination of international best practice in waste prevention policy and programmes.	Establish national waste prevention networks, linking industry with government.
	Prepare and circulate a report documenting current best practice in waste prevention policy and programmes, with detailed case studies. Emphasis should be placed on decoupling waste generation from, for example, GDP.
	Prepare and disseminate information on product-services, highlighting opportunities for both developed and developing countries.
	Develop integrated resource policies, spanning the life-cycle of resources used in various goods and products (this may also reduce hazardousness of certain types of wastes).
CDM and JI methodologies for waste prevention practices, and to account for GHG savings gained through resource recovery (i.e. recycling).	Support research into viable methodologies for waste minimisation projects (i.e. validating GHG savings from materials recovered for recycling).
	Develop guidance on structuring recycling and waste prevention projects to fit within existing CDM methodologies.
	In consultation with a panel of international experts, propose clear guidelines for what projects should and should not be eligible for CDM and JI (this will necessarily define a

	baseline of waste management practices for developing countries)
Promotion of best-practice resource recovery systems and processing, especially in developing nations	Investigate climate impacts of recycling processes and resource recovery activities in developing nations, particularly those importing recyclable materials for processing.
Support for informal recycling sector in developing nations.	Promote legalisation of the informal waste sector in developing countries. Provide waste pickers with resources to form associations, access funds for improved equipment, and agree contracts for access to waste sources. Develop case studies of informal sector recycling that demonstrate the resource recovery, economic, and climate benefits of these activities. Prepare strategies in collaboration with relevant organisations and local authorities of developing countries to ensure protection of livelihood and improvement of quality of life of the informal recycling sector. Develop guidelines for local authorities for consideration of the informal recycling sector when assessing changes to existing waste management systems.
Support for targeted LCA and CBA-type studies at local levels, to support decision-making vis-à-vis waste prevention policy.	Develop an experts list and form expert panels for consideration and peer review of key studies. Create a database of existing LCA and CBA-type studies relevant to waste prevention.
Support for development of marginal abatement cost curves	Engage expert panel to research and develop marginal abatement cost curves to help inform funding priorities, particularly for EIT and developing nations. Disseminate findings to relevant funding organisations and support their application to projects.
Develop strategies for local financing of waste management activities in developing countries.	Develop strategies, in collaboration with local authorities of developing countries, for the initiation and continuation of local financing for waste management. Priority should be given to development of local, sustainable funding mechanisms (i.e. waste disposal fees, public-private partnerships, out-sourcing to private sector), with limited initial use of international donor funds. Care should be taken to include the informal recycling sector as key stakeholders. Analyse the financial implications and feasibility for each funding mechanism (i.e. timing and size of required resources) and disseminate general information to local authorities of developing nations. Provide technical and financial support to enable under-represented countries to access finance sources (i.e. assist with project identification and assessment, and funding applications). This could include an extension of UNEP's Capacity Development for Clean Development Mechanism Project. Define and assist distribution of an enhanced UNFCCC financial mechanism, as applied to the waste sector. Ensure that funding emphasis is equally placed on waste

	collection systems and logistics, not only capital and infrastructure.
Support for development of comprehensive waste and climate change reports and strategies for developing (and EIT) countries	Link with UNEP ISWM programme to ensure climate impacts and mitigation opportunities are addressed in waste reports and strategies. Provide expert advice on what information is needed, and how it can best be incorporated into national reports/strategies.
Centralised collation and dissemination of global waste sector information of relevance to climate change.	Develop and lead an international strategy for the collection of global waste and waste management data, in collaboration with other international organisations (i.e. the International Energy Agency, ISWA, etc). Establish an information clearinghouse for waste and climate change. Use existing national and international waste networks (i.e. ISWA and country branches) to publicise and disseminate information. Support development of national waste networks in countries where these do not currently exist (link with UNEP ISWM programme).
Collaborative, international focus on the rapid deployment of simple, proven waste practices and technologies.	Establish a panel of organisations involved in funding waste and climate related projects, particularly those with relevant experience, such as the Methane to Markets Partnership and Waste Concern. Develop regional databases of appropriate ‘green’ waste technologies for different waste streams, including technology specifications, suppliers, cost estimates, and a general assessment of risks.

