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Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

28-Mar-2012

English - Or. English

ENVIRONMENT DIRECTORATE
ENVIRONMENT POLICY COMMITTEE

ENV/EPOC/WGWPR(2010)1/FINAL
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Working Group on Waste Prevention and Recycling

GREENHOUSE GAS EMISSIONS AND THE POTENTIAL FOR MITIGATION FROM MATERIALS MANAGEMENT WITHIN OECD COUNTRIES

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JT03318785

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ACKNOWLEDGMENTS

This report was prepared by Christopher Evans, Adam Brundage, Deanna Lizas, Veronica Kennedy, Nikhil Nadkarni, Emily Rowan, and Randall Freed from ICF International. The work was overseen by Henrik Harjula and Peter Börkey and received additional inputs from Anthony Cox and Soizick de Tilly (all OECD).

We are furthermore grateful to Pamela Mathis, Robert Renz, Rubab Bhangu, and Wendy Jaglom (all ICF) for their valuable contributions and research support as well as for the contributions of Dr. Bärbel Birnstengel of Prognos AG, and Unico van Kooten of the Dutch Waste Management Association.

We would like to thank the United States, Germany, Spain and Finland for the financial support that they have provided for this work and without which this work would not have been possible.

EXECUTIVE SUMMARY

Key Messages

- Due to the integrated stages of materials production, consumption and end-of-life management, a systems view is needed to assess GHG emissions associated with materials and waste.
- When viewed from a life-cycle perspective, GHG emissions arising from material management activities are estimated in this study to account for 55 to 65 percent of national emissions for four OECD member countries. This suggests that there is a significant opportunity to potentially reduce emissions through modification and expansion of materials management policies.
- Integrated waste management practices represent one set of materials management options available that can achieve GHG reductions in OECD member countries
- An order-of magnitude estimate of life-cycle GHG reductions across potential municipal solid waste management scenarios shows that achievable reductions are on the order of current annual emissions from the conventional waste sector quantified in OECD countries' GHG inventories. In other words, in most countries, at least 4 percent of current annual GHG emissions could be mitigated if waste management practices were improved.
- The new OECD report "Greenhouse gas emissions and the potential for mitigation from materials management within OECD countries" provides support to governments in showing the importance of using a life-cycle approach to analyse GHG mitigation options from materials management. Further, the literature suggests that substantial emission reductions can be achieved at low or zero costs.

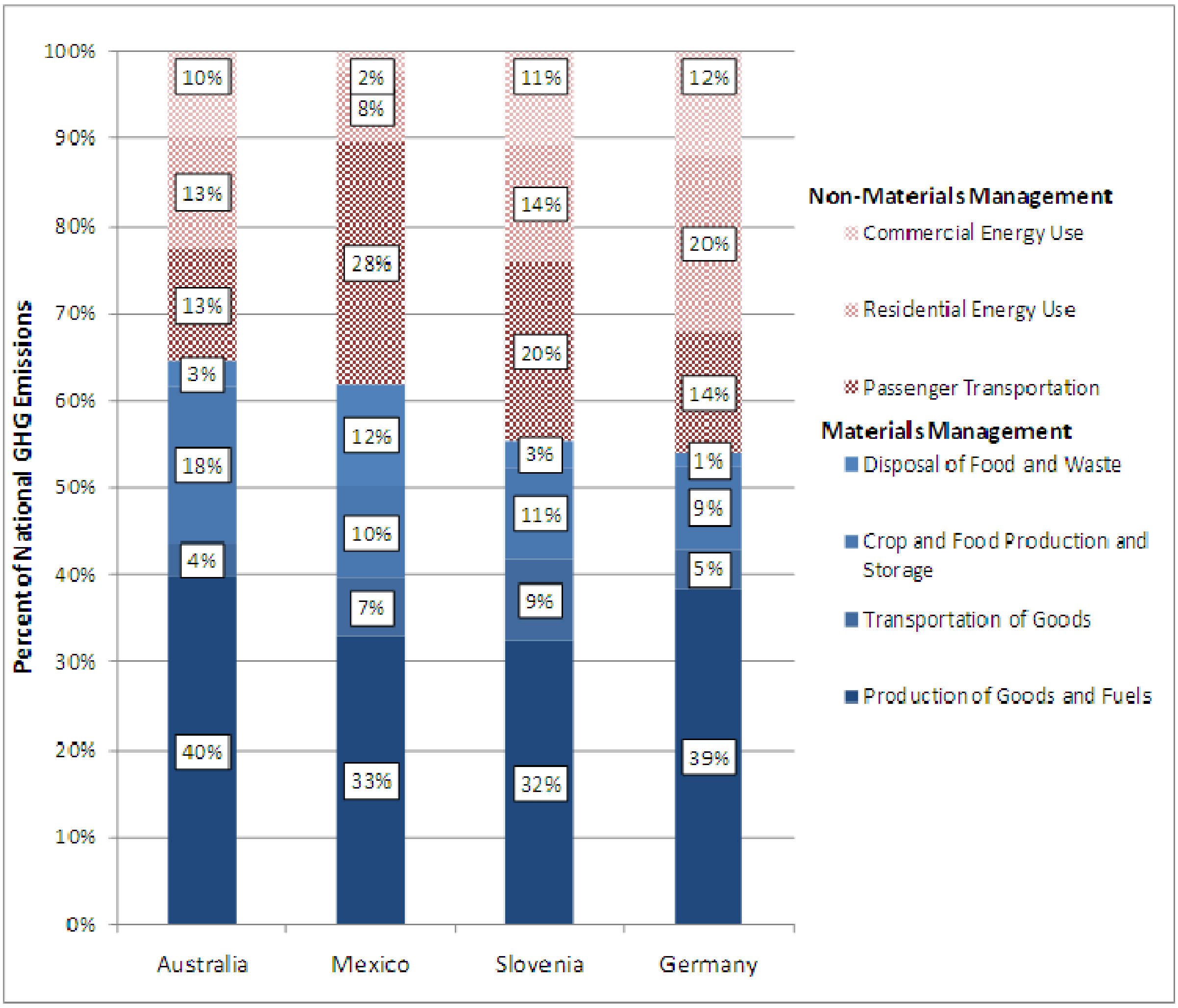
Consider life-cycle analysis in order to assess GHG emissions from materials and waste more accurately

Although GHG emissions from the waste sector typically account for 3 to 4 percent of total emissions in OECD member countries' GHG emission inventories, this emission source only considers direct emissions primarily from landfill methane emissions and incinerators. In contrast, a life-cycle perspective of materials management-related GHG sources encompasses emissions from the acquisition, production, consumption, and end-of-life treatment of physical goods in the economy. This perspective allows policy-makers to evaluate a more complete, systems-based understanding of the relationships between materials management activities and their associated climate-related impacts.

A large share of total country GHG emissions originate from material management activities

The forthcoming OECD report outlines a method for reallocating GHG emissions estimated by sector into systems categories to reveal emissions attributable to materials management from a life-cycle perspective.[1] The materials management categories include: the production of goods and fuels, transportation of goods, crop and food production and storage, and disposal of food and waste. Results from four OECD country case studies (*i.e.,* Australia, Mexico, Slovenia, and Germany) conducted suggest that annual GHG emissions attributable to materials management activities may account for more than half of national GHG emissions (estimated at 64 percent in Australia, 62 percent in Mexico, 55 percent in Slovenia, and 54 percent in Germany). Overall, this study and others[2] find that materials management activities account for a significant share of national GHG emissions in OECD countries (Figure 1).[3]

Figure 1. National GHG emissions for Australia, Mexico, Slovenia, and Germany according to 'systems based' categories related to materials management (MM) and non-MM activities



Key findings from Figure 1 include:

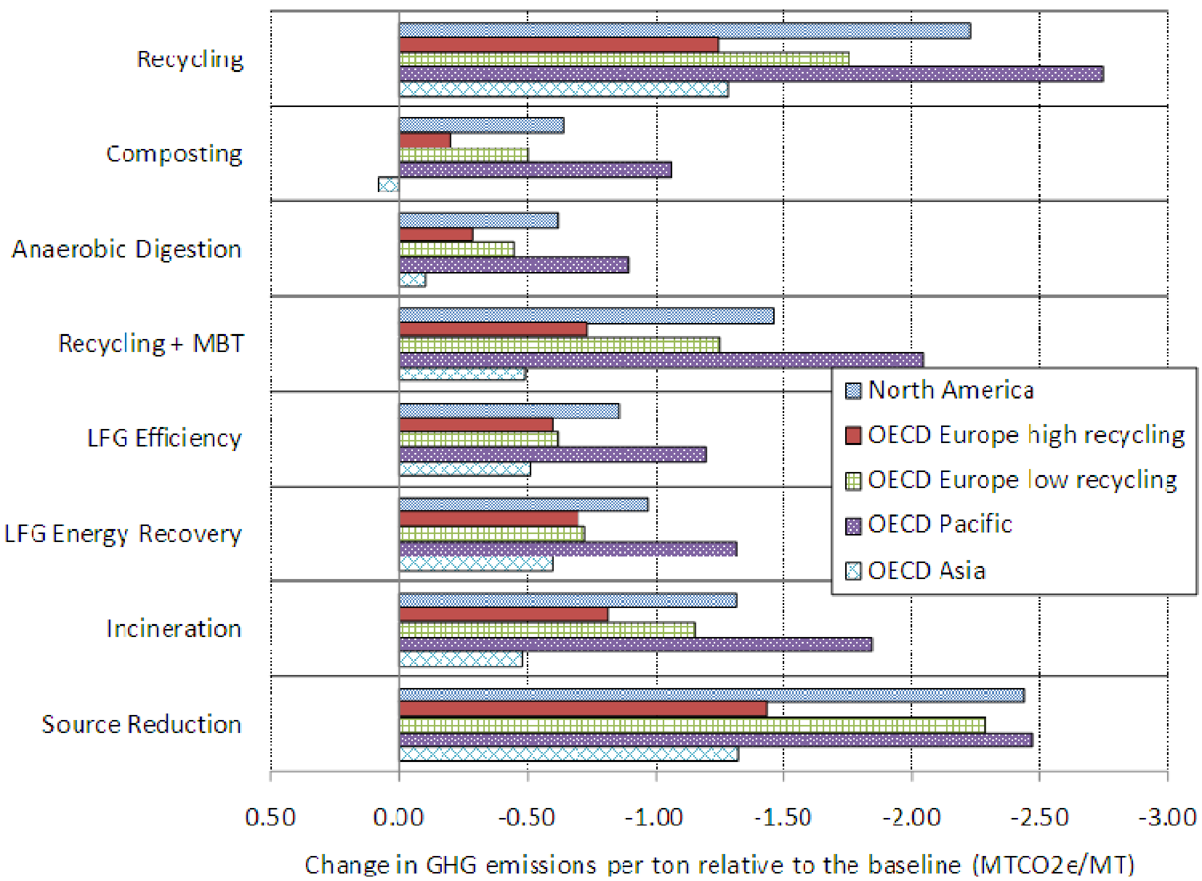
- Across the four analysed OECD member countries, materials management related emissions account for more than half of total GHG emissions (ranging from 54 to 64 percent).
- The emissions associated with the production of goods and fuels are the largest emissions source across the four OECD countries analysed.
- Emissions associated with the disposal of food and waste represent the minority of total emissions across the four analysed OECD countries (ranging from 1 to 12 percent). This range depends largely on infrastructure and current practices. For example, unlike the high recycling rates in Germany, Mexico relies heavily on landfilling. Not surprisingly, disposal emissions are significantly higher for Mexico at 12 percent, indicating an opportunity to improve technologies and likely reduce emissions.

GHG reductions can be achieved through alternative waste management practices

To assess the role that municipal solid waste (MSW) management practices could play in abating GHG emissions, the report investigated eight different scenarios: (i) MSW recycling; (ii) food and garden waste composting; (iii) anaerobic digestion of food and garden wastes with energy recovery; (iv) recycling and Mechanical Biological Treatment (MBT); (v) landfill gas (LFG) collection; (vi) energy recovery from collected LFG; (vii) incineration, and (viii) source reduction. For each scenario, we modelled the change in GHG emissions between the baseline of unchanged management practices from today and alternative MSW practices individually adopted at their technically achievable potentials.[4]

Figure 2 presents the results from this analysis on the *effectiveness* of each scenario, or the amount of GHG emissions reduced for each metric ton of MSW diverted from baseline practices in 2030 to an alternative MSW practice. In the recycling scenario for example, Figure 2 shows that each additional metric ton of MSW diverted to recycling reduces GHG emissions by 1.3 to 2.7 metric tons of carbon dioxide (CO_2) on average across the OECD regions. Similarly, reducing one metric ton of MSW materials at the source reduces GHG emissions by 1.3 to 2.5 metric tons of CO_2 on average.

Figure 2. Change in GHG's Per Metric Ton of MSW Diverted to Alternative MSW Management Scenarios Relative to Baseline Practices in 2030 across OECD regions[5]



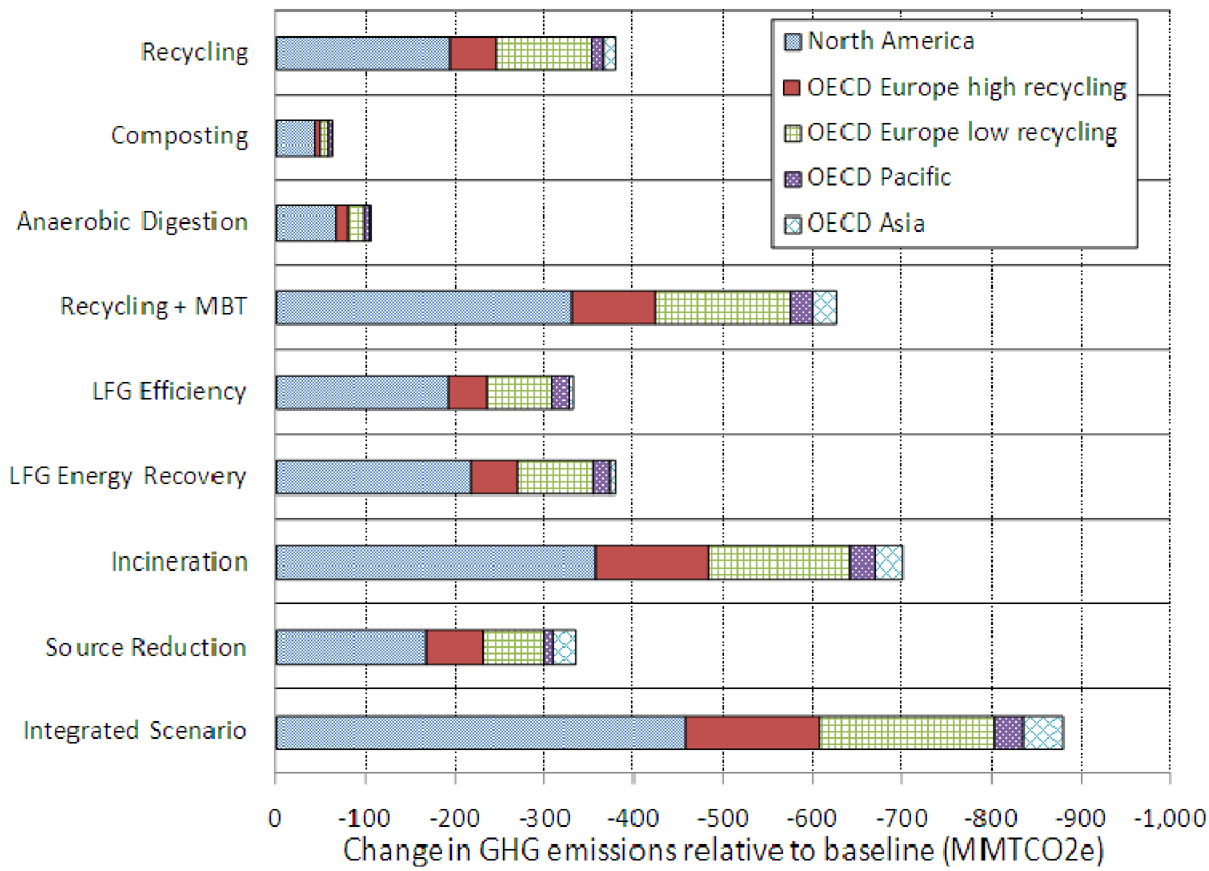
Key findings from Figure 2 include:

- Across all regions, recycling and source reduction provide the highest reduction in GHG emissions per metric ton of MSW diverted.
- Increased energy recovery through LFG collection and incineration provide moderate reductions per metric ton of MSW managed under these practices, and composting and anaerobic digestion provide the least reductions per metric ton, on average.
- Diverting MSW from baseline practices to composting in OECD Asia slightly increases GHG emissions due to the high fraction of MSW that is currently incinerated with energy recovery in this region.
- Current MSW management in each region affects the additional GHG reductions that can be achieved by alternative practices. For example, OECD Pacific and North America achieve a higher reduction per ton of MSW diverted than other regions largely because more MSW is currently sent to landfills without gas capture in these regions; as a result, each metric ton of MSW diverted to alternative MSW practices provides a larger reduction in GHGs than in OECD Europe and OECD Asia.

Estimation of life-cycle GHG reductions across potential waste management scenarios...

In terms of the *absolute* reduction in GHG emissions, the implementation of individual alternative waste management options at technically-achievable levels offers significant GHG mitigation opportunities, ranging from 330 to 700 million metric tons of carbon dioxide equivalent (MMTCO2e) across all OECD member countries when viewed from a life-cycle perspective.[6] In an integrated scenario, where several management options are implemented in concert, the total life-cycle abatement potential increases to nearly 900 MMTCO2e. Figure 3 presents the life-cycle GHG mitigation potential for each alternative MSW management scenario relative to the baseline in each OECD region in 2030. The results of Figure 3 are not meant to imply a ranking of the different management practices; this is represented by the *effectiveness* in terms of GHG reductions per metric ton of MSW diverted for each scenario, as shown in Figure 2. Instead, Figure 3 incorporates both the GHG reductions per metric ton of MSW diverted and the total amount of MSW diverted to yield a range of absolute GHG reductions achievable across the scenarios. The result is an order-of-magnitude estimate of the absolute life-cycle GHG reductions achievable from implementing alternative MSW management practices.

Figure 3. Change in GHGs Relative to Baseline Practices through Implementation of Alternative MSW Management Scenarios in 2030 across OECD Regions



Key findings from Figure 3 include:

- Scenarios that affect a wide range of material types can achieve large absolute GHG reductions. For instance, recycling and source reduction are the most *effective* at reducing GHG emissions for each metric ton of MSW diverted to these options. However the incineration and LFG recovery scenarios reduce GHG emissions from larger portions of MSW.
- Increasing recycling rates in regions with lower rates can provide a sizable reduction in emissions. In most regions, paper and cardboard recycling generates most of the recycling scenario's GHG mitigation.
- The greatest reductions in life-cycle GHGs are achieved through integrated waste management practices. The final integrated scenario—where MSW source reduction, recycling, and composting are implemented and the remaining MSW fraction is processed in highly-efficient incineration facilities with energy recovery—results in life-cycle GHG reductions of 878 MMTCO2e relative to the 2030 baseline scenario. This is 16 percent greater than the largest reduction achieved by the non-integrated management scenarios. To provide context, 878 $MMTCO_2e$ represents over 6 percent of current annual OECD emissions in the aggregate.[1]
- The volume of waste generation in each region largely influences the magnitude of GHG mitigation. For example, because MSW generation in North America is nearly two-and-a-half times larger than in "low recycling" European countries, the total GHG reductions in North America are greater by roughly the same order of magnitude.

Together, Figure 2 and Figure 3 show which practices are most effective at reducing GHG emissions per metric ton of MSW diverted, and the range of GHG reductions achievable when each scenario is exercised to its technical potential. A key finding from this analysis is that recycling and source reduction provide the greatest GHG reductions per metric ton of MSW diverted, on average, while other practices—such as increased energy recovery from LFG capture, incineration, and anaerobic decomposition—can achieve significant GHG reductions by broadly acting on the remaining MSW fractions. The integrated scenario demonstrates this point and underscores the need for an integrated approach to MSW management that emphasises source reduction and recycling, while reducing GHG emissions from remaining fractions that are sent for disposal through strategies such as highly-efficient incineration and landfill gas collection with energy recovery.

Substantial emission reductions can be achieved at low or zero costs

A recent study by Monni *et al.,* (2006) evaluates the relative benefits of various waste management alternatives in terms of costs and mitigation potentials with respect to methane emissions from landfills.[7] A summary of their study is shown on the following page in Table 1. Monni *et al.,* (2006) calculated the maximum landfill gas mitigation potentials of different waste management options at five different marginal emission reduction cost levels.[8]

The table displays the reduction potential of landfill methane emissions by measures whose unit cost is below the overall marginal emission reduction cost level (USD 0, 10, 20, 50, or 100 per metric ton of CO_2). The quantity of emission reductions possible is categorised by waste management option and region, where "OECD" designates OECD countries not included in the economies in transition category, "EIT" designates economies in transition, and "Non-OECD" designates countries included in neither the OECD nor the EIT category (*i.e.* developing countries). For example, the table shows that a reduction of 43 $MMTCO_2e$ of methane is possible in OECD countries using Landfill Gas Recovery for energy at costs below USD 10 per metric ton of CO_2e reduced.

[1] Data from OECD.stat. Data on GHG emissions does not include Mexico, Chile and Korea.

Table 1. GHG Reduction Potential Landill Methane Emissions by Waste Management Alternative and by Various Marginal Costs in Year 2030

		MMTCO$_2$e of CH$_4$ reduced				
Waste management practice	**Region**	**USD/metric ton CO2e**				
		$0	$10	$20	$50	$100
Anaerobic digestion	OECD	0	0	1	5	5
	EIT	0	0	0	20	24
	Non-OECD	0	0	30	68	95
	Global	0	0	31	94	124
Composting	OECD	0	0	0	0	3
	EIT	0	0	0	6	19
	Non-OECD	0	0	0	58	81
	Global	0	0	0	64	102
Mechanical biological treatment	OECD	0	0	0	0	0
	EIT	0	0	0	0	0
	Non-OECD	0	0	0	0	19
	Global	0	0	0	0	19
LFG recovery - energy	OECD	27	43	41	23	22
	EIT	56	29	15	0	0
	Non-OECD	328	368	306	138	43
	Global	411	440	362	162	65
LFG recovery - flaring	OECD	0	6	1	0	0
	EIT	0	17	0	0	0
	Non-OECD	0	12	0	0	0
	Global	0	34	1	0	0
Waste incineration with energy recovery	OECD	124	222	237	266	266
	EIT	0	101	156	156	140
	Non-OECD	0	0	166	515	653
	Global	124	323	558	936	1,059
Total	OECD	151	270	280	295	296
	EIT	56	147	171	182	182
	Non-OECD	328	380	501	779	890
	Global	535	797	953	1,255	1,369

The table indicates that substantial emission reductions can be achieved at low or zero costs.[9] More significant reductions would be possible at higher marginal costs, due mostly to the additional mitigation potential of thermal processes for waste-to-energy. The model indicates that a 151 MMTCO$_2$e reduction is possible for OECD countries at a marginal carbon cost of USD 0, and a 270 MMTCO$_2$e reduction is possible at costs at or below USD 10 per metric ton of CO$_2$e. Globally the mitigation potential is significantly larger at 535 and 797 MMTCO$_2$e at a cost of respectively at of USD 0 and 10 per ton of CO$_2$e.

A separate 2009 study on abatement costs by McKinsey found that direct use of landfill gas, waste recycling, and electricity generation from landfilling have global cost savings of about EUR 12 to 34 per metric ton of CO$_2$e.

For further information on OECD work on materials management: see www.oecd.org, and to access the full report "*Greenhouse gas emissions and the potential for mitigation from materials management within OECD countries*". This study provides a framework for analysing the relationship between materials management and greenhouse gas (GHG) emissions. It seeks to offer policymakers an improved understanding of the importance of considering life-cycle GHG emissions in order to manage materials and wastes more sustainably.

END NOTES

1 The approach makes use of GHG inventory data submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

2 A similar study conducted by the U.S. Environmental Protection Agency found that 42 percent of GHG emissions in the United States were attributable to materials management activities (EPA 2009b).

3 The GHG emissions inventories obtained from the UNFCCC for the four OECD member countries vary in terms of overall magnitude of emissions, level of detail, and transparency.

4 The baseline in 2030 assumes no change to current waste management practices, even though there are already policies and voluntary programs in place in OECD countries that will continue to increase the implementation of alternative or improved waste management practices. Our baseline therefore underestimates the extent to which alternative practices will be in place by 2030 even without any additional policies to promote these practices.

5 We categorized OECD member countries into five groups based on geography and baseline recycling rate to account for differences in MSW generation and composition, management practices, and region-specific factors that affect GHG emissions from management practices.

6 The composting and anaerobic digestion scenarios are not included in this range because the reductions in these scenarios can be individually added to the recycling scenario since they address mutually-exclusive categories of waste.

7 This study evaluated emissions reductions in the waste sector using two different modelling approaches to develop future MSW management scenarios. First, the authors developed a set of dynamic emissions scenarios that considered existing policy measures and changes in waste management systems, as well as the timing of GHG emissions from landfills. Second, they use a partial-equilibrium economic model (the Global TIMES model) to develop economic potential scenarios that optimise emissions reductions in 15 world regions in 2030.

8 The table evaluates reductions from a baseline scenario that assumes (1) waste generation will increase with growing population and GDP (using SRES scenario A1 data), (2) waste management practices will not change significantly, and (3) landfill gas recovery and utilisation will continue to increase at the historical rate of 5 percent per year in developed countries. The estimates were generated using the Global TIMES model, with data taken primarily from EPA (2006a).

9 It is important to note that the results generated by this model incorporate different boundaries than the mitigation potential results we show in the OECD study since Monni *et al.,* (2006) only incorporates avoided landfill methane emissions from disposal of MSW.

List of Abbreviations

CO_2e	Carbon dioxide equivalent
EC	European Commission
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
GWP	Global Warming Potential
IEA	International Energy Agency
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH
IPCC	Intergovernmental Panel on Climate Change
LFG	Landfill gas
MBT	Mechanical biological treatment
MMT	Million metric tons
MSW	Municipal solid waste
OECD	Organisation for Economic Co-operation and Development
RDF	Refuse-derived fuel
SMM	Sustainable Materials Management
UNFCCC	United Nations Framework Convention on Climate Change
WARM	Waste Reduction Model
WRAP	Waste & Resources Action Programme
WTE	Waste-to-energy

1.0 INTRODUCTION

1. Activities at each stage of the material life-cycle—including extraction, processing, manufacturing, transportation, use, and ultimate disposal—impact the environment. In order to fully understand the relationships between the type, quantity, and ways in which materials are produced, used, and managed at end-of-life and the associated environmental impacts (*e.g.*, energy and water use, resource depletion, toxicity, greenhouse gas emissions), a life-cycle approach provides the appropriate perspective. It helps inform sustainable materials management (SMM) policies and practices to reduce those impacts.

2. OECD's first workshop on SMM established the following working definition for SMM: "an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity" (OECD, 2010).

3. OECD is exploring options to facilitate SMM. Several member countries already work to reduce environmental impacts from the ways in which their citizens consume materials such as fuels, minerals, agricultural, and forestry resources. These countries are also shifting to a more materials-oriented (rather than waste-oriented) perspective, and are seeking opportunities to redirect wastes into inputs for energy or new products (OECD, 2010).

4. The goal of this study is to provide OECD with a framework for observing the relationship between materials management and environmental impact, as measured in terms of greenhouse gas (GHG) emissions. We offer two separate but interrelated analyses that account for GHG emissions associated with the material life-cycle:

a) The first section of this report outlines a method for reallocating estimates of GHG emissions by sector (the conventional organising principle for national emission inventories) to reveal emissions attributable to materials management from a life-cycle perspective. Results from four case studies conducted in this analysis suggest that annual GHG emissions attributable to materials management activities account for over 50 percent of national GHG emissions in OECD countries. A similar study conducted by the EPA (2009b) that found that materials management activities are associated with 42 percent of total GHG emission in the United States. Overall, these five estimates suggest that materials management activities account for a large share of national GHG emissions in OECD countries.

b) The second section provides an "order of magnitude" estimate of the technical potential GHG abatement (*i.e.*, reducing emissions) from integrated municipal solid waste (MSW) management policies in OECD countries. This analysis is based on baseline practices and regional life-cycle GHG emission factors for alternative practices such as recycling, composting, and waste-to-energy recovery. Results from this analysis suggest that the implementation of alternative waste management options at technically-achievable levels offer significant GHG mitigation opportunities when viewed from a life-cycle perspective.

5. Finally, we discuss how these analyses can help inform SMM policies and approaches to GHG mitigation, and examine limitations of the analyses.

2.0 OBJECTIVES AND SCOPE

6. The conventional sectoral view of national GHG emissions in OECD member countries, as dictated by IPCC emission inventory guidance (IPCC, 2006a), includes annual emissions from the solid waste sector, estimated to contribute to less than 5 percent of anthropogenic GHG emissions (IPCC, 2007, p. 596). However, this estimate considers only direct emissions[2] associated mainly with methane emissions from degrading waste in landfills, emissions from wastewater, and incinerators. Viewed from a materials management perspective (*i.e.*, emissions associated with the life cycle of materials from extraction through manufacturing, use, and disposal), the "GHG footprint" of waste is significantly larger.

7. Similarly, assessing the role of integrated waste management activities—such as source reduction, recycling, biological treatment (*e.g.*, composting, anaerobic digestion, and mechanical biological treatment), and waste-to-energy—in promoting SMM requires a perspective that cuts across conventional industrial and economic sectors to evaluate the life-cycle benefits of waste management alternatives that reduce GHG emissions relative to existing practices.

8. This study seeks to promote a more comprehensive understanding of the GHG emissions over the life cycle of materials as they flow through the economy and examine the available opportunities for reducing the size of the GHG footprint of waste and materials. To those ends, this report presents the results of two primary analyses:

a) A methodology that will enable OECD member countries to estimate the percentage of GHG emissions associated with materials management.

b) "Order-of-magnitude" estimates of the GHG emissions mitigation potential of different policy options and a discussion of the costs of waste management practices and the cost per metric ton of GHG emissions reductions to the extent that data are available.

9. The scope of the first analysis within this study encompasses current, national GHG emissions from individual OECD member countries. It establishes a methodology to evaluate GHG emissions and sinks attributable to materials management activities based on inventory data compiled by OECD member countries. This provides a snapshot of the broad scope of national GHG emissions that are related to materials management activities in OECD countries.

10. The second analysis of this study focuses on the future mitigation potential from alternative MSW management practices implemented in 2030 across five OECD regions. We focus on municipal solid waste (MSW) in particular because of its broad, diverse composition that is generated not just from households and residences, but also commercial sources such as office buildings, institutions, and small businesses. Other industrial waste, while significant in volume and with a potentially important GHG mitigation potential, are not included in the analysis.

11. There are substantial opportunities to promote integrated MSW management practices that support SMM, and a broad set of stakeholders are involved in, and affected by, management practices relating to MSW. Finally, OECD member countries maintain relatively consistent information available on MSW generation, composition, and management and the GHG emission implications of these materials have been studied in several recent studies. We acknowledge that MSW forms only a portion of total waste generation across OECD countries (for example, in Canada, MSW represents only approximately 7 percent

[2] Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity. This can include emissions from fossil fuels burned on site, emissions from agency-owned or agency-leased vehicles, and other direct sources (EPA 2011).

of the total solid waste stream), and that other streams—such as construction and demolition materials, industrial wastes, and agriculture and forestry wastes—offer other important opportunities for SMM and GHG mitigation, however, these waste types are not included in the scope of this report.

12. Both sections of this report represent broad, screening-level analyses that, given the time and resources that were available, are limited to: data that are already available from existing tools and literature, and rough estimates that have been made, ensuring a consistent methodology across materials, management activities, and OECD member countries.

13. The remainder of the report is divided into two primary sections that present the analyses that were conducted to meet the twin objectives of this study. Section 3.0 provides the methodology that was developed to enable OECD member countries to estimate the share of their national GHG emissions associated with economic activities that highlight materials consumption and production. Section 4.0 provides an assessment of the mitigation potential from implementing alternative MSW management practices across OECD member countries in 2030, relative to baseline practices. This section also provides a short discussion of the cost implications of implementing the various MSW management alternatives, and estimates of the cost of GHG abatement from certain management practices. Finally, Section 0 summarises key findings and provides conclusions from both sections, offering insights into how GHG emissions could be further reduced from the perspective of an integrated materials and waste management approaches.

3.0 MATERIALS MANAGEMENT ALLOCATION FOR GHG EMISSIONS

14. This chapter presents and applies a methodology to enable OECD member countries to estimate the share of national GHG emissions associated with activities that highlight materials consumption and production. The main objective is to provide a methodology that organises GHG emissions estimates according to cross-sectoral system processes (*e.g.*, production of goods, disposal of goods), rather than economic sectors (*e.g.*, energy, industrial processes). Allocating emissions by system provides policy makers with a framework for estimating the relative GHG impact of economic activities that span multiple sectors. In this section of the report, we present our methodology for reallocating emissions and then apply this methodology to four OECD member countries with varying levels of data availability.

3.1 Sector versus Systems-Based Emissions Categories

15. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) must submit national reports containing GHG emissions estimates. Therefore, countries organise emission estimates in their national GHG inventories according to the sector-based categories used by the UNFCCC. From a policy perspective, this sector-based organisation structure facilitates emission tracking, framing strategies, and evaluating the impacts of technological advancements on a particular sector. It also allows for consistency and comparability of GHG emissions between nations. However, GHG emissions associated with activities or processes (such as materials management and land management) that cut across multiple sectors are difficult to assess with the sector-based inventory structure. Sector-based inventories indicate that emissions from the waste sector contribute to less than 5 percent of global GHG emissions (IPCC, 2007, p. 596). However, materials management practices can also impact upstream emissions associated with the manufacture or transport of materials.

16. A systems perspective offers a different view for evaluating GHG emissions and integrated approaches for reducing those emissions. Using a systems-based view of GHG emissions reallocates emissions into categories that allow for an assessment of the relative GHG impacts of economic activities and national consumption patterns and potential opportunities to reduce those GHGs. The systems-based methodology established here allocates GHG emissions from sector-based inventories into materials management and non-materials management categories:

a) The materials management categories cover the different life stages of goods and include: the production of goods and fuels,[3] transportation of goods, crop and food production and storage, and disposal of food and waste; and

b) The non-materials management categories include passenger transportation, residential energy use, and commercial energy use (see Table 1).

17. Allocating GHG emissions into these system categories (shown in Table 1) allows policymakers to distinguish between emissions sources that would be targeted by sustainable materials management practices from those that are not directly affected by such policies.

[3] Production of goods and fuels category also includes non-energy emissions from the use of certain products, including fire extinguishers, solvents, aerosols, and others.

18. The methodology for reallocating GHG emissions into systems categories focuses on the production, consumption, and end-of-life treatment of materials (*i.e.*, goods and foods) from a materials management point of view. Improvements in the energy consumption in the use phase of products are guided by other types of policies and programs (*e.g.*, those that improve energy efficiency). An example of a UNFCCC GHG emissions source that is included in the "Production of Goods and Fuels" systems category is the "Manufacturing industries and Construction" UNFCCC sub-category, which includes emissions from the production of metals, chemicals, pulp/paper, and food. In contrast, emissions associated with personal transport of individuals are considered non-materials management and are included in the "Passenger Transportation" systems category. Emissions associated with freight transport are included in the "Transportation of Goods" systems category. Emissions sources that relate to energy consumption for the residential and commercial sectors (*i.e.*, heating and cooling services) are not considered materials management and included in the Commercial or Residential Energy use systems categories (see Table 1). Agriculture emissions are considered materials management emissions sources. An analysis by the EU's Joint Research Centre concluded that the full food production and distribution chain (from "Farm-to-Fork") is a significant contributor to environmental impacts of private consumption as measured by various impact categories including global warming (EU, 2006).