A structure for the strategy is proposed in Figure 9.

Figure 9 Proposal for strategic framework (UNEP-lead international programme targeting waste and climate change)



4.4.6 Approach

The elements described above could be achieved through a variety of institutional arrangements. The ultimate design of these arrangements should take into account current mandates and modes of cooperation, as well as opportunities to expand and build on these. It must also take into account political as well as practical factors. Consensus must be reached with respect to vision, goals, and functions before an operating structure (approach) can be designed.

A collaborative mechanism could include a core body of relevant stakeholders, expert panels, government-industry interest groups, and regional/national programme coordinators. The form of this mechanism must be determined by its desired function.

4.5 Summary of framework strategy development

A range of activities focussed on waste and climate change are currently being led by international organisations, including UNEP. However, there is a lack of a cohesive approach, which has resulted in gaps, duplication, and regional disparity in programmes offered. A central mechanism is needed to collaborate with existing organisations to ensure accessibility to and dissemination of relevant information across the globe, effective use of resources to achieve climate benefit through integrated waste management, promotion of best practice, and rapid transfer of simple, effective, proven technologies and knowledge to developing countries.

UNEP is ideally placed to lead this global initiative, through partnerships with other international organisations already active in the field. The development of a framework strategy to implement the proposed mechanism requires input from a range of stakeholders. To this end, the current report is intended as a further step in a global dialogue to engage the international waste community, identify the key issues, and create a strategy that will deliver significant climate benefit in the waste sector.

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Appendix A – UNEP Decision GC 25/8

UNEP Government Council decision (GC 25/8) on Waste Management acknowledges the role of UNEP and its International Environmental Technology Centre (IETC) of the Division of Technology, Industry and Economics (DTIE) as a potential leader in the area of climate impact mitigation through waste management. Decision GC 25/8 requests the Executive Director of UNEP to achieve the following tasks:

- To provide further assistance to developing countries in their efforts to strengthen national implementation of an Integrated Waste Management (IWM) approach;
- To support the implementation of the actions in the Bali Declaration on Waste Management for Human Health and Livelihood;
- To invite international organisations, governments, and industry and business sector stakeholders to provide resources and technical assistance, including creating a conducive environment for facilitating investments in waste management;
- To strengthen support in the field of waste management in line with the Bali Strategic Plan for Technology Support and Capacity Building; and
- To propose IWM as a key priority area for the UN “Delivering as one” initiative.

The full text of GC 25/8 is presented below:

Recalling its decisions 24/5 of 9 February 2007 and SS.X/1 of 22 February 2008 on waste management,

Recalling also the Johannesburg Plan of Implementation of the World Summit on Sustainable Development[24] and internationally agreed development goals, including the Millennium Development Goals,

Conscious that the increased amount of wastes and the associated hazards that they pose are having a severe impact on the environment at the global, regional and local levels, on natural resources, on public health, on local economies and on living conditions, and thus threatening the attainment of internationally agreed development goals, including the Millennium Development Goals,

Reaffirming that waste management is a significant issue, especially for developing countries, and that international organizations should undertake more focused and coordinated actions to fill current gaps in the support given to developing countries' efforts,

Welcoming the Bali Declaration on Waste Management for Human Health and Livelihood adopted by the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal at its ninth meeting, held in Bali in June 2008, which recognized that waste, if not managed in a safe and environmentally sound manner, may trigger serious consequences for the environment, human health and sustainable livelihood, and therefore reaffirmed the commitment to preventing the illegal transboundary movement of hazardous wastes, to minimizing the generation of hazardous wastes and to promoting the safe environmentally sound management of waste within each country,