Table 2. Systems categories for emissions allocation

OECD Systems Categories	Materials Management Activity?
Production of Goods and Fuels	Yes
Transportation of Goods	Yes
Crop and Food Production and Storage	Yes
Passenger Transportation	No
Residential Energy Use	No
Commercial Energy Use	No
Disposal of Food and Waste	Yes

3.2 Defining Materials Management

19. Each of the system categories outlined in the section above is categorised as either materials management or non-materials management. This differentiation allows countries to determine the percentage of national emissions that could be influenced by sustainable materials management policies. The OECD Sustainable Materials Management (SMM) workshop held in November, 2005 in Seoul, provided a working definition of sustainable materials management as follows:

"Sustainable Materials Management is an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity" (OECD, 2010).

20. For purposes of this analysis, we have expanded upon this definition to clarify which GHG emission sources may fall under "materials management":

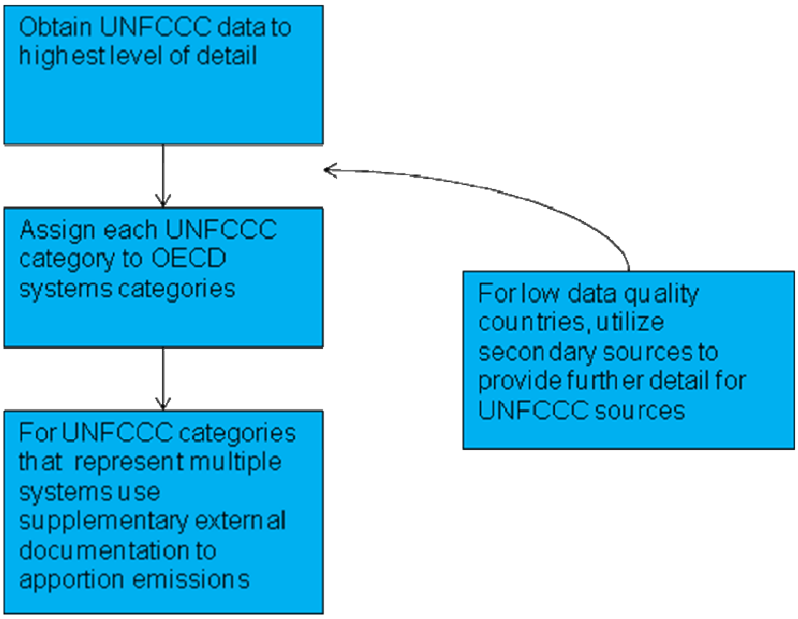
Materials management-related GHG emissions include those associated with the production, consumption, and end-of-life treatment of physical goods in the economy. Relevant activities include the extraction and harvesting of resources, production of goods (including crops and food), transportation of goods, use and consumption of goods, and recycling, recovery, or disposal of waste. The emissions resulting from the relevant source activities can be influenced by integrated material, product, and waste *management policies that address environmental impacts over the entire life cycle of materials and products.*

3.3 Methodology for Reallocating Sector Emissions Estimates into Systems-Based Categories

21. Starting with the materials management definition described above, we can re-allocate emissions from the UNFCCC GHG Inventory categories into the systems categories described in Table 1.

22. The general methodology for preparing a systems re-allocation of UNFCCC GHG emissions categories is shown in Figure 4. The Land Use, Land Use Change and Forestry (LULUCF) UNFCCC category is not included in the reallocation analysis. The LULUCF emissions category provides an estimate of the carbon sink for land management practices and including this category would complicate the reallocation of emissions sources across other sectors. Therefore, we present LULUCF emissions (and sinks) as a separate stand-alone category for one of our case studies in Appendix B.

Figure 4. Simplified flow diagram for systems categories reallocation methodology for GHG emissions



3.3.1 Step 1: Obtain emissions inventory data at the highest level of detail available

23. As part of their responsibilities as Parties to the Climate Change Convention, OECD member countries have submitted national GHG inventories to the Climate Change secretariat. The latest available GHG inventories consisting of the national inventory report (NIR) and common reporting format (CRF) are available through the UNFCCC.[4]

24. The UNFCCC's GHG flexible data query tool allows the user to extract the most recent GHG data reported across sector categories. Any OECD country can therefore use these inventory data as the foundation for reallocating sector emissions to systems-based perspective. For OECD countries that have access to more detailed data, it is recommended that the reallocation of emissions to the systems categories be based on the most detailed emissions estimates. The UNFCCC GHG data interface provides emissions

[4] http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php

estimates across seven major categories (Tier 1) and up to four sub-category levels of detail (Tier 2, Tier 3, Tier 4, and Tier 5).

25. For example, within the Energy Tier 1 category, there are two Tier 2 levels (Fuel Combustion and Fugitive Emissions from Fuels). Within the Fuel Combustion Tier 2 level, emissions are further segregated into Tier 3 categories (Energy Industries, Manufacturing Industries and Construction, Transport, Other Sectors, and Other). Finally, these Tier 3 levels are further segregated into Tier 4 categories.

3.3.2 Step 2: Assign each UNFCCC category to OECD systems categories

26. After obtaining the latest and most detailed UNFCCC GHG data, the second step is to determine what portion of each source category is allocated to the different systems categories presented in Table 1. The systems categories represent cross-cutting UNFCCC source categories. Four out of the seven systems categories represent emissions related to materials management. As defined earlier, the materials management systems categories represent emissions associated with the production, consumption, and end-of-life treatment of physical goods in the economy. The sections below detail the materials management and non-materials management categories recommended in this analysis. Appendix A provides additional details and the full mapping of the GHG emissions for the Australia and Mexico case studies described below. In addition, Appendix A provides the reallocation mapping for two additional countries (Slovenia and Germany). In general, the list of emissions sources allocated to each system category corresponds to the highest tier UNFCCC categories available (see Appendix A).

Materials Management System Categories

27. The Production of Goods and Fuels systems category includes emissions from energy consumed during the production of goods and fuels, fugitive emissions associated with fuels consumed during the production of goods and fuels, and high global warming potential (GWP) emissions from the production of halocarbons and sulphur hexafluoride (SF_6) and other sources.[5] The complete list of emissions sources included in this system category is listed below:

- Emissions from electricity used by industry in the production of goods and fuels.
- Emissions from petroleum refining associated with oil consumption in the industrial sector.
- Emissions from manufacture of solid fuels and other energy industries.
- Emissions from manufacturing industries and construction.
- Fugitive emissions from coal mining and handling associated with coal consumption in the industrial sector and other non-energy.
- Fugitive emissions from oil production associated with oil consumption in the industrial sector and other non-energy.
- Fugitive emissions from natural gas production associated with natural gas consumption in the industrial sector and other non-energy.
- Fugitive emissions from venting and flaring of oil and natural gas.
- Fugitive emissions from other fuels.
- Emissions from industrial production of mineral, metal and chemical and other goods.
- Emissions from the production of halocarbons and SF6.

[5] Production of goods and fuels category also includes non-energy emissions from the use of certain products, including fire extinguishers, solvents, aerosols, and others.

- Halocarbon and SF6 emissions from industrial use of refrigeration and AC equipment.
- Halocarbon and SF6 emissions from foam blowing, fire extinguishers, aerosols/metered dose inhalers, solvents, semi-conductor manufacture, electrical equipment, other halocarbon and SF6 emissions and solvent and other product use.

28. **The Transportation of Goods** systems category includes emissions from fuel combustion or other energy consumption during the transportation of freight as well as additional emissions associated with refrigerated transport.

- Emissions from transportation of freight, including road freight, railway freight, shipping freight, and freight transported through other means.
- Halocarbon and SF_6 emissions associated with refrigerated transport.

29. **The Crop and Food Production and Storage** systems category includes emissions from energy consumed in agriculture, forestry, fishing and other operations. The category also includes the portion of fugitive emissions from coal, oil, and natural gas production that is associated with fuel consumption in the agriculture, fishing and other operations sectors. The complete list of emissions sources included in this category is below:

- Emissions from the production of electricity used in the agriculture, forestry, fishing and other sectors.
- Emissions from fuel combustion in the agriculture, forestry, and fisheries sectors.
- Fugitive emissions from coal mining and handling associated with coal consumed in the agriculture, forestry, fishing, and other non-specified.
- Fugitive emissions from oil production associated with agriculture, forestry, fishing, and other non-specified.
- Fugitive emissions from natural gas production associated with agriculture, forestry, fishing, and other non-specified.
- Halocarbon and SF6 emissions associated with retail food, cold storage and other appliances.
- Emissions from the agriculture sector.

30. **The Disposal of Food and Waste** systems category includes emissions associated with waste management processes, such as landfilling and combustion of municipal solid waste, as well as wastewater treatment.

- Emissions from the waste sector.

Non-Materials Management System Categories

31. The final three systems categories represent emissions associated with activities that are not considered materials management. These systems categories include emissions that result from activities such as residential or commercial heating and cooling and passenger transport.

32. **The Passenger Transport** systems category includes emissions associated with fuel combusted or energy consumed during transportation of passenger, as well as fugitive emissions associated with the fuel consumed in passenger transport. The complete list of emissions sources included in this category is shown below:

- Emissions from petroleum refining associated with oil consumed by the transport sector.

- Emissions from energy used for non-freight transportation.
- Emissions from other stationary and mobile.
- Fugitive emissions from coal mining and handling associated with transport.
- Fugitive emissions from oil and natural gas production associated with transport.
- Halocarbon and SF6 emissions associated with motor vehicle AC.

33. **The Residential Energy Use** systems category includes emissions from electricity and fuel consumed in the residential sector, as well as fugitive emissions associated with residential fuel consumption. The complete list of emissions sources included in this category is shown below:

- Emissions associated with electricity consumed in the residential sector.
- Emissions from petroleum refining associated with oil consumed in the residential sector.
- Emissions from fuel combusted in the residential sector.
- Fugitive emissions from coal mining and handling associated with residential coal use.
- Fugitive emissions from oil and natural gas production associated with residential oil and natural gas consumption.
- Halocarbon and SF6 emissions from residential AC use.

34. **The Commercial Energy Use** systems category includes emissions from electricity and fuel consumed in the commercial sector, as well as fugitive emissions associated with commercial fuel consumption. The complete list of emissions sources included in this category is shown below:

- Emissions associated with electricity consumed in the commercial and public services sector.
- Emissions from petroleum refining associated with oil consumed in the commercial and public services sector.
- Emissions from fuel combusted in the commercial and public services sector.
- Fugitive emissions from coal mining and handling associated with commercial and public services coal use.
- Fugitive emissions from oil and natural gas production associated with commercial and public services oil and natural gas consumption.
- Halocarbon and SF6 emissions from commercial AC and Chillers.

3.3.3 Step 3: For UNFCCC categories that represent multiple systems, use supplementary external documentation to apportion emissions

35. As described above, different countries report different levels of detail across the UNFCCC categories of emissions. For certain systems categories (*i.e.*, "Disposal of Food and Waste") the mapping of the UNFCCC source category (*i.e.*, "Waste") is straightforward since the entire Tier 1 category comprises this system. Therefore, it is not necessary to obtain data with more detailed estimates of the sub-sectors within the UNFCCC "Waste" category. For other UNFCCC categories (*i.e.*, "Energy"), more detailed category estimates (*i.e.*, through sub-category Tier 4) allow for a more accurate re-allocation of emissions to systems categories.

36. Furthermore, the availability of data to parse out the various emissions sources varies by country. For example, while it may be ideal to allocate emissions across the transport sector into freight (*i.e.*, materials management) versus passenger (*i.e.*, not materials management) by each mode (*i.e.*, air, water, road, and rail), the underlying level of detail necessary to inform this allocation might not be available for a particular member country. Therefore, it is important to utilise external documentation to

further break out the UNFCCC source categories into the systems categories. The following list of resources is useful for informing the breakdown of the UNFCCC categories into the systems categories defined in Table 3.1. Some of the resources listed include data that can be utilized for all OECD countries (e.g., the IEA Energy Statistics data and the EPA "Global Mitigation of Non-CO2 Greenhouse Gases" resource).

- International Energy Agency (IEA) Energy Statistics data (IEA, 2010).
- Country-specific GHG inventory reports available through the UNFCCC.
- Transportation data statistics from sources such as the North American Transportation in Figures Report (DOT *et al.*, 2000).
- Global Mitigation of Non-CO2 Greenhouse Gases (EPA, 2006a).
- Other country-specific energy reports such as energy balance reports from the state department of energy.

37. Other OECD member countries can also gather similar types of reports and statistics, where available, to disaggregate the UNFCCC categories into systems categories.

38. The resulting systems perspective will provide valuable insight into the portion of total GHG emissions associated with materials management and allow OECD member countries to use the resulting emissions breakdown to gain a deeper understanding of the relative importance of the materials management-related sources of GHG emissions.

3.4 Case Study Examples of Methodology

39. Due to the wide variation in reported detail of GHG estimates across UNFCCC categories, we used two OECD member countries as examples to highlight the methodology for reallocating emissions according to systems categories. This section presents a methodology for member countries to follow to estimate the share of national GHG emissions associated with materials management. To help illustrate this approach, we show the application of this methodology using two OECD countries, Australia and Mexico, with varying levels of data availability. In addition, we provide additional analysis for Slovenia and Germany as described at the end of this section and shown as full system-based GHG allocation mapping in Appendix A.

3.4.1 Australia: Case study 1

40. We obtained Australia's detailed GHG emissions data, reported at the Tier 4 level for most categories, from the UNFCCC's GHG flexible data query which represented GHG emissions from 2007. Adopting the systems allocation methodology to Australia as a case study provided insight into the reallocation procedure. The reallocation of GHG emissions relied on using relatively detailed data provided to the UNFCCC supplemented by external sources such as data on energy statistics from the IEA and government sources on transportation. In the process of mapping of the UNFCCC source categories to the systems categories, we highlight a few important methodological assumptions below. The full mapping of the UNFCCC categories to systems categories is presented in Appendix A.

a) Apportioning emissions associated with electricity and heat production.

The emissions associated with the "Public Electricity and Heat Production" as listed in the UNFCCC Tier 4 category represent the largest individual source of emissions in the Australia GHG Inventory. These emissions were reallocated across the seven systems categories using final total electricity consumption information from the IEA's "Electricity/Heat Data" for year 2007 (Table 2).

Table 3. Reallocating Electricity and Heat emissions data to systems categories

Systems categories for materials management perspective	IEA sector consumption	Percent of final consumption associated with electricity and heat production (derived from IEA) (sum = 100%)
Production of Goods and Fuels	Industry	45%
Transportation of Goods	None	0%
Crop and Food Production and Storage	Agriculture / Forestry, Fishing, Other Non-Specified	1%
Passenger Transportation	Transport	1%
Residential Energy Use	Residential	30%
Commercial Energy Use	Commercial and Public Services	23%
Disposal of Food and Waste	None	0%

b) Apportioning emissions associated with petroleum refining.

The emissions associated with "Petroleum Refining" as listed in the UNFCCC Tier 4 sub category and the "Fugitive Emissions from Fuels" Tier 2 categories are apportioned across multiple systems categories using total final consumption data from the IEA's "Energy Statistics" on Coal, Oil, and Natural Gas. These emissions are associated with extracting, producing, refining, distributing, and storing fuels which are used across multiple systems categories. For example, emissions associated with "Petroleum Refining" were reallocated using Oil "Energy Statistics" to the following systems categories (Table 3). To simplify the analysis, we assumed that the petroleum refining emissions associated with transport were fully associated with Passenger Transportation systems category. A similar allocation method was applied to map the "Fugitive emissions from Fuels" using the combined percentages of oil, natural gas and solid fuels (*i.e.*, Coal) across the systems categories.

Table 4. Reallocating petroleum refining emissions data to systems categories

Systems categories for materials management perspective	IEA sector consumption	Percent of final consumption associated with petroleum refining
Production of Goods and Fuels	Industry & Non-Energy Use	12%
Transportation of Goods	None	0%
Crop and Food Production and Storage	Agriculture / Forestry, Fishing, Other Non-Specified	6%
Passenger Transportation	Transport	79%
Residential Energy Use	Residential	1%
Commercial Energy Use	Commercial and Public Services	2%
Disposal of Food and Waste	None	0%

c) Apportioning emissions associated with refrigeration equipment.

Emissions associated with high global warming potential (GWP) gases in Refrigeration and AC equipment is apportioned according to EPA's *Global Mitigation of Non-CO_2 Greenhouse Gases* report that defines the distribution, refrigeration, and air-conditioning sector emissions by end-use (Table 4) (EPA, 2006a).[6] The EPA report provides a regional distribution of refrigeration and air conditioning sector high GWP emissions by end-use. For all OECD countries, within the UNFCCC Tier 1 Industrial Processes category, the "Refrigeration and AC Equipment" emissions source is the only source for which it is necessary to apportion across systems categories. All other Industrial Processes sources are considered fully within the "Production of Goods and Fuels" system category.

Table 5. Reallocating Refrigeration and AC equipment emissions data to systems categories

Systems categories for materials management perspective	EPA Global Mitigation Report sector consumption	Percent of final consumption associated with refrigeration and AC equipment based on regional distribution.
Production of Goods and Fuels	Industrial Process	4%
Transportation of Goods	Refrigerated Transport	12%
Crop and Food Production and Storage	Retail food, Cold Storage	33%
Passenger Transportation	MVACs (motor vehicle AC)	47%
Residential Energy Use	Residential AC, other appliances (refrigerators, dehumidifiers, etc.)	1%
Commercial Energy Use	Commercial AC, Chillers	4%
Disposal of Food and Waste	None	0%

41. Using the systems reallocation, each UNFCCC source category is apportioned according to the systems they represent. However, not all the UNFCCC source categories are apportioned across multiple systems categories. Many UNFCCC source categories are represented fully in a particular systems category. For example, the emissions associated with "Manufacture of Solid Fuels and Other Energy Industries" Tier 4 UNFCCC category are fully represented in the "Production of Goods and Fuels" systems category.

42. The Figure below represents Australia's 2007 GHG emissions reallocated by systems category (Figure 5).

[6] Given the similarity in technologies for refrigeration and AC equipment in the OECD, it is assumed that the results of this study can be applied across the OECD.

Figure 5. Systems-based GHG emissions for Australia in 2007

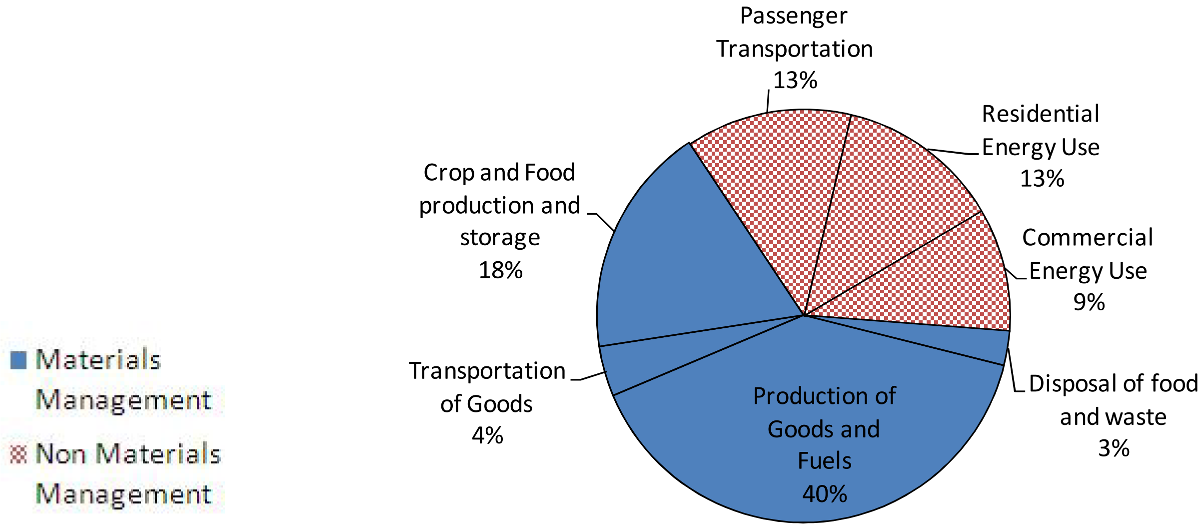


Table 6. Systems-based GHG emissions for Australia in 2007

Category	Total MMT CO_2e	Percent of Total	Overall classification
Production of Goods and Fuels	215	40%	Materials Management
Transportation of Goods	21	4%	Materials Management
Crop and Food production and storage	98	18%	Materials Management
Disposal of food and waste	15	3%	Materials Management
Residential Energy Use	70	13%	Non Materials Management
Commercial Energy Use	52	10%	Non Materials Management
Passenger Transportation	70	13%	Non Materials Management
Total GHG Emissions in 2007	541	100%	

43. The system-based view of GHG emissions in Australia illustrates that the majority, or roughly 64 percent of the country's GHG emissions is associated with materials management activities compared to approximately 36 percent of GHG emissions associated with other non-materials management activities. This suggests that there is significant opportunity to potentially reduce emissions through a modification and expansion of materials management policies.

3.4.2 Mexico: Case Study 2

44. The Australia case study represents the application of the methodology to reallocate GHG emissions from conventional UNFCCC source categories into systems categories for an OECD country that reports emissions data at a relatively high level of detail. The level of data availability and detail

facilitates a more informed reallocation of GHG emissions from UNFCCC source categories to the systems-based categories. However, several OECD countries, such as Mexico, report data at a level that is less detailed than that for Australia and other countries. We therefore chose Mexico as a second case study in order to illustrate the additional data analysis needed to allocate emissions from the sector categories to the systems categories in situations with low data availability. The basic method is to use external data sources (generally detailed energy generation, transformation, and consumption data) to apportion Tier 3 emissions totals into Tier 4 emissions sources. Once the Tier 4 UNFCCC emissions sources are estimated, the process for reallocating to systems-based categories is similar to the analysis conducted for Australia as described above. We highlight a selection of the additional steps needed to break out Mexico's GHG emissions inventory based on reported data to the UNFCCC:

a) Apportioning emissions associated with Energy Industries into UNFCCC Tier 4 categories.

The "Public Electricity and Heat Production" source is one of the largest individual emissions sources. Our methodology allocates emissions from this source across all seven systems categories using the total electricity consumption information available through IEA (IEA, 2010). However, unlike Australia, Mexico does not report emissions for this Tier 3 category into its constituents including the "Public Electricity and Heat Production," "Petroleum Refining," and "Manufacture of Solid Fuels and Other Industries" Tier 4 categories. Therefore, it is necessary to first allocate total Energy Industries emissions into their respective Tier 4 categories, which can then be further subdivided into the relevant systems categories. Countries in this position will need to utilise data that reveals the energy mix and respective sectoral national consumption. In the case of Mexico, 31 percent of consumed energy was utilised in central electricity plans, 43 percent utilised in petroleum refineries, 25 percent utilised the natural gas sector, and 1 percent was utilised for other sources (SENER, 2003). Our analysis applied these consumption percentages, as shown in table 6, to the Energy Industries Tier 3 emissions total in order to estimate emissions at the Tier 4 category level.

Total emissions from Tier 3 UNFCCC Energy Industries category = 153 MMTCO2e

Table 7. Reallocating Tier 3 Energy Industries Emissions to Tier 4 Emissions Sources

Energy Type Transformed in each facility type	2002 Percent of Energy Use	UNFCCC Tier 4 Categories under Energy Industries under 1.A.1 Energy Industries	Emissions allocated to each Tier 4 category ($MMTCO_2E$)
Central Electricity power plants	31%	Public Electricity and Heat Production	153 x 31% = 47
Refineries	43%	Petroleum Refining	153 x 43% = 66
Natural gas plants	25%	Manufacture of Solid Fuels and Other Industries	153 x 26% = 39
Other	1%		

b) Apportioning emissions associated with Tier 3 UNFCCC Transport category into Tier 4 categories.

Mexico reports total emissions for energy consumed in the transportation sector, but these emissions need to be broken out into the Tier 4 categories in order to be allocated into systems-based categories. Countries in this position will need to utilise data that reveals the relative contribution of each transportation mode to the total. For Mexico, we relied on SENER (2003) which reported energy consumed in each transportation mode.

Total emissions from Tier 3 category 1.A.3 Transport = 114 MMTCO2e.

Table 8. Reallocating Tier 3 Energy Industries Emissions to Tier 4 Emissions Sources

Transportation Mode	Percent of Energy Consumed by each transportation mode	UNFCCC Tier 4 Categories under 1.A.3. Transport	Emissions allocated to each Tier 4 category ($MMTCO_2E$)
Air	6.7%	Civil Aviation	114 x 6.7% = 7
Road	89.8%	Road Transportation	114 x 89.8% = 103
Train	1.3%	Railways	114 x 1.3% = 1
Shipping	2.0%	Navigation	114 x 2.0% = 2
Electric	0.2%	Other Transportation	114 x 0.2% = <1

45. As described above, apportioning UNFCCC Tier 3 categories into their respective Tier 4 categories enables a more informed systems category allocation. The methodology for reallocating Mexico's GHG emissions into systems-based categories is the same as was applied to Australia.

47. The Figure below represents Mexico's 2002 GHG emissions reallocated by systems category (Figure 6).

Figure 6. Systems-based GHG Emissions for Mexico in 2002

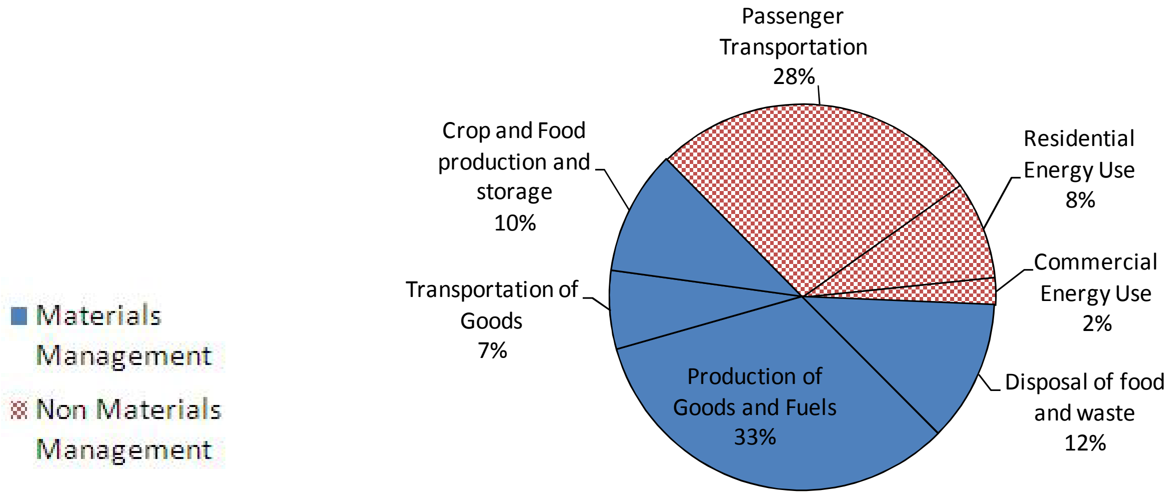


Table 9. Systems-based GHG emissions for Mexico in 2002

Category	Total MMT CO_2e	% of Total	Overall Classification
Production of Goods and Fuels	183	33%	Materials Management
Transportation of Goods	36	7%	Materials Management
Crop and Food production and storage	58	10%	Materials Management
Passenger Transportation	66	28%	Non Materials Management

Residential Energy Use	45	8%	Non Materials Management
Commercial Energy Use	13	2%	Non Materials Management
Disposal of food and waste	153	12%	Materials Management
Total GHG Emissions in 2007	553	100%	

48. The system-based view of GHG emissions in Mexico illustrates that roughly 62 percent of GHG emissions are associated with materials management activities compared to approximately 38 percent of GHG emissions associated with other non-materials management activities. With the majority of Mexico's GHG emissions associated with materials management activities, there is significant opportunity to potentially reduce emissions through a modification and expansion of materials management policies.

49. In addition to the Australia and Mexico case studies presented above, we also conducted a systems reallocation analysis of GHG emissions for two additional OECD member countries, Slovenia and Germany. Similar to Australia, GHG emissions available through the UNFCCC for Slovenia and Germany are reported at a relatively high level of detail. The level of data availability and detail facilitates a more informed reallocation of GHG emissions from UNFCCC source categories to the systems-based categories.

50. The results are presented below in Figure 7 and Figure 8 along with full mapping of GHG emissions to systems categories presented in Appendix A. Figure 7 and Figure 8 illustrate that for Slovenia and Germany, the system-based reallocation of GHG emissions offers a similar perspective on the share of materials management emissions. The majority (54 percent for Germany and 55 percent for Slovenia) of GHG emissions are associated with materials management. Although there are differences across the systems categories, the systems-based perspective indicates that emissions associated with materials management represent the majority of overall GHG emissions.

Figure 7. Systems-based GHG Emissions for Slovenia in 2008

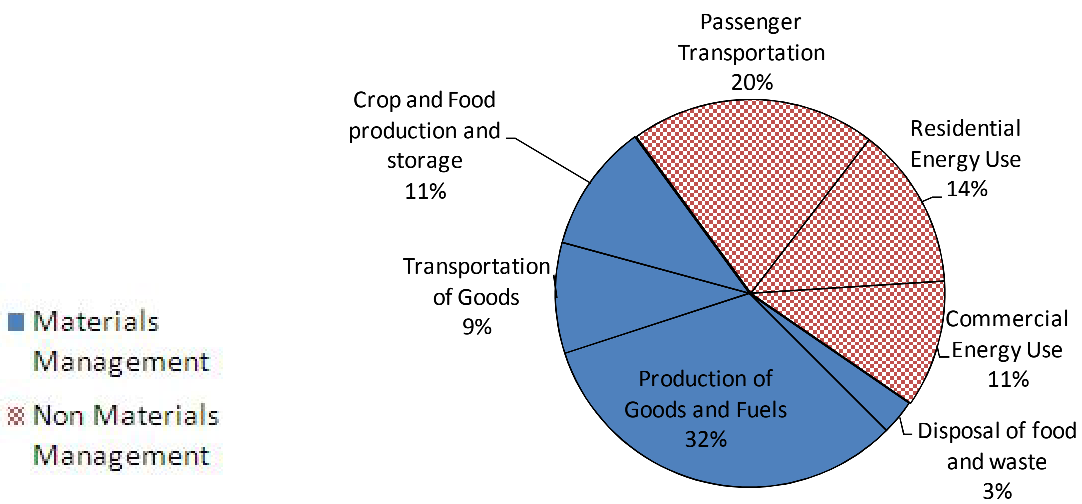
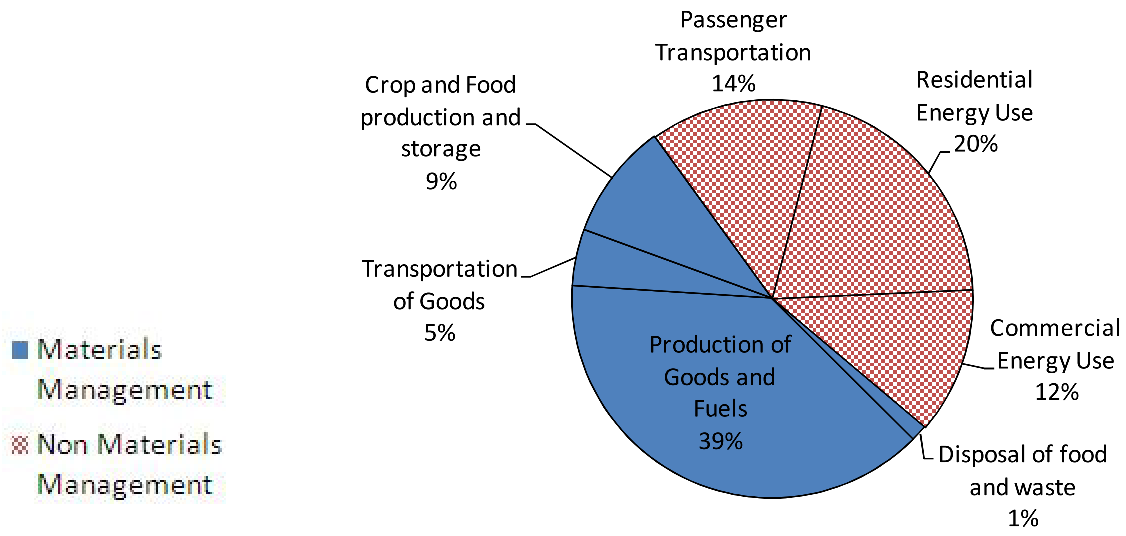


Figure 8. Systems-based GHG Emissions for Germany in 2008



3.5 Conclusions

51. This section presented a methodology to enable OECD member countries with varying levels of GHG emissions source details to estimate the share of national GHG emissions associated with economic activities that highlight materials consumption and production.[7] As the results show for four OECD member countries, when viewed from a systems-based perspective, the GHG emissions associated with materials management represent a large share of national GHG emissions, albeit for a very small sample of countries. These results are consistent with a similar study conducted by the EPA (2009b) that found that materials management activities are associated with 42 percent of total GHG emission in the United States.

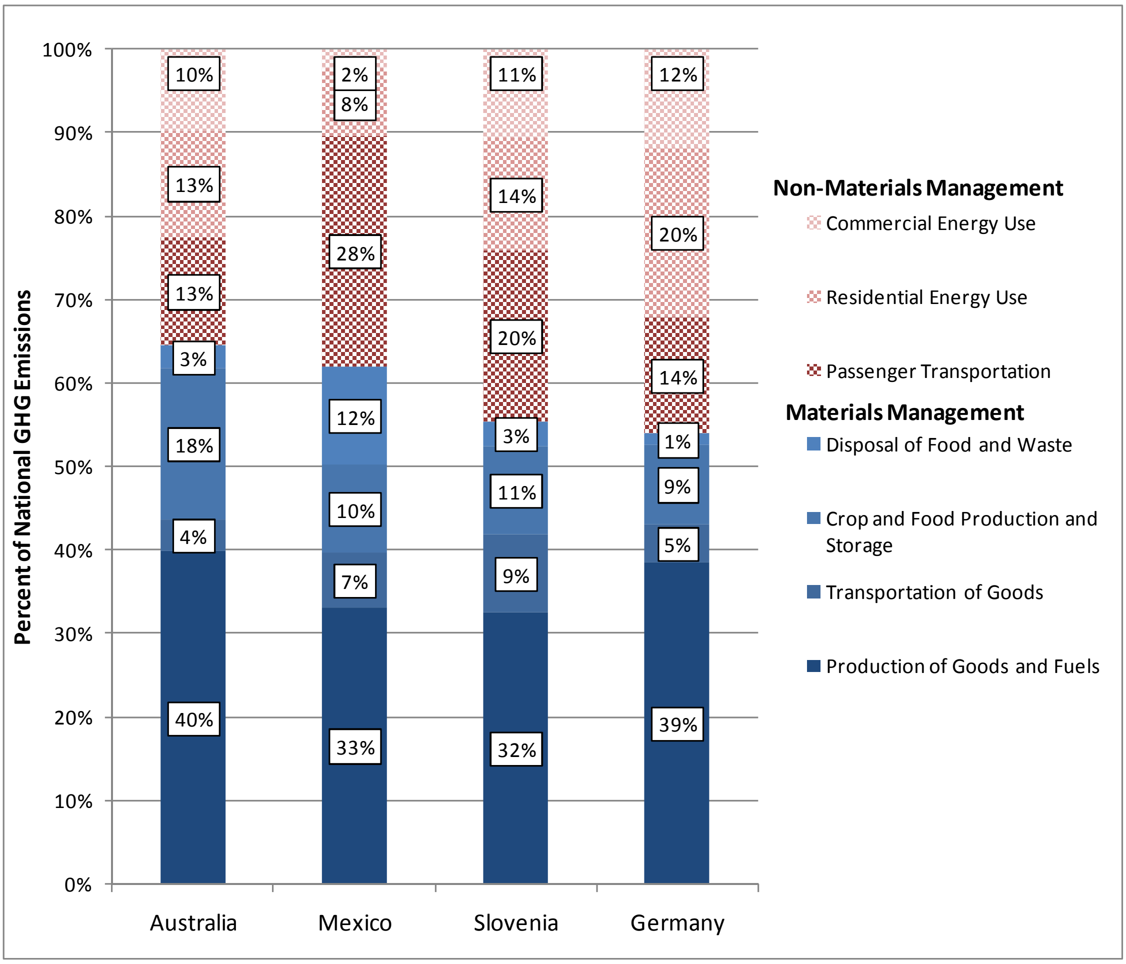
52. Although the GHG emissions inventories obtained from the UNFCCC for the four OECD member countries are different in terms of overall magnitude of emissions, level of detail, and transparency, the systems based reallocation offers some interesting insights:

- Across the four analysed OECD member countries, materials management related emissions account for more than half of total GHG emissions.
- The emissions associated with the production of goods and fuels are the main emissions source across the four OECD countries analysed.
- Emissions associated with public transport (a non-materials management system category) are larger than the emissions associated with transport of goods (a materials management system category) across the four analysed OECD member countries.