Acknowledging with appreciation the report of the Executive Director on waste management[25] and the need for further implementation of its recommendations, and also the role of the International Environment Technology Centre,

Recognizing that stronger efforts and support for means of implementation are needed to assist Governments in developing national policy frameworks to encourage a shift from what is termed an "end-of-pipe" approach in waste management to an integrated waste management approach,

1. *Requests* the Executive Director to provide further assistance to developing countries in their efforts to strengthen national implementation of an integrated waste management approach through the programme of work and budget;

2. *Also requests* the Executive Director to support the implementation of the actions envisaged in the Bali Declaration on Waste Management for Human Health and Livelihood within the mandate of the United Nations Environment Programme, and within available resources as reflected in the programme of work and budget;

3. *Invites* international organizations and Governments and members of the industry and business sector to provide resources and technical assistance to developing countries, including creating a conducive environment for facilitating investment in waste management, to enable them to pursue actively integrated waste management;

4. *Requests* the Executive Director to strengthen support for capacity-building and technology support in the field of waste management, in line with the Bali Strategic Plan for Technology Support and Capacity-building, and further to undertake demonstration and pilot projects on waste management, in cooperation with relevant actors, including among others the United Nations Industrial Development Organization and the United Nations Development Programme, and within available resources as reflected in the programme of work and budget;

5. *Recommends* to the Executive Director that he propose integrated waste management as a key priority area for the United Nations "Delivering as one" initiative;

6. *Calls upon* Governments and other relevant stakeholders to strengthen public-private partnership in waste management to provide additional means for assisting developing countries to

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24 *Report of the World Summit on Sustainable Development*, Johannesburg, South Africa, 26 August-4 September 2002 (United Nations publication, Sales No. E.03.II.A.1 and corrigendum), chap. I, resolution 2, annex.

25 UNEP/GC.25/5/Add.2.

implement the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, including for the construction of the necessary facilities and infrastructure in waste management;

7. *Recognizes* the need for more intensive awareness-raising designed to change the attitude of waste generators, particularly industrial and municipal waste generators, consumers and the informal sector with regard to the "3Rs" concept (reduce, reuse and recycle), environmentally sound waste management and, where appropriate, the need for final disposal of wastes in the States in which they were generated;

8. *Invites* Governments and relevant organizations to provide extrabudgetary resources for the implementation of the present decision in supporting the United Nations Environment Programme and other entities including the Secretariat of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal in its programmes and activities;

9. *Invites* the Conferences of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and other relevant multilateral environmental agreements, the United Nations Human Settlements Programme, the United Nations Development Programme and other relevant United Nations bodies, international institutions, forums and processes to consider further actions regarding waste management, taking into account the recommendations and the description of the outcome of cooperation with other bodies contained in the report by the Executive Director, and to inform the Governing Council, through the Executive Director, on the outcome of their consideration;

10. *Requests the* Executive Director to forward his report[26] to the entities referred to in paragraph 9 above;

11. *Also requests* the Executive Director to present a report on progress in the implementation of the present decision to the Governing Council at its twenty-sixth session.

Appendix B – Bali Declaration

Bali declaration on waste management for human health and livelihood

We, the Ministers and other heads of delegation from the Parties to the Basel Convention and from other States,

Having met in Bali, Indonesia, from 23 to 27 June 2008, on the occasion of the ninth meeting of the Conference of the Parties to the Basel Convention on the Control of the Transboundary Movement of Hazardous Wastes and Their Disposal, and in particular during the World Forum on Waste Management for Human Health and Livelihood,

Mindful that the conditions of life on our planet are threatened and that the challenge for Governments, civil society and the private sector is to protect and improve the environment and human health and livelihood for present and future generations,

Declare that:

1. We reaffirm our commitment to the principles and purposes of the Basel Convention adopted on 22 March 1989, including the fundamental objective to protect, by strict control, human health and the environment against the adverse effects resulting from the generation, transboundary movement and management of hazardous wastes and other wastes, in a spirit of solidarity and partnership and are willing to contribute to a new momentum to achieve the Convention's objectives;