[7] It should be noted that national GHG inventories do not include GHG emissions linked to imports and exports. In this study a production, rather than a consumption perspective is taken, i.e. allocating emissions to production rather than consumption.

- Emissions associated with the disposal of food and waste represent the minority of total emissions across the four analysed OECD countries (ranging from 1 to 12 percent). However, as discussed earlier, the disposal of food and waste emissions considers only direct emissions associated mainly with methane emissions from degrading waste in landfills. As shown in this analysis and summarised in Figure 3.6, when viewed from a systems-based perspective, emissions associated with materials throughout their life cycle represent the majority of total GHG emissions (ranging from 54 to 64 percent).

Figure 9. Summary of system-based GHG emission reallocation for analysed OECD countries



53. Allocating emissions by systems provides policy makers with a framework for estimating the relative GHG impact of economic activities that span multiple sectors. The analysis illustrates the magnitude and potential for GHG mitigation opportunities associated with materials management that transcend conventional economic sectors. When viewed from a systems perspective, the relative GHG emissions impact across the full life cycle of materials can be further understood and options for increasing the sustainability of materials use and management can be further realised.

4.0 GHG MITIGATION POTENTIAL OF ALTERNATIVE WASTE MANAGEMENT PRACTICES

54. This section evaluates the life-cycle GHG mitigation potential resulting from implementing alternative MSW management practices—relative to current, or baseline, practices—across OECD member countries in 2030 and is a separate analysis from the previous section. The goal of this analysis is to provide an "order-of-magnitude" estimate of the emission mitigation potential of different MSW management options that could be achieved through policy options. The main assumptions used in this analysis are also presented in Appendix C (Table of Assumptions).

55. The analysis investigates life-cycle GHG reductions from eight different MSW management scenarios. We define MSW management as the collection and management of waste, including recyclable materials such as metals and glass, plastics, paper and wood, organics, mixed categories, and composite products from household, commercial, institutional, and light industrial sources.

56. Each scenario increases a specific alternative waste management practice to its technically achievable potential in 2030 and evaluates the reduction in life-cycle GHG emissions against a baseline where management practices remain unchanged from today. The eight scenarios include: (i) MSW recycling; (ii) food and garden waste composting; (iii) anaerobic digestion of food and garden wastes with energy recovery; (iv) recycling and Mechanical Biological Treatment (MBT); (v) landfill gas collection; (vi) energy recovery from collected landfill gas; (vii) incineration, and (viii) source reduction.

57. This section also provides information on the costs of MSW management practices and abating GHG emissions, although a detailed economic analysis was not included in the scope of this report. The economic information summarised in this report is provided to support additional economic analyses of the abatement potential from alternative management of MSW and other waste streams.

4.1 Scope and Method

58. The scope of this analysis is limited to MSW generation in OECD member countries. We examine the life-cycle GHG mitigation potential resulting from implementing alternative MSW management practices relative to a baseline that assumes no change in current practices by 2030. The scope of this assessment includes three important aspects:

59. We adopt a life-cycle perspective of GHG emission reductions from MSW management practices. The integrated nature of materials management options requires a life-cycle perspective in order to evaluate the full range of GHG emission reductions achievable. MSW materials are produced from a long chain of life-cycle stages that cross-cut conventional industrial and economic sectors, including: (i) extraction and processing of raw materials, (ii) the manufacture of new products, (iii) the transportation of materials and products to markets, (iv) use of products by consumers, and (v) end-of-life management practices. Consequently, MSW management decisions can affect GHG emissions through one or more of the following pathways:

- GHG emissions associated with energy use for raw material acquisition, manufacturing processes, and transportation;

- Non-energy GHG emissions associated with manufacturing processes. For example, non-energy GHG emissions are produced by converting limestone into lime, which is used in the production of steel and aluminium;
- Methane emissions from the degradation of organic materials at end-of-life;
- Carbon dioxide and nitrous oxide emissions from waste combustion; and
- Carbon storage in landfills, soils, and forests.

60. The life-cycle boundaries established for each MSW management option are described further in section 4.3. We did not analyze the potential for GHG emission reductions from MSW management practices resulting during the use of products by consumers. Instead, we assumed that the energy consumed during the use phase would be approximately the same regardless of the final end-of-life management practice.

61. Our baseline in 2030 assumes no change in current waste management practices and no change in the composition of municipal solid waste.We recognise that there are already policies and voluntary programs in place in OECD countries that will continue to increase the implementation of alternative or improved waste management practices.
Our baseline therefore underestimates the extent to which alternative practices, such as recycling, composting, and waste-to-energy recovery, will be in place by 2030 even without any additional policies to promote these practices. Given the uncertainty about the evolution of the composition of MSW in OECD countries, it was decided to keep the composition constant.

62. We selected this baseline, however, because there is a high level of uncertainty in how MSW practices will evolve between now and 2030, and projections of future MSW management may over- or underestimate the actual implementation of these options. Developing a baseline that assumes no change in current practices by 2030 is simple to communicate and allows us to evaluate the full range of future GHG benefits resulting from adopting alternative practices beyond current levels in 2030.

63. We evaluate the change in MSW management resulting from alternative MSW management practices relative to our baseline over the year 2030, and consider all future GHG emission reductions that result from this change in practices. Although we assess the GHG benefits resulting from a change in MSW management practices over one year (*i.e.*, 2030), not all GHG emission reductions resulting from this alternative scenario will occur within the same year. For example, organic materials can take several decades to degrade into methane emissions in landfills; consequently, the benefits of avoiding methane emissions by diverting organics from landfills also occur over a timeframe of several decades.

64. In our analysis, we have considered the full life-cycle GHG benefits of alternative MSW management practices, regardless of when they occur over time. Since the timing of GHG benefits is a unique characteristic of waste management practices that is unlike mitigation options in other sectors, it is important to consider the life-cycle benefits of these practices in order to assess their full mitigation potential.

65. Based on this understanding of the scope, we evaluated the GHG mitigation from alternative MSW management practices using the following method:

1. **Developed regional groups of OECD member countries.** We separated OECD member countries into regional groups to distinguish between areas with different MSW generation rates,

waste composition, and existing MSW management practices. Developing these regional groups enabled us to investigate of the variation of these aspects between different regions. We recognise that conditions will also differ within the regional groups defined by this analysis, but an investigation of these aspects at a more localised level was beyond the scope of this assessment.

2. **Described MSW management options.** We developed a set of management options based on MSW management practices that are already adopted in OECD countries and emerging technologies that have not yet achieved wide-scale implementation. These options include: recycling, composting, anaerobic digestion, mechanical biological treatment (MBT), landfilling (with and without gas collection), incineration with energy recovery, and source reduction.

3. **Established current MSW generation, composition, MSW management practices for each regional group.** Using data from the OECD and industrial associations for OECD countries in North America, Europe, Asia, and the Pacific, we developed estimates of current MSW generation, composition, and the MSW management practices described in step 2 for each regional group identified in step 1.

4. **Evaluated GHG emissions and emission reductions for each MSW management option.** From an assessment of existing life-cycle studies and calculation methods, we developed GHG emission factors for each option. These emission factors describe the GHG emissions or emission reductions resulting from a unit of waste being managed by that option. For recycling and composting, we based our emission factors on existing estimates from European and North American data sources (Defra, 2009; EPA, 2006b; Prognos, 2008). For landfilling, incineration, anaerobic digestion, MBT, we developed a consistent methodology for GHG emissions or emission reductions from each option based on parameters from several data sources (EPA, 2006b; IFEU, 2009; Prognos, 2008).

5. **Extrapolated baseline generation, composition, and MSW management practices from today out to 2030 for each regional group.** We considered a case where waste composition and MSW management practices remain the same in 2030 as they are today, and used OECD projections (OECD 2008b) to estimate MSW generation in each region by 2030.

6. **Specified alternative MSW management scenarios in 2030.** In contrast with the baseline, which assumes no change from current MSW management practices, we defined eight mutually-exclusive scenarios that represent upper-bound, technically-achievable limit for each alternative management practice.[8] For example, we defined a recycling scenario that describes a future where OECD member countries achieve the maximum technically-achievable rate of recycling MSW materials.

7. Compared the MSW managed by alternative versus baseline management practices for each scenario and calculate the GHG mitigation potential. We calculated the mitigation potential for each alternative scenario by multiplying the quantity of MSW managed by each practice by that practice's corresponding GHG emission factors. We then took the difference in these results between the baseline and the alternative scenario to calculate the net change in GHG emissions. Based on these findings, we developed an integrated MSW management scenario that utilised the most effective options at reducing GHG emissions.

[8] We defined the technical potential as the extent to which each option would be technologically achievable and fully implemented by 2030 irrespective of potential limitations posed by economic, institutional, political, and behavioural barriers.

66. Each element of this methodology is described in further detail in the subsequent sections of this chapter.

4.2 Regional Breakdown of OECD Member Countries and Electricity Generation GHG Emission Factors

67. We categorised OECD member countries into five groups based on geography and baseline recycling rates to account for differences in MSW generation and composition, management practices, and region-specific factors that affect GHG emissions from management practices, such as the fuel mix and carbon intensity of electricity production. Countries were divided into groups based on their geographical location, and the availability of data on representative management practices and GHG emission factors within each region. Table 9 below shows which countries are included in each group.

Table 10. Regional Breakdown of OECD Member Countries for Analysis

Region	Regional Group	Countries
North America	North America	Canada, Mexico, United States
OECD Europe	High-Recycling OECD Europe	Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland, United Kingdom
	Low-Recycling OECD Europe	Czech Republic, Greece, Hungary, Poland, Portugal, Slovak Republic, Spain
OECD Pacific/Asia	OECD Pacific	Australia, New Zealand
	OECD Asia	Japan, South Korea

68. We split OECD Europe into two groups based on differences in waste management practices: High-Recycling Europe includes those countries with recycling rates higher than 15 percent, while Low-Recycling Europe includes those countries with recycling rates below 15 percent.[9]

69. Based on the carbon intensity of each region's fuel mix, three region-specific electricity GHG emission factors were created for estimating emissions from electricity used by materials management practices, and for emissions offsets from energy recovered by waste-to-energy practices (*e.g.*, landfills with gas collection and energy recovery, waste-to-energy incinerators, anaerobic digestion facilities). Average GHG emission factors were used to estimate emissions from producing electricity used to operate facilities and equipment, while marginal emission factors were used to estimate avoided GHG emissions[10] from electricity production that is offset by energy recovery from waste-to-energy management practices.[11] Marginal emission factors are used to calculate GHG emissions offsets from waste-to-energy practices because these factors represent the GHG emissions-intensity of power plants that respond to marginal

[9] This distinction does not imply that 15 percent is a high or low recycling rate absolutely. The terms "high" and "low" recycling are only used to distinguish areas of Europe that employ a different set of MSW management practices so that we can distinguish between these areas in our results.

[10] For the purposes of this report, avoided GHG emissions are emissions that would have been generated to meet demand for heat, electricity, or the production of materials such as steel and aluminium, but which are offset, or avoided, by energy or material recovery achieved through alternative waste management practices, such as landfill gas energy recovery, incineration, and reuse or recycling.

[11] For the purposes of this report, average GHG emissions factors for electricity are a weighted-average GHG emissions intensity of power generation supplied to the grid in a region. Marginal GHG emission factors represent the emissions intensity of non-baseload power plants (i.e., power plants that "follow demand") that adjust to marginal changes in the supply and demand of electricity.

changes in demand for electricity. In other words, marginal emission factors represent the power plants that are most likely to be backed off the grid as a result of incremental changes in the supply of electricity from waste-to-energy plants.[12]

70. Average and marginal GHG emission factors for OECD member countries were weighted by each country's annual electricity generation to produce electricity emission factors for the three regions; North America, OECD Europe, and OECD Pacific/Asia (EIA 2010, based on IEA electricity data). Table 10 below shows the average and marginal electricity emission factors for the three regions. It is important to note that increased shares of low-CO_2 electricity in the grid mix of OECD countries in the future will lower the GHG benefit from electricity offset by waste-to-energy recovery. Given the scope, and resources available, however, a detailed analysis of future electricity grid mixes across all OECD regions was not possible in this study.

Table 11. Electricity Emission Factors by Region (kg CO2-equivalent/kWh)

Region	Total Electricity Average GHG Emissions Intensity *(kgCO_2-equivalent/kWh)*	Marginal GHG Emissions Intensity[13]
North America	0.62	0.95
Europe	0.38	0.77
Pacific/Asia	0.50	0.81

4.3 Description of MSW Management Options and GHG Emission Factors

71. Nine different waste management practices were included in the analysis. These nine practices were developed based on an assessment of common management options for MSW in OECD countries, and emerging technologies that have not yet achieved wide-scale implementation. Together, they describe a representative range of MSW management practices in OECD countries.

72. This section provides a description of each management practice, discusses the life-cycle boundaries that were included in the assessment, and describes the data sources used to develop the emission factors. Further details on the emission factors are provided in Appendix D.

73. For the consistency across the data sources used to develop emission factors for this study, we have excluded carbon storage effects associated with landfilling, composting, and recycling. Accounting for carbon storage in landfills, soil, and forests has a significant impact on the emission reductions estimated by this study. For a full discussion of these effects and their treatment in this analysis, please see Box 1.

[12] In some cases, electricity from waste-to-energy plants may not displace power plants that respond to marginal changes in demand, but rather plants that supply the base load. In this case, the use of average emissions factors would be more appropriate and our approach would lead to over-estimating the GHG mitigation potential of waste-to-energy plants.

[13] Based on average GHG emissions intensity of fossil-fired generation for each region. Factors are developed from the IEA's Electricity Information Database 2007 using CO2 emissions from EIA's Fuel Combustion Database 2006. Marginal GHG emission factors do not include transmission and distribution losses, since it is assumed that electricity from waste-to-energy practices offsets electricity generation at the grid.

74. We did not analyze the potential for GHG emission reductions from MSW management practices resulting during the use of products by consumers. Although consumers' use of products (e.g., personal computers) can in some cases account for significant energy use and GHG emissions, we assumed that the energy consumed during use would be approximately the same regardless of the final end-of-life management practice. Because this report compares GHG emissions from baseline MSW management practices to alternative scenarios, use-phase GHG emissions in the baseline and alternative scenarios will effectively cancel out.

75. **Recycling** is defined as reuse of a material in a production process that diverts the material from the waste stream (except reuse as fuel) (OECD, 2008a, p. 24). Recycling a material can produce the same type of material or product (referred to a closed-loop recycling), or a different product (*i.e.*, open loop recycling). GHG emissions are reduced through the displacement of virgin inputs in the manufacturing process, thus eliminating or lowering energy needs in the extraction of raw materials and processing.

76. The life-cycle boundaries for the GHG emission factors for recycling in this study include the emissions from recycling a material, offset by the amount of energy that would have been needed to produce the same amount of material from virgin inputs.

77. The GHG emission factors for recycling materials in North America are taken from U.S. EPA (2006b) and the EPA's Waste Reduction Model (WARM)[14]. WARM provides life-cycle energy and GHG emission factors for recycling materials in the United States; WARM's life-cycle boundaries are generally consistent with the system boundary established for this report, and the tool contains the best-available life-cycle data available on materials management practices in the United States.

78. GHG emission factors for Europe are taken from Prognos (2008), a study produced by a coalition of European waste management associations. The study estimates the potential to reduce European GHG emissions through intelligent waste management strategies, focusing on recycling and on energy recovery through waste management.

79. We did not locate a consistent data source for recycling GHG emission factors for OECD Pacific/Asia. Consequently, we applied recycling emission factors that are representative of European practices to this region. This assumption will affect our results depending upon the extent to which recycling practices or processes in OECD Pacific/Asia are substantially different than Europe. Due to similarities in the level of economic development and infrastructure, we believe that this is an appropriate assumption for an "order-of-magnitude" assessment of the GHG reduction potential.

80. These two sets of factors represent the best-available data we found on life-cycle GHG implications from recycling. However, it is important to note that, due to methodological differences in the analyses, the life-cycle boundaries of the two analyses may not be entirely consistent.[15] As a result, there is some uncertainty in making comparisons across regions with the recycling results of this analysis.

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[14] The Canadian Government has developed a similar tool, the "Greenhouse Gas Calculator for Waste Management", that contains GHG emission factors specific to Canada (Environment Canada, 2010). The Canadian energy profile is less fossil-fuel intensive than in the United States; however, for the purposes of this assessment, given that the United States produces a much larger share of materials than Canada, applying U.S.-specific factors to North America is a reasonable first approximation.

[15] For example, Prognos (2008) employs a substitution factor for several material types that adjusts for the assumption that certain recycled materials do not perform as well as primary materials by assuming that more recycled material is needed to achieve functional equivalence in remanufacturing. Recycling emission factor estimates from EPA (2006b) incorporate loss rates that adjust for the fraction of material that is collected for recycling, but rejected or lost as residue during the remanufacturing process. Consequently, while EPA (2006) factors account for losses in the

81. **Composting** is defined as the decomposition of organic waste using micro-organisms to produce compost, which is a bulk-stabilised humus residue that can be used as a soil amendment or as a medium for growing plants (EC, 2001). Composting is a waste management practice for organic materials, primarily food waste and garden waste, and the practice often takes place in the form of centralised composting facilities that use a variety of management techniques to optimise decomposition.

82. GHG emissions from composting include emissions from collection, transport, and mechanical handling of compost. In addition, long-term carbon storage in soils takes place in the form of un-decomposed carbon compounds. The emission factors for composting are applicable to centralised, municipal composting. Carbon dioxide emissions from aerobic decomposition of biomass are assumed to be balanced out by carbon uptake from replanted biomass resources (*i.e.*, net biogenic carbon dioxide emissions are considered zero).

83. The emission factors for composting are taken from WARM (EPA, 2006b) for North America and from Defra (2009) for Europe and Pacific/Asia. The emission factors are based on a life-cycle assessment and include not only the emissions from treating and processing the organic waste compost facilities and also transporting the organic waste to the facilities. Notably, while WARM's default emission factors incorporate benefits associated with soil carbon sequestration for composting organics, this benefit was not included in our modelling to be consistent with the emission factors provided by DEFRA and consistent with the exclusion of long-term carbon storage associated with the landfilling emission factors. It is assumed that composting facilities operate efficiently and methane emissions associated with anaerobic breakdown of biodegradable waste are not incorporated into the composting emission factor.

84. **Landfilling** is the managed placement of untreated MSW into the earth (EC, 2001) and is a waste management option for all waste streams. Landfills generate methane and other gases as a result of anaerobic decomposition of organic materials. They can be a large source of methane emissions if the gas is not captured. Two types of management practices are analysed in this study: landfills that collect landfill gas and landfills that do not collect landfill gas. Captured landfill gas can be flared, or it can be used for a mix of electricity generation and heating, in which case the recovered energy displaces consumption of conventional fuels.[16] There may be limited uses for heat recovered at the facility since it cannot be transported long distances.

85. The life-cycle boundaries include GHG emissions associated with landfill operation and methane emissions from landfills. Our emission factors were developed from methodologies developed in WARM (EPA, 2006b) and IFEU (2009). For landfills that collect gas for electricity generation, we calculated an energy-recovery offset based on the GHG emissions that would have been emitted by generating the same amount of electricity from other fuel sources in each region.[17] [18] Long-term carbon sequestration of landfilling is not included in these emission factors as discussed in Box 1.

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recycling process they assume that recycled products are functionally equivalent and do not include substitution factors.

[16] LFG collected for energy recovery can be used for either electricity generation or direct use as process heat, but we restricted our analysis to consider electricity generation; in other words, we assume that all LFG collected for energy recovery is used to produce electricity.

[17] Electricity generation GHG emission factors were taken from EIA Voluntary Reporting of Greenhouse Gases Program, available from www.eia.doe.gov/oiaf/1605/emission_factors.html, accessed June 1, 2010. See section 4.2 for details. This information is compiled from the International Energy Agency (IEA)'s Electricity Information Database 2007 and CO2 Emissions from EIA's Fuel Combustion Database 2006.

86. **Incineration** is the combustion of solid waste in bulk at high temperatures. It is a waste management option for all waste streams and is comprised of two categories: waste-to-energy systems (WTE) and incineration without WTE. GHG emissions are generated when fossil carbon is incinerated and converted primarily to carbon dioxide. Carbon dioxide emissions from biomass-based materials in MSW can be considered biogenic and excluded if the biomass is sourced from feed stocks that are harvested and replanted on a sustainable basis. With a WTE incinerator, the heat from burning waste can be partially recovered for electricity generation or direct use as process heat. Energy recovery offsets fuel consumption that would otherwise have occurred to generate the same amount of electricity and/or heat.

87. The baseline emission factors for both types of incineration are adapted from methodologies developed by EPA (2006b) and IFEU (2009). Both of these studies develop GHG emission factors based on the GHG emissions from the incineration process, the energy content of the material incinerated, the efficiency of energy recovery by the WTE plant, and an energy-recovery offset based on the GHG emissions that would have been emitted by generating the same amount of electricity or process heat from other fuel sources in each region.[17,19] Carbon dioxide emissions from biogenic sources are assumed to be zero.

88. We assumed that the MSW incinerated would be low in water content. Additionally, we assume that recovered energy is used for a mix of power and heat; as is the case with the landfilling, recovered heat may not always be usable. We assumed that the baseline incineration plants achieve a 10 percent efficiency for electricity generation and a 30 percent efficiency for heat production (Prognos, 2008, p. 44; CEWEP, 2006, p. 22). The carbon intensity of power generation in 2030 is assumed to be unchanged, as well.

89. **Anaerobic digestion** is the decomposition of organic waste by micro-organisms in an oxygen-starved environment, in order to produce a methane-rich gas referred to as biogas. It is a waste management option for organic components of MSW. Anaerobic digestion takes places in an airtight vessel called the digester, in which the pH, temperature, and moisture of the decomposing waste are controlled for optimal methane production. Biogas produced by the digester is then burned in a combined heat and power unit, which displaces the consumption of heat and electricity and associated emissions. The ability to use recovered heat depends on the availability of a nearby demand for heat; this may be challenging—particularly in warmer climates where there is less demand for space heating. After the organic MSW is digested, the remaining fraction is typically landfilled. The long-term sequestration of carbon, which happens when the residual biowaste that does not degrade into biogas is buried in landfills, is not included in the boundaries of the analysis (IPCC, 2007; IFEU, 2009).

90. The emission factor calculation is adapted from IFEU (2009). The factor is developed based on an assumption of the methane generation rate for bulk biowaste, the efficiency of biogas collection and conversion into electricity, and an energy-recovery offset based on the GHG emissions that would have been emitted by generating the same amount of electricity from other fuel sources in each region.[17] Although the inert digestate produced from anaerobic digestion is typically landfilled, we count all of the initial waste diverted to anaerobic digestion as diversion from the landfill. From a GHG emissions perspective, the inert digestate does not produce emissions in the landfill.

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[18] We assume an average landfill gas capture efficiency of 75 percent across all regions. Of the landfill gas captured, we assume that roughly 60 percent is flared and 40 percent is recovered for electricity generation at an efficiency of 25 percent. We assume that 10 percent of methane that is emitted is oxidized to biogenic CO_2.

[19] Heat generation emissions were based on IFEU (2010).

91. As is the case with landfilling and incineration, the emission factor for anaerobic digestion is based on two assumptions: (1) constant carbon intensity for power generation between now and 2030, and (2) that the energy produced is used for electricity generation.[20]

92. Mechanical-biological treatment (MBT) is a series of operations to sort and treat MSW prior to landfilling the biodegradable components and any remaining waste. First, mechanical treatments such as sorting, shredding, and crushing divide the MSW into component-specific fractions for subsequent management. Metals that have not already been extracted from MSW are recycled, offsetting the emissions of primary metal production. Next, waste fractions with high calorific value are removed and processed into refuse-derived fuel (RDF), primarily for use in cement kilns. This co-incineration of RDF displaces the use of other fuels. The organic fractions of the MSW are then biologically stabilised through a prolonged composting process, and the output, an inert compost residue, is landfilled. Methane emissions from landfilling this residue are minimised by the stabilisation process. Impurities in the waste, typically consisting of paper and plastic, are incinerated, and energy recovery is utilised at the incinerator, displacing the use of other fuels. The boundaries of our model of the MBT process encompass all of the various outputs of the MBT process, as well as the process emissions. (IPCC, 2007, p. 602; IFEU, 2009, p. 52)

93. The emission factors for MBT are adapted from a methodology developed in IFEU (2009). The GHG emission factor includes emissions from operating the MBT facility and for landfilling the treated organic components of MSW. It also includes an avoided-emission offset[21] based on the fraction of metals recovered and recycled, and energy recovery from the incineration of impurities and combustion of MSW as RDF. The energy-recovery offset is based on the GHG emissions that would have been emitted by generating the same amount of electricity and process heat from other fuel sources in each region.[22]

94. This emission factor is applicable to mixed MSW entering an MBT facility. We have not tailored this emission factor in our recycling and MBT scenario to reflect the precise composition of waste that is sent to MBT facilities in each region, post-recycling.

95. Source reduction, or waste minimisation, refers to practices that reduce the amount of materials entering the waste stream. It includes changes in the design, manufacture, purchase, or use of materials, and can result from any activity that reduces the amount of a material needed and therefore used to make products. Specific examples of source reduction include: redesigning products to use less materials (e.g., lightweighting, material substitution), reusing products and materials (e.g., refillable water bottles instead of disposable cups), extending the useful lifespan of products and avoiding materials in the first place (e.g. reducing junk mail).

96. The emission factors for source reduction are calculated from the GHG emissions avoided[21] from producing the material and/or manufacturing the product. Source reduction incorporates the stages of the material life-cycle including the "upstream" GHG emissions emitted in the raw material acquisition, manufacture, and transport stages of the source-reduced material. The GHG emission factors for source

[20] We assume an average gas yield of 100 normal cubic meters per metric ton of biowaste processed, containing 60% methane by volume that is captured and converted into electricity at an efficiency of 30% based on IFEU (2009).

[21] For the purposes of this report, avoided GHG emissions are emissions that would have been generated to meet demand for heat, electricity, or the production of materials such as steel and aluminium, but which are offset, or avoided, by energy or material recovery achieved through alternative waste management practices, such as landfill gas energy recovery, incineration, and reuse or recycling.

[22] Electricity generation GHG emission factors were taken from EIA Voluntary Reporting of Greenhouse Gases Program, available from www.eia.doe.gov/oiaf/1605/emission_factors.html. Accessed June 1, 2010. Heat generation emissions were based on IFEU (2010).

reduction of materials in North America are based on U.S. EPA (2006b) and the EPA's Waste Reduction Model (WARM). Source reduction GHG emission factors for Europe are based on Prognos (2008).

97. We did not locate a consistent data source for source reduction GHG emission factors for OECD Pacific/Asia. Consequently, we applied source reduction emission factors that are representative of European practices to this region. This assumption will affect our results depending upon the extent to which upstream production practices or processes for material production in OECD Pacific/Asia are substantially different than Europe. Due to similarities in the level of economic development and infrastructure, we believe that this is an appropriate assumption for an "order-of-magnitude" assessment of the GHG reduction potential.

Box 1. Treatment of Carbon Storage in Landfills, Soils, and Forests

The treatment of changes in carbon storage in landfills, soils, and forests resulting from MSW management practices affects estimates of net GHG emissions and emission reductions. For consistency among the different literature sources used to develop the GHG emission factors used in this study, however, we have not included carbon storage estimates. This section provides an overview of these three sources of carbon storage, and provides an example of the sensitivity of GHG emission factors to the treatment of carbon storage.

Landfill carbon storage occurs because a portion of organic materials placed in landfills does not decay into landfill gas and instead remains in long-term storage within the landfill (IPCC, 2006c, p. 3.23; IPCC, 2007, p. 589; EPA, 2006b, p. 6). It is estimated that as much as 20 million metric tons of carbon were stored in landfills in OECD countries in 2002 (IPCC, 2007, p. 592). Excluding landfill carbon storage reduces the GHG reduction benefits provided by landfilling, and increases the estimated GHG emission reductions of other MSW management practices relative to landfilling. Since the scenarios developed in section 4.5 are defined as alternative management scenarios relative to landfilling without landfill gas capture, the emission reductions provided by these scenarios will be larger than estimates including landfill carbon storage.

Soil carbon storage from the application of compost to land can potentially occur through four pathways: (i) direct accumulation of carbon from compost in soils; (ii) indirect accumulation of other non-compost carbon stimulated by the nitrogen in compost; (iii) the formation of stable carbon compounds, or humic substances, which are resistant to microbial attack and remain in long-term storage within soils; and (iv) composting may lead to a "multiplier effect" by increasing the ability of soils to store carbon from other non-compost sources. (EPA, 2006b, p. 51). Models have been developed to investigate the effects of soil carbon storage and other soil dynamics resulting from organic amendments to soils (Bruun et al, 2006; Coleman and Jenkinson, 2008; NREL, 2006), but the storage effects vary depending on compost and soil characteristics as well as other factors (EPA, 2006, p. 61; Prognos, 2008, p. 40). An in-depth analysis of these effects across all regions was beyond the scope of this assessment. Excluding soil carbon storage from our estimates, however, decreases the total net benefit for composting. As result, we may underestimate the full benefits offered by composting relative to other practices evaluated in this study.

Forest carbon storage can occur when paper or wood products are reduced at source or recycled, reducing the demand for virgin wood. Consequently, trees that would otherwise be harvested are left standing in forests, resulting in a larger quantity of carbon remaining sequestered. In the long term, some of the short-term storage benefits are offset by less planting in new managed forests due to market interactions. Models developed by the U.S. Department of Agriculture's Forest Service have shown that the forest carbon storage benefit can be long-term, lasting for several decades
(EPA, 2006b, p. 41). Miner and Perez-Garcia (2007) estimated that increasing forest stocks in managed forests contribute to storage of 60 million metric tons of CO_2e per year, providing a short- to medium-term carbon storage benefit, although this estimate has a high level of uncertainty (between -50 to +100 percent). Excluding forest carbon storage from our analysis reduces the estimated GHG benefits of recycling and source reduction paper and wood products. As a result, we may underestimate the full benefits offered by recycling and source reduction relative to other practices in this study.

4.4 Baseline Scenarios for MSW Management in OECD Countries

98. This section describes the method we used to develop estimates of baseline MSW management practices in OECD countries. We developed estimates of the following three aspects of MSW generation and management for each of the groups identified in section 4.2:

- The quantity and composition of MSW generated;
- A baseline, or base case, that describes the mix of current MSW management practices; and
- A projection of baseline MSW generation to 2030, assuming that composition and the mix of management practices remain constant.

4.4.1 Quantity and Composition of MSW Generation in Each OECD Region

99. In this report, generation refers to the amount of waste created or produced by a country prior to recycling, landfilling, or any other waste management practice. We defined the generation and composition of MSW for the OECD area by the following sub-regions (as described in section 4.2 above): North America, High-Recycling and Low-Recycling OECD Europe, OECD Pacific, and OECD Asia. Regional waste generation data was taken directly from the OECD Environmental Outlook (OECD, 2008b) for 2005. To estimate the amount of waste generated for the High-Recycling European region and the Low-Recycling European region, the total amount of waste generated in Europe based on OECD (2008b) was scaled by the amount of waste generated in individual countries under each recycling-rated region as found in OECD's Environmental Data Compendium for 2006/2008 (OECD, 2008a).

100. Waste generation by material (in percent of total MSW generation) was then applied to the waste generation totals to develop the amount of waste generated per material category for each region. The waste material categories were determined based on data availability and were applied consistently across the five regions based on IPCC classifications (IPCC, 2006b). The waste material categories used are: food waste, garden waste, paper/cardboard, wood, textiles, rubber/leather, plastic, ferrous metals (*e.g.*, steel), aluminium, glass, and other waste. Because IPCC data do not separate food and garden waste, nor do they separate ferrous and aluminium metals, additional data sources or assumptions were necessary to develop consistent estimates for each region. Information on how the generation percentages were developed for each region is outlined below, and Table 11 provides the final estimates for waste generated by material category in 2005 for each region. Figure 10 illustrates the final MSW waste composition for each region.

101. In addition to estimating MSW generation in 2005, we used OECD projections of generation rates (OECD 2008b) to develop estimates of MSW generation in 2030. These projections are based on estimated annual percentage increases in MSW generation between 2005 and 2030. The results are shown in Table 12, assuming the composition of MSW generation remains constant between now and 2030. The assumptions we used to extrapolate the MSW baseline to 2030 are discussed in section 4.4.3.