2. We also reaffirm our commitment to sustainable development, including those principles set out in Agenda 21, including chapters 20 and 21, as agreed upon at the United Nations Conference on Environment and Development in 1992;

3. We further reaffirm our commitment to the Johannesburg Declaration on Sustainable Development and the Johannesburg Plan for Implementation, which aimed to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development – economic development, social progress and environmental protection – at the local, national, regional and global levels;

4. We are convinced that full and effective action to implement the Basel Convention will contribute to the achievement of sustainable development, notably internationally agreed development goals, including those contained in the United Nations Millennium Declaration, through waste prevention and minimization, the control of transboundary movements of hazardous wastes and safe and environmentally sound management of waste. In this way, progress can be made in the area of poverty eradication, health, education, gender equality, environmental sustainability and the global partnership for development;

5. We are fully aware that waste, if not managed in a safe and environmentally sound manner, may have serious consequences for the environment, human health and sustainable livelihood, and therefore we reaffirm our commitment to preventing the illegal transboundary movement of hazardous wastes, to minimizing the generation of hazardous wastes and to promoting the safe and environmentally sound management of waste within each country;

6. We are convinced that if those actions are taken, there is high potential to improve the health and livelihood of all citizens and to provide economic opportunities through the safe and efficient reduction, re-use, recycling, recovery, treatment and disposal of waste. We believe that we could help to realize such potential benefits by encouraging the incorporation of sound waste management in development and sustainability strategies and through strengthened cooperation at all levels;

7. We will further promote international, regional and inter-agency cooperation, coordination and planning, including among the Basel Convention, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants, to facilitate capacity-building, information sharing and technology transfer in tackling hazardous waste issues, including through the implementation of the Bali Strategic Plan for Technology Support and Capacity-building;

8. We note that resource mobilization is an important task to be undertaken for achieving the objectives of the Basel Convention. In this context, as set out in decision VIII/34 on resource mobilization and sustainable financing, in particular its paragraph 5, which takes into account the co-benefits between the environmentally sound management of waste and climate protection, we encourage raising of such resources, including from the flexible mechanism under the United Nations Framework Convention on Climate Change and its Kyoto Protocol;

9. We call upon international and regional partners to support and enhance the implementation of the Basel Convention at the bilateral, regional and global levels by providing adequate resources and assistance for the safe and environmentally sound management of hazardous and other wastes and we believe that a public-private partnership approach could be an important way to advance activities for the environmentally sound management of waste. In this context, we also recall the importance of the role played by the Basel Convention regional centres in enhancing the implementation of the Convention and the need to support the building of their capacity to improve their effectiveness;

10. We encourage the following actions by Parties and by relevant public and private organizations, including international and regional organizations and programmes, to:

(a) Promote awareness-raising of the link between waste management, health and livelihood and the environment;

(b) Strengthen subregional and regional cooperation on waste and health issues by promoting national, regional and international human and appropriate technical capacities;

(c) Improve waste shipment and border controls to prevent illegal movements of hazardous and other wastes, including through capacity-building, technology transfer and technical assistance;

(d) Improve cooperation between national authorities in the waste, chemicals and health sectors and, in collaboration with other relevant authorities and stakeholders, in the development and implementation of effective and sound waste management systems;

(e) Increase capacity-building and promote and, where possible, enhance, public and private investment for the transfer and use of appropriate technology for the safe and environmentally sound management of waste;

11. We invite the World Health Assembly to consider a resolution related to the improvement of health through safe and environmentally sound waste management.

Appendix C – International activity

Table 16 provides an extensive, but not exhaustive, list of initiatives that have specifically identified links to waste and climate change. Public information regarding specific activities is not always available, therefore descriptions are necessarily brief. More detailed examples of a number of projects are presented in Table 17.