Figure 10. Composition of MSW Generated by Region (Percent)

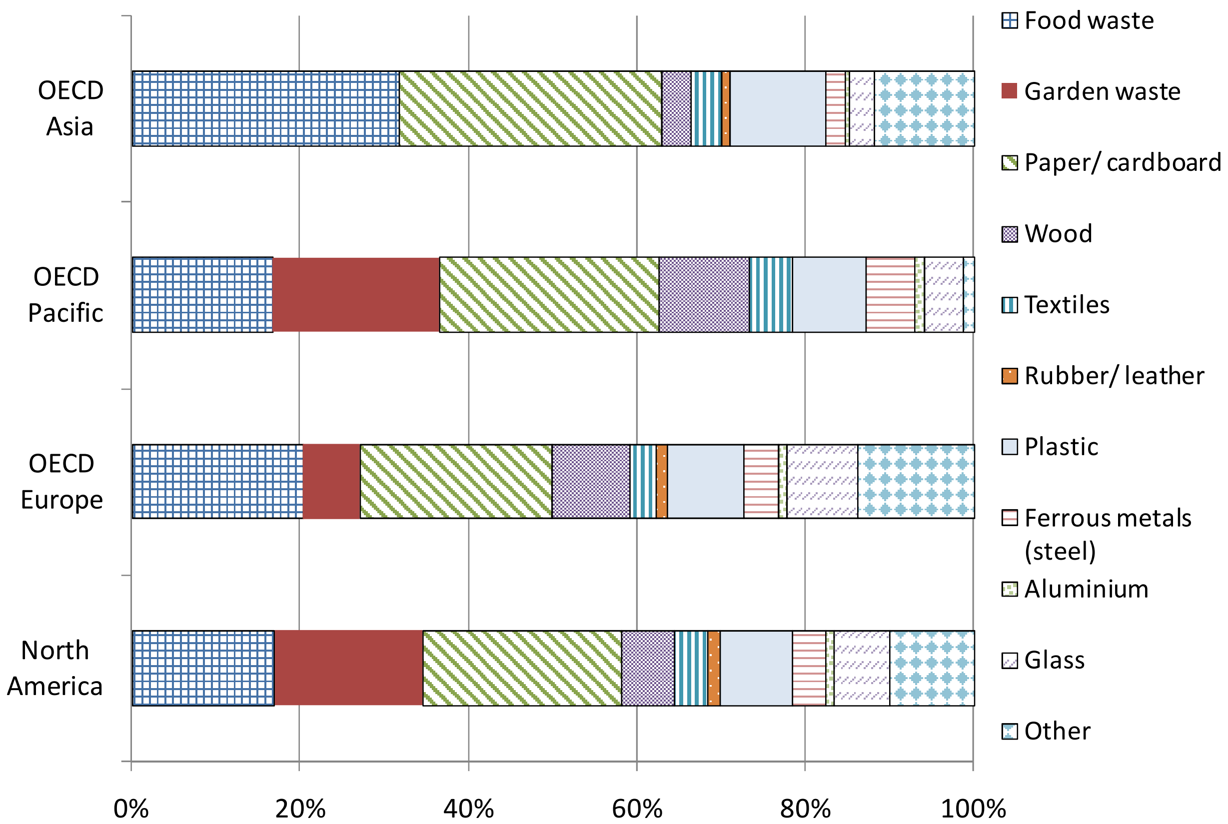


Table 12. Waste Generated by Region and Material Category in 2005 (Million Metric Tons)

OECD Region	Food	Garden	Paper/ cardboard	Wood	Textile	Rubber/ leather	Plastic	Ferrous metals	Alumi-nium	Glass	Other	Total
North America	48	50	67	18	11	4	25	11	3	19	28	284
High-Recycling Europe	34	11	38	15	5	2	15	7	1	14	23	166
Low-Recycling Europe	23	8	26	10	4	1	10	5	1	10	16	113
Pacific	3	3	4	2	1	0	1	1	0	1	0	17
Asia	23	0	23	3	3	1	9	2	0	2	9	74
OECD Total	131	72	158	48	24	8	60	25	6	46	76	654

Table 13. Waste Generated by Region and Material Category in 2030 (Million Metric Tons)

OECD Region	Food waste	Garden waste	Paper/ cardboard	Wood	Textiles	Rubber/ leather	Plastic	Ferrous metals	Alumi-nium	Glass	Other	Total
North America	66	68	92	25	15	6	34	15	4	26	39	389
High-Recycling Europe	48	16	54	22	8	3	22	10	2	20	33	238
Low-Recycling Europe	33	11	37	15	5	2	15	7	1	14	22	162
Pacific	4	4	6	2	1	0	2	1	0	1	0	22
Asia	31	0	30	3	3	1	11	2	0	3	11	97
Total	182	100	219	67	33	12	83	35	8	64	106	908

North America

102. The percent of waste generated by material category in North America was taken from IPCC (2006b). Since IPCC (2006b) does not provide estimates of food waste and garden waste separately, the food waste percentage from IPCC (2006b) was weighted by estimates from EPA (2009a) for U.S. food and garden waste to calculate the percent of waste generated that is food and garden waste for North America. Similarly, to estimate the separate shares of ferrous metal and aluminium generation from IPCC data, the ratio for ferrous and aluminium generation in the United States (EPA 2009a) was used to scale the total metal waste percentage provided by IPCC (2006b). The resulting percentages were then scaled, so that the sum of all material categories was 100 percent.

High-Recycling and Low-Recycling Europe

103. The percent of waste generated by material category in the High-Recycling Europe and the Low-Recycling Europe regions was estimated using data from IPCC (2006b). The waste composition for High-Recycling Europe and Low-Recycling Europe were assumed to be equal. The simple averages of IPCC data for Eastern Europe, Northern Europe, Southern Europe, and Western Europe were used to estimate the generation of food waste, garden waste, paper/cardboard, and wood. Similar to North America, the IPCC data does provide a separate estimate for garden waste; the share of garden waste generated was estimated by scaling the IPCC data by the ratio of garden waste to food waste provided by IFEU (2009) for middle-income European Union countries. The amount of rubber/leather and other waste generated for Eastern Europe as provided in IPCC (2006b) was used for both High-Recycling and Low Recycling Europe regions, while the simple average of estimates from Eastern Europe and Northern Europe were used for textiles, plastic, metal and glass. It was assumed that the ratio of ferrous metal to aluminium metal would be similar to the United States, based on EPA (2009a). The resulting percentages were then scaled, so that the sum of all material categories was 100 percent.

Pacific

104. The percent of waste generated by material category for the Pacific region was assumed to be equal to the waste composition for Australia as presented by Warnken Ise (2007) except for ferrous metals, which included construction and demolition material. Ferrous metals in the Pacific region were assumed to be 5 percent of MSW generation based on data for Australia from the OECD Environmental Data Compendium (OECD, 2008a). The resulting percentages were then scaled, so that the sum of all material categories was 100 percent.

Asia

105. The percent waste generated for food, paper/cardboard, and plastic for the Asia region were estimated by taking the weighted average of those percentages for Japan and South Korea (i.e., OECD Asia) as presented in OECD (2008a). Although there are quantities of garden waste generated from residential and commercial sources, the data were unavailable to determine the amount of garden waste generated. Thus, garden waste generation and food waste were not separated for the OECD Asia region, and were handled jointly as food waste. IPCC (2006b) provided the generation percentages for wood, textiles, rubber/leather, metals, and glass. Metals were broken down into ferrous and aluminium using the same ratio as for North America and European regions, and other waste was estimated to be the remaining amount of waste generated that was not assigned to a category.

4.4.2 Baseline MSW Management Practices in Each OECD Region

106. We developed regional baseline waste management practices for the OECD area by the following sub-regions (as described in section 4.2 above): North America, High-Recycling and Low-Recycling OECD Europe, OECD Pacific, and OECD Asia. These base cases are not in terms of GHG emissions estimates, but are expressed as the quantities of MSW managed by baseline waste management practices. These base cases provide a broad and comprehensive picture of current waste management practices in OECD countries. Table 13 and Table 10 provide the assumed MSW management practice rates employed by region. Further discussion on how these estimates were derived is provided below. Table 14 provides the amount of MSW recycled or composted by material type.

Table 14. Percent of Total MSW Managed by Each Waste Management Practice in the Base Case

OECD Region	Recycling/Composting				Incineration		Landfilling		Other[b]
	Recycling	Composting	Anaerobic digestion[a]	MBT[a]	No waste-to-energy	Waste-to-energy	Gas collection	No gas collection	
North America	20%	10%	0%	0%	0%	11%	30%	28%	1%
High-Recycling Europe	25%	10%	0%	0%	1%	25%	22%	9%	8%
Low-Recycling Europe	5%	10%	0%	0%	0%	7%	50%	21%	7%
Pacific	22%	10%	0%	0%	0%	0%	25%	43%	0%
Asia	25%	2%	0%	0%	0%	55%	8%	4%	6%

[a] OECD-wide estimates of anaerobic digestion and mechanical-biological treatment were not available for base case estimates. MSW is managed by these practices to some extent in OECD countries, but they currently represent a small—but growing—fraction of MSW management practices. In Europe, MBT is now being used in Germany, Austria, Italy Denmark, Belgium, France, and potentially other countries, although total throughput in 2006 was approximately 13 million metric tons in Europe, or less than 5% of MSW generated in the European Union (IPCC, 2007)

[b] Other management practices include intermediate processing; other material recycling and chemical treatment for disposal; hazardous waste treatment; lake, sea, river disposal and burning of waste in open areas; and processing of municipal waste into refuse derived fuel pellets for use as fuel in power production depending on the region.

Table 15. Material-specific MSW Recycling Rates (Percent)a

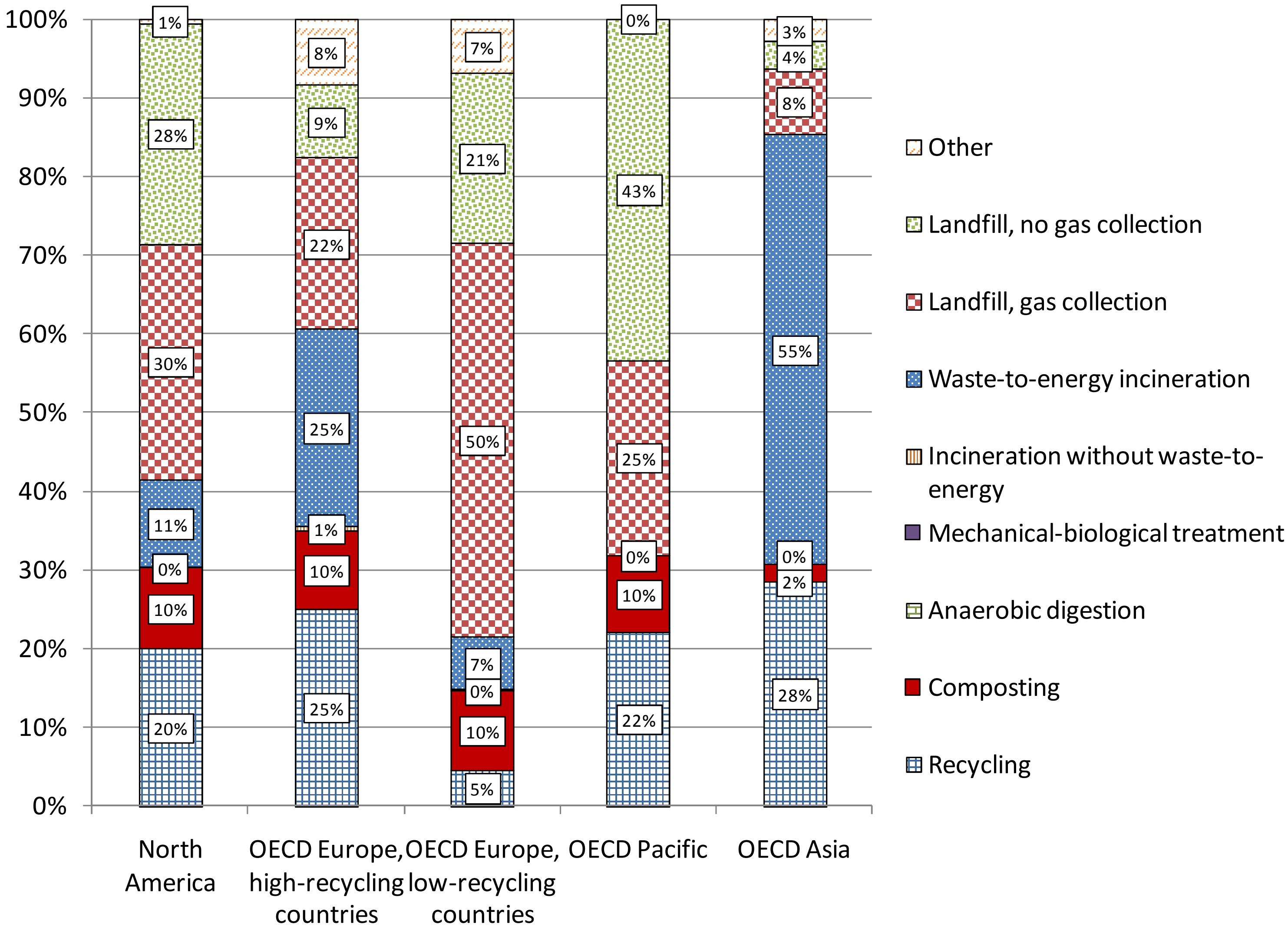
OECD Region	Food	Garden	Paper/ cardboard	Wood	Textile	Rubber/ leather	Plastic	Ferrous metals	Aluminium	Glass	Other
North America	2%	56%	52%	10%	15%	14%	7%	38%	21%	22%	26%
High-Recycling Europe	37%	37%[b]	54%	8%	27%	12%	29%	64%	55%	61%	0%
Low-Recycling Europe	37%	37%[b]	14%	0%	3%	0%	3%	6%	5%	8%	0%
Pacific	10%	41%	56%	21%	20%	0%	11%	21%	12%	40%	0%
Asia	7%	0%	72%	22%	0%	0%	5%	89%[c]	92%[c]	72%	0%

[a]Percent of total amount of each waste type generated, not share of total generation.

[b] Assumes same recycling rate for garden waste as for food waste due to a lack of data on garden waste composting in European countries.

[c] Recycling rates for metals are based on steel and aluminium cans only. Likely overestimates actual recycling rate, since steel and aluminium cans typically have high recycling rates relative to other metal materials

Figure 11. Prevalence of MSW Management Practices by Region (Percent)



North America

107. The percent of waste managed by practice for North America is a weighted average of the practices in the United States, Mexico, and Canada, based on the amount of waste generated in each country. Rates by waste material for the United States were obtained from EPA's *Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2008*(EPA, 2009a). Rates for recycling, composting, anaerobic digestion, and mechanical-biological treatment for Canada and Mexico were obtained from the OECD (2008a) and IFEU (2009), respectively, except for the following: the recycling rates for wood, textiles, rubber and leather, and other were assumed to be the same for Canada and Mexico as for the United States; and the recycling rates for plastics, metals, and aluminium for Canada were assumed to be the same as for the United States. The rate for incineration for Canada was based on IPCC (2006b), but data on the rate of incineration in Mexico were not located. For Canada, the remaining waste was assumed to be landfilled with and without gas collection in the same proportions as the United States. Mexico's landfilling rate was based on OECD data (2008a) and it was assumed that all waste landfilled was at landfills without gas collection. All the rates were then weighted by the baseline waste generated for each country in North America, and the amount of remaining MSW was assumed to be managed under "other" practices.

High-Recycling and Low-Recycling Europe

108. The percent of waste managed by practice for these regions was estimated using several different data sources. Material-specific recycling rates were based on IFEU (2009, p. 18) and OECD data (2008a, Table 4-A-B) and scaled according to the overall recycling rate in the High-Recycling and Low-Recycling regions based on OECD (2008a, Table 2c). Rates for composting were estimated based on the composting rates for the EU-27 from IFEU (2009) and the amount of waste generated for the applicable wastes. These data were only available for food waste, but it was assumed that this rate was also applicable to garden wastes. Insufficient data were located on rates of anaerobic digestion or mechanical-biological treatment in Europe, so the quantity of MSW managed by these practices was assumed to be negligible in the base case. Denmark, Germany, Belgium, and France have implemented anaerobic digestion systems. MBT is now being used in Germany, Austria, and Italy among other countries, although total MBT throughput from all waste sources in 2006 was approximately 13 million metric tons (IPCC, 2007, p. 602), or less than 5 percent of MSW generated in the European Union, suggesting that these practices only handle a small share of MSW currently. Incineration and landfilling rates for each region were calculated the same way as for recycling with one caveat. For landfilling, the rates broken down into with and without landfill gas collection were estimated by weighting the total landfilling rate by the maximum landfill gas capture for OECD countries from Monni *et al.,* (2006) for landfilling with gas collection, and assigning the remaining amount to landfilling without gas collection. The remaining unmanaged waste was assumed to be managed under "other" practices.

Pacific

109. The percent of MSW managed by practice for this region was estimated using several different data sources. Material-specific recycling and composting rates were based on data from Warnken Ise (2007), which provides data for Australia, and these rates were assumed to be representative of the entire region.[23] Data were not located on the current share of MSW managed by anaerobic digestion or MBT (OECD, 2008a; Warnken Ise, 2007); consequently, it was assumed that these practices currently manage a negligible portion of MSW in the Pacific. The rate for landfilling with gas collection was estimated by taking the total landfilling rate estimate from Warnken Ise (2007) and weighting by the amount of landfill

[23] To the extent possible, we excluded non-MSW waste streams that were included in the Warken Ise estimates; however, the estimates used to develop the Australia baseline may include some non-MSW streams.

gas collected in Australia as reported in Australia's national inventory submission to the UNFCCC (Department of Climate Change, 2009). The amount remaining from the total landfilling rate from Warnken Ise (2007) was then assumed to be landfilling without gas collection. The landfilling rates were calculated such that the sum of MSW management practices covered 100 percent and the amount of waste estimated to be recycled. Again, the rates for Australia were assumed to represent the entire region. No waste was assumed to be managed under "other" practices.

Asia

110. The percent of waste managed by practice for the region was estimated by weighting the practices by country by the amount of waste generated in each country. Recycling rates for Japan and South Korea (i.e., OECD Asia) were calculated from data provided in the OECD (2008a). The composting rate for Japan was taken from Tekes Tokyo (2004) and it was assumed South Korea represents a negligible amount of recycling relative to Japan. No data were found to indicate that Japan or South Korea use anaerobic digestion or MBT, so these rates were assumed to be zero. Based on data from the OECD (2008a), all incinerated waste was assumed to be in waste-to-energy facilities and this overall rate was calculated using the implied rates for Japan and South Korea from the same data source. Landfilling rates for these countries were also taken from OECD data (2008a), but we applied the maximum landfill gas capture for OECD countries from Monni *et al.,* (2006) to the these rates to estimate the landfilling with landfill gas collection versus without landfill gas collection. The amount of remaining waste unallocated to one of these waste management practices was assumed to be managed under "other" practices.

4.4.3 Extrapolation of MSW Baseline to 2030

111. We extrapolated waste generation by material type to 2030. The current waste management practice rates, their relative contributions to overall waste management, and the relative contribution of each material type to overall waste generation were held constant. Thus, for example, existing policies that will increase landfill gas collection were not taken into account. As discussed in section 4.4.1, Figure 10 provides the waste generation projections for each region in 2030. We used OECD projections of generation rates (OECD 2008b) to develop estimates of MSW generation in 2030 based on estimated annual percentage increases in MSW generation between 2005 and 2030.