Table 16 Current international activity with relevance to waste and climate change[20]

Organisation	Level of activity	Nature of activity	Activity description
World Bank	Global / Regional / National /Local	Technical Policy & regulation Financial Institutional	Solid Waste Management Strategic Planning Institutional Capacity Building Financial Capacity Building Analysis of Technology Choices Private Sector Involvement Community Initiatives
World Bank Prototype Carbon Fund (WB-PCF)	Local	Financial	Wood waste cogeneration[21] Waste management
Global Environment Facility (GEF)	National	Institutional Technical Financial	Waste management Landfill gas recovery Biofuels from agricultural waste Waste to energy
Organisation for Economic Co-operation and Development (OECD)	Regional/ National	Technical Policy & regulation Financial Institutional	Waste Prevention and Minimisation (Sustainable Material Management – some joint initiatives with UNEP SCP Branch) Radioactive waste management Extended Producer Responsibility Environmentally Sound Management Recycling markets Transboundary Movements of Waste
Non-Governmental Organizations	Regional/ National / Local	Social Technical	3Rs, resource efficiency Research publications (i.e. technology performance) Example: Waste Concern, a social business enterprise implementing composting and waste reduction projects in S Asia and supporting CDM waste projects.

[20] Sources: RIM Background Paper for Consultations, UNEP, 3rd Draft – October 2009; OECD (2008), *Inventory of international initiatives related to sustainable materials management* – Working Group on Waste Prevention and Recycling. ENV/EPOC/WGWPR(2007)4/FINAL; websites of individual organisations listed.

[21] http://wbcarbonfinance.org/Router.cfm?Page=PCF&ft=Projects

Organisation	Level of activity	Nature of activity	Activity description
Asian Development Bank (ADB)	Regional	Technical Financial Policy & regulation Institutional Social	Grants, loans and technical assistance for (eg)[22]: Utilisation of agricultural waste Recycling of coal waste Hazardous waste management/ treatment Capacity building/ training
Inter-American Development Bank (IADB)	Regional	Financial	Loans, grants, guarantees and investments for[23]: Sanitation Solid waste management
World Business Council for Sustainable Development (WBCSD)	International (national branches)	Institutional Technical	Eco-efficiency programme
Northern Alliance for Sustainability (ANPED)	Regional	Institutional Technical	Sustainable Production and Consumption Working Group
European Commission	Regional	Policy & regulation Institutional	Various directives, thematic strategies, and policy, eg: WEEE, Waste prevention and recycling, End-of-life vehicles
The Group of Eight (G8)	Global	Institutional Policy & regulation	Promotion of 3Rs (reduce, reuse, recycle) and climate change abatement through global exchange of information and experience.
International Climate Initiative (ICI)	National	Technical	Waste treatment Waste to energy
Methane to Markets Partnership	Global	Technical Policy & regulation	International public-private initiative that advances methane recovery from sectors, including landfills.
UN Agencies (in addition to UNEP)			
Secretariat of the Basel Convention (SBS)	Global / Regional / National	Technical Policy & regulation Institutional Social	E-Waste management in SE Asia National plans for hazardous waste management (POPs)
UNFCCC	Global / local	Technical	Clean Development Mechanism (CDM) and Joint Implementation (JI) – LFG capture, AD, composting

[22] http://www.adb.org/projects/summaries.asp?browse=1&type=&query=waste

[23] http://www.iadb.org/projects/searchDocs.cfm?keyword=waste&IDBOperation=&dept=&Country=&docType=&subregion=&Topic=WASA&fromMonth=&fromYear=&toMonth=&toYear=&projDocLang=&orderby=IDBIDOLSORTDATE&sort=reversealphabetical&recsPage=10&lang=en

Organisation	Level of activity	Nature of activity	Activity description
United Nations Department of Economic and Social Affairs (UN DESA)	Global	Institutional	Sustainable Consumption and Production (i.e. the Marrakech Process)
United Nations Industrial Development Organization (UNIDO)	Global / Regional / National / Local	Technical Policy & regulation Institutional	Reuse of computer equipment in Africa Product and Market Development for Sisal and Henequen Capacity building Energy and the Environment
International Maritime Organisation (IMO)	Global	Policy & regulation	Waste management in developing coastal countries Specific Waste Assessment Guidance Ship Recycling Convention
Economic and Social Commission for Asia and the Pacific (UN ESCAP)	Regional / National / Local	Technical Policy & regulation Institutional Social Financial	Sustainable waste management in small cities CITYNET
UN Centre for Regional Development (UN CRD)	Regional / Local	Policy & regulation Institutional Social	Sustainable Production and Consumption / 3R (Reduce, Reuse & Recycle) project
UN Habitat	Regional / National / Local	Technical Policy & regulation Institutional	Waste management[24] Strategy development Capacity building Pipeline projects
United Nations Development Programme (UNDP)	Regional / National / Local	Technical Policy & regulation Institutional Social	Training[25] Capacity building Sustainable waste management Waste management strategy
United Nations Economic and Social Council (UNESC)	Regional / National	Social	Education/ Capacity building workshops Advisory services on policy
Food and Agriculture Organisation (FAO)	Regional / National	Technical Policy & regulation	Bioenergy from agricultural waste[26] (CDM support)

Table 17 presents examples of specific waste and climate change projects, initiated by a number of international organisations. The majority of these projects involve energy and waste,

[24] http://www.unhabitat.org/list.asp?typeid=13&catid=514

[25] http://webapps01.un.org/dsd/scp/public/searchProgrammesByKeyword.do?searchLine=solid+waste+management

[26] http://www.fao.org/bioenergy/54838/en/

either replacing conventional fuels with waste materials (i.e. biomass waste) for heat and power generation, or recovering landfill gas for energy generation. This appears to be a general trend where international organisations offer assistance at a technical level, and may also be influenced by the CDM (see section below).

Table 17 Examples of specific projects initiated by international organisations

Project description	Country	Agency / Mechanism
Waste treatment centres in the Marga-Marga region	Chile	ICI
Biomass, Human and Animal Waste Treatment and Bioenergy Generation	St. Vincent and the Grenadines	ICI
Support for the Brazilian government in governing and implementing a refrigerator recycling programme and setting up a sample installation	Brazil	ICI
Integrated Approach to Wood Waste Combustion for Heat Production	Poland	GEF
Obtaining Biofuels and Non-wood Cellulose Fiber from Agricultural Residues/Waste	Peru	GEF
Economic and Cost-effective Use of Wood Waste for Municipal Heating Systems	Latvia	GEF
Solid Waste Management and Landfill Gas Recovery	Latvia	GEF
Reduction of Methane Emissions and Utilization of Municipal Waste for Energy in Amman	Jordan	GEF
Promoting Methane Recovery and Utilization from Mixed Municipal Waste	China	GEF
Year of action against waste (SCP initiative)	Pacific Island states	UNEP

Appendix D – CDM waste projects

Examples of recent CDM projects: waste handling and disposal[27]

Project title	Host Country	"Donor" country(ies)	Emissions reductions (t CO_2-e per year)
Methane capture and destruction on Las Heras landfill in Mendoza, Argentina	Argentina	France	30599
AESA Misiones (Proactiva Group) Sanitary Landfill Gas capture and flaring project	Argentina	Spain France	37236
Lusakert Biogas Plant (LBP), methane capture and combustion from poultry manure treatment	Armenia	Denmark	62832
Anaconda Landfill Gas Project	Brazil	Switzerland	120423
AWMS Methane Recovery Project BR06-S-28, Santa Catarina, Brazil	Brazil	Switzerland United Kingdom of Great Britain and Northern Ireland	4228
GEEA Biomass 5 MW Power Plant Project	Brazil	Japan	19486
Regional landfill projects in Chile	Chile	France	70299
Municipal Solid Waste (MSW) Composting Project in Urumqi, China	China	Germany	16065
Taiyuan Xingou Landfill Gas Recovery and Utilization Project	China	Switzerland	43419
Composting of organic waste in Wuzhou	China	Germany	41880
Shenyang Laohuchong LFG Power Generation Project	China	Italy	136570
Fedepalma sectoral CDM umbrella project for methane capture, fossil fuel displacement and cogeneration of renewable energy	Colombia		757067
Co-composting of EFB and POME project	Guatemala		22940
3.66 MW poultry litter based power generation project by Raus Power in India	India	Switzerland	51353
Upgradation, Operation and Maintenance of 200 TPD Composting facility at Okhla, Delhi	India	Germany	33461
3 MW Poultry Litter Based Power Generation Project, Hyderabad	India	United Kingdom of Great Britain and Northern Ireland	65794
Gikoko-Bekasi-LFG Flaring Project	Indonesia	Netherlands	69987
Talia Landfill Gas Recovery Project and Electricity Production	Israel	Austria	73640

[27] http://cdm.unfccc.int/Projects/projsearch.html

Project title	Host Country	"Donor" country(ies)	Emissions reductions (t CO_2-e per year)
Composting of solid biomass waste separated from the Palm Oil Mill Effluent (POME) through the use of AVC Sludge Dewatering System at Tanjung Panjang Palm Oil Mill Sdn. Bhd.	Malaysia	United Kingdom of Great Britain and Northern Ireland	31058
Tecamac – EcoMethane Landfill Gas to Energy Project	Mexico	United Kingdom of Great Britain and Northern Ireland	57196
Ecatepec – EcoMethane Landfill Gas to Energy Project	Mexico	United Kingdom of Great Britain and Northern Ireland	209253
OULJA Landfill gas recovery and flaring	Morocco		32481
Ancon – EcoMethane Landfill Gas Project	Peru	United Kingdom of Great Britain and Northern Ireland	69012
Quezon City Controlled Disposal Facility Biogas Emission Reduction Project	Philippines	Italy	116339
Sudokwon Landfill Gas Electricity Generation Project (50MW)	Republic of Korea		1210342
EnviroServ Chloorkop Landfill Gas Recovery Project	South Africa	Japan	188390
Cassava Waste To Energy Project, Kalasin, Thailand (CWTE project)	Thailand	Japan	87586
Landfill Gas Recovery and Flaring for 9 bundled landfills in Tunisia	Tunisia	Italy	317909
Landfill gas recovery and electricity generation at "Mtoni Dumpsite", Dar Es Salaam, Tanzania	United Republic of Tanzania		202271
Montevideo Landfill Gas Capture and Flare Project	Uruguay	Spain	201790

About the UNEP Division of Technology, Industry and Economics

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development.

The Division works to promote:

> sustainable consumption and production,
> the efficient use of renewable energy,
> adequate management of chemicals,
> the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

- **The International Environmental Technology Centre** - IETC (Osaka and Shiga), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
- **Sustainable Consumption and Production** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
- **Chemicals** (Geneva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.
- **Energy** (Paris and Nairobi), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
- **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
- **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies.

UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

For more information,
see **www.unep.fr**

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UNEP

The Governing Council of the United Nations Environment Programme (UNEP) has directed its International Environmental Technology Centre (IETC) branch to take action in the area of waste management. There are substantial co-benefits of waste management in the context of climate change. As a first step to realize these co-benefits, this report seeks (a) to examine the potential of climate impacts and benefits of different waste management activities, and (b) to present a UNEP-lead framework strategy to assist member countries in prioritising their resources and efforts for waste management and climate change mitigation. The framework strategy is intended to align with the internationally recognised waste management hierarchy, in which waste prevention receives the highest priority, to optimise the co-benefits for climate change mitigation.

DTI/1314/JP