4.5 Alternative Scenarios for MSW Management and Calculating GHG Emission Benefits

4.5.1 Describing the Alternative Scenarios for MSW Management Practices

112. This section analyses eight alternative scenarios to existing MSW management practices in 2030 to estimate potential GHG emission reductions. Table 15 presents the eight alternative scenarios that we evaluated, and the MSW materials included in each scenario. To the extent possible based on available literature, each alternative scenario describes the "technically-achievable potential" of implementing each waste management practice.

113. We define "technical potential" as the extent to which each option could be technologically achievable and fully implemented by 2030, largely irrespective of potential limitations posed by economic, institutional, political, and behavioural barriers. We chose to specify technical potential scenarios because they are useful in providing an "order-of-magnitude" estimate of the upper bound of GHG mitigation potential, which was the goal of this analysis. We based these estimates on existing studies that investigated upper-bounds on the implementation of MSW management practices over a similar timeframe as our study. The assumptions behind each scenario are summarised in Table 15.

114. In addition, we assumed that each alternative scenario can be applied to the same extent across all regions. This is a reasonable assumption for technical potential scenarios, which focus on technological

limitations. The economic, institutional, political, and behavioural factors that are not explicitly addressed in these scenarios are likely to have a greater effect on regional targets. Also, this approach enables an assessment of the full mitigation potential in each region, comparing current waste management practices to a common target.

115. Each scenario models a waste management practice being set to a technical potential limit. Except for the recycling and composting or, separately, the recycling and anaerobic digestion scenarios, each alternative scenario is mutually-exclusive and non-additive from other scenarios. Also, as the scenarios are based on technical potential limits for each individual practice, we have not equalised scenarios for the level of effort involved. That is, we have not attempted to assess the economic or logistical feasibility of these scenarios or compare them in regard to level of effort required – both scenarios simply reach the technically potential limits that we have established.

116. While these scenarios describe technical potentials for alternative management of MSW, specific products and materials may offer additional opportunities to further reduce GHG emissions within the MSW. For example, Box 2 describes reductions that can be achieved by recovering high-global warming potential (GWP) gases from refrigerated appliances. Evaluating the full range of GHG reductions on a product-specific level was beyond the scope of this report, but the case study in Box 2 provides a qualitative example of additional benefits available from SMM practices.

Box 2. Additional Options for Increasing GHG Benefits from End-of-Life Materials Management: Recovering High-GWP Gases from Refrigerated Appliances

While this analysis is focused on material MSW streams, additional GHG emission reductions can be quantified based on a product-focused analysis. In particular, household refrigerated appliances—including refrigerators, freezers, window air-conditioners (ACs), and dehumidifiers—represent a significant source of potential GHG emission savings through the recovery of high-global warming potential (GWP) refrigerants and foam blowing agents at time of equipment disposal.

Older refrigerators/freezers, window ACs, and dehumidifiers contain ozone-depleting refrigerants, including chlorofluorocarbons (*e.g.*, CFC-12) and hydrochlorofluorocarbons (*e.g.*, HCFC-22), which are also potent GHGs. Indeed, these substances have direct global warming potentials (GWPs) up to 10,900—meaning that they are up to 10,900 times more effective at damaging the climate system than carbon dioxide (CO2) on an equal mass basis. In addition, older refrigerators/freezers also contain ozone-depleting blowing agents (*e.g.*, CFC-11, HCFC-141b) used in foam insulation. Although refrigerants and foam blowing agents used in newly manufactured units do not deplete the ozone layer, many are potent GHGs covered under the Kyoto Protocol (*e.g.*, HFC-134a). The table included in this box compares the GWPs for these gases.

Given that an old refrigerator/freezer can contain up to 0.23 kg (0.5 pounds) of CFC-12 refrigerant and 0.45 kg (1 pound) of CFC-11 foam blowing agent,[24] the disposal of each unit represents the potential emission of up to 4.6 MTCO2e.[25] In light of the large stock of refrigerators, freezers, window ACs, and dehumidifiers in use throughout OECD countries, the responsible disposal of these products is critical for minimising GHG emissions. For example, in the United States alone, where roughly 9 million refrigerators/freezers are disposed of annually (EPA, 2008a), up to 41.8 million MTCO2e can be avoided through proper recovery of refrigerant and foam from household refrigerators/freezers.

Currently, all OECD countries legally require the recovery of high-GWP refrigerants and some (*e.g.*, EU, Japan) also mandate the recovery of high-GWP foam blowing agents. But in many cases, these gases may be released at equipment end-of-life due to limited mandates, poor regulatory enforcement, inadequate infrastructure, and/or lack of economic incentives.

In addition to the GHG benefits that can be realised through proper disposal of high-GWP refrigerants and foams contained in refrigerated household appliances, additional environmental benefits can be realised by recycling the durable components and ensuring the safe disposal of hazardous materials, such as mercury, PCBs, and used oil—all of which may be contained in old refrigerators/freezers.

Characteristics of Gases Used as Refrigerants and Foam-Blowing Agents in Household Appliances Reaching End-of-Life

Compound	GWP	Predominant Use in Appliances
CFC-11	4,750	Foam
CFC-12	10,900	Refrigerant
HCFC-22	1,810	Refrigerant
HCFC-141b	725	Foam
HFC-134a	1,430	Refrigerant

*GWP calculations are based on the 100-year direct GWPs provided in the IPCC (2007). GWP values are relative to CO_2, which has a GWP of 1.

[24] This is the typical size of units in the United States; units used in Europe and Japan are significantly smaller, and may contain roughly half the amount of refrigerant and foam per unit.

[25] It should be noted that not all of this original charge remains at equipment end-of-life or is technically recoverable from the unit.

Table 16. Alternative MSW management scenarios, relative to baseline waste management practices

No.	Scenario	Description	Applicable Material(s)	Assumptions	Sources / Notes
1	Recycling	All recyclable materials are recycled at their technically-achievable rates.	All MSW recyclables	Technical-potential recycling rates are distinct for each material type: paper/cardboard: 85%, wood: 60%, textiles: 50%, plastic: 40%, ferrous metals: 95%, aluminium: 87%, glass: 85%. Recycling is assumed to divert MSW in constant proportions from baseline rates of landfilling (with and without gas collection) and incineration.	Rates are taken from Prognos (2008).[26] Rates for rubber/leather and 'other MSW' are set equal to baseline due to lack of data on technical potential recycling limits.
2	Composting	All food and garden waste materials are composted at technically achievable rates.	Food and garden waste	80% of food and garden waste is composted, diverting in constant proportions from baseline rates of landfilling (with and without gas collection) and incineration.	Rates are from Prognos (2008)
3	Anaerobic digestion with energy recovery	All food and garden waste materials are anaerobically-digested at technically achievable rates.	Food and garden waste	80% of food and garden waste is anaerobically digested. All of the waste that would have been composted is sent to anaerobic digestion, and the remainder is diverted in constant proportions from baseline rates of incineration and landfilling (with and without gas collection) of organic waste are evenly reduced.	Anaerobic digestion rates are taken from Warnken Ise (2007). We assume that all waste fractions that were collected for composting can be wholly diverted to anaerobic digestion
4	Recycling and Mechanical Biological Treatment (MBT)	All recyclable materials are recycled at their technically-achievable rates; MBT is applied to the technically-achievable portion of remaining MSW for additional recovery before it is landfilled or incinerated.	All MSW recyclables and food and garden waste	Recycling rates are identical to Scenario 1. Out of the remaining MSW, 75% is processed by MBT, and 25% is sent to landfilling (with and without gas collection) and incineration in constant proportions to baseline rates of landfilling and incineration.	IFEU (2009, p. 52-53), estimates that 25% of MSW processed by MBT cannot be sorted and is sent for disposal in landfills.

[26] In developing scenarios for future solid waste practices in 2030, Prognos (2008) considered policy drivers and economic market forces. We based our recycling rate technical potentials on the most aggressive scenarios in this study, which defined "strict and ambitious" policy drivers coupled with "additional market influences and dynamics" that favor the recovery and reuse of MSW materials (p. 26). We assumed that these scenarios could be applied to MSW and would achieve close to technical-potential limits of recycling.

No.	Scenario	Description	Applicable Material(s)	Assumptions	Sources / Notes
5	Increased landfill gas capture efficiency and collection	Aggressive landfill gas collection systems that collect landfill gas at highest technically-achievable rate are applied across all operating landfills where gas collection is technically feasible.	Paper, wood, food and garden wastes	The amount of MSW sent to landfills remains at its current rate in each OECD region; however, all landfills are equipped with LFG collection systems. A technical-potential LFG capture efficiency of 87% is achieved at all landfills.	Monni *et al.,* (2006) describes how 100% of landfills could be outfitted with LFG collection. The capture efficiency is taken from Barlaz *et al.,* (2009) for aggressive landfill gas collection over 100 years.[27]
6	Increased landfill gas energy recovery	Energy from landfill gas is recovered for electricity generation at the highest technically-achievable collection efficiency across all operating and closed landfills where gas collection is technically feasible.	Paper, wood, food and garden wastes	This scenario uses all of the assumptions from Scenario 5. In addition, it is assumed that 100% of recovered LFG is utilised for electricity generation.	We assumed that it is possible to scale up electricity generation at landfills so that all captured LFG is utilised for this purpose.[28]
7	Incineration	Combustible materials are sent to highly-efficient incineration facilities at the highest technically-achievable rate.	Plastics, rubber, paper, textiles, wood and other combustible MSW materials	Recycling and composting rates are maintained at each OECD region's baseline levels, and remaining waste is incinerated at waste-to-energy facilities up to a maximum MSW incineration rate of 85%, diverting from landfilling (with and without gas capture). The resulting energy is harnessed in combined heat and power units, with 50% of the energy recovered for heat and 16% recovered for electricity.	The incineration rate is taken from Monni (2006). We find that, in each OECD region, most remaining waste after composting and recycling is sent to WTE incinerators, resulting in landfilling of only non-combustible MSW fractions. Optimised energy recovery through combined heat and power is detailed in eunomia (2008).
8	Source reduction	The generation of non-organic waste is reduced at a technically feasible source reduction rate, through policies and practices that reduce materials use and disposal. Food and garden waste were not evaluated due to a lack of data.	All MSW materials	All material waste except for food and garden waste and 'other MSW' are reduced by 30% by 2030 relative to baseline practices. The reduction results in a uniform diversion from all MSW disposal pathways.	Source reduction rates are taken from ILSR (2008), which uses a 1% annual source reduction rate.

[27] Corresponds to regions receiving more than 63.5 cm (25 inches) precipitation annually. Regions with wetter conditions will exhibit lower landfill gas collection efficiencies.

[28] Landfill gas capture may also be used for direct-use applications (*e.g.*, process heat), but this analysis focused exclusively on landfill gas collection for electricity generation.

4.5.2 Method for Calculating GHG Emission Reductions

117. To calculate the mitigation potential for each alternative scenario, we multiply the quantity of MSW (separated out by multiple material types) managed by each practice by that practice's corresponding material-specific GHG emission factors. We then take the difference in these results for the baseline and each alternative scenario to calculate the net change in GHG emissions for each practice. The total change in GHG emissions is equal to the sum across all practices.

118. For example, consider a hypothetical scenario where a region generates 100 metric tons of MSW in 2030, landfilling 70 percent of this waste and recycling 30 percent in the baseline. Assume that landfilling generates 0.25 metric tons of CO_2e per metric ton of MSW landfilled from landfill methane emissions, and recycling reduces GHG emissions by 0.5 metric tons of CO_2e per metric ton recycled by offsetting energy and emissions from products that would otherwise have been manufactured from virgin materials. We would estimate the GHG emission reductions associated with switching to a scenario where 60 percent of the MSW is recycled and 40 percent landfilled with the following calculation:

$$E_{landfilling} = 100 \times 0.25 \times (40\% - 70\%) = -7.5 \text{ metric tons } CO_2e$$
$$E_{recycling} = 100 \times (-0.5) \times (60\% - 30\%) = -15 \text{ metric tons } CO_2e$$
$$E_{total} = -7.5 + (-15) = -22.5 \text{ metric tons } CO_2e$$

119. This result shows that the change from landfilling to recycling reduces 7.5 metric tons of CO_2e from avoiding GHG emissions produced by landfilling MSW and an additional 15 metric tons of CO_2e from emissions savings associated with recycling to provide a total net reduction of 22.5 metric tons CO_2e.

4.6 Results of GHG Mitigation Potential for Alternative MSW Management Scenarios

120. The results of this analysis are presented in two separate graphs. First, the results are shown in terms of the *effectiveness* of each scenario, or the average amount of GHG emissions reduced for each metric ton of MSW diverted from baseline practices in 2030. Second, the results are shown in terms of the *absolute* reduction in GHGs across each scenario. Together, the results show which practices are most effective at reducing GHG emissions and the total amount of GHG reductions achievable when each scenario is exercised to its technically-achievable potential.

121. Figure 12 presents the *effectiveness* of each scenario in terms of the average amount of GHG emissions reduced for each metric ton of MSW diverted from baseline practices in 2030. In the recycling scenario for example, each additional metric ton of MSW diverted to recycling reduces GHG emissions by 1.3 to 2.7 metric tons of CO_2 on average across the OECD regions.[29] Similarly, source reducing one metric ton of MSW materials reduces GHG emissions by 1.3 to 2.5 metric tons of CO_2 on average.[30]

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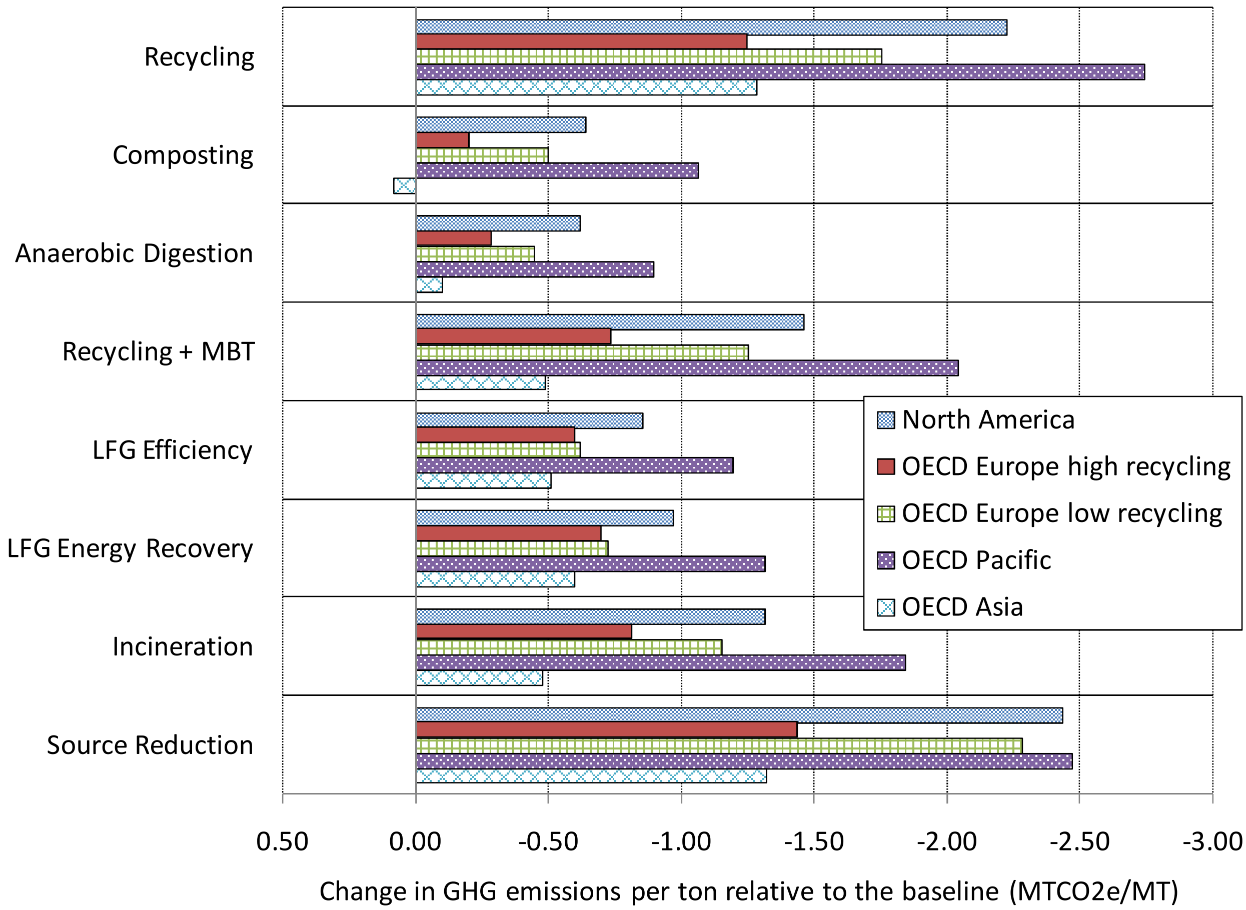
[29] Although we present our results in terms of average GHG reductions per metric ton of MSW, the underlying calculations account for the composition of materials recycled (e.g., the amount of paper, wood, textiles, plastic, steel, aluminium, and glass recycled). The material-specific recycling rates assumed are provided in Table 15. Refer to Appendix C for the material-specific emission factors used in this analysis.

[30] Source reduction is the most effective practice in every region except OECD Pacific region, where recycling is more effective than source reduction. This counter-intuitive result occurs because diverting MSW from recycling to source reduction yields less GHG reductions than diverting MSW from landfills with no gas collection to recycling. Since a large fraction (43 percent) of MSW is landfilled without gas collection in OECD Pacific, and source reduction diverts waste in constant proportions from recycling and landfilling, the recycling scenario (which diverts waste entirely from landfilling) is slightly more effective than source reduction in this region.

Figure 12. Change in GHG Emissions Per Metric Ton of MSW Diverted to Alternative MSW Management Scenarios Relative to Baseline Practices in 2030 across OECD Regions[31]



122. The results in Figure 12 show that, across all regions, the source reduction or recycling scenarios provide the highest reduction in GHG emissions per metric ton of MSW diverted. On average, increasing energy recovery from LFG collection and incineration scenarios provide moderate GHG reductions per metric ton, while the composting and anaerobic digestion scenarios provide the least amount of reductions.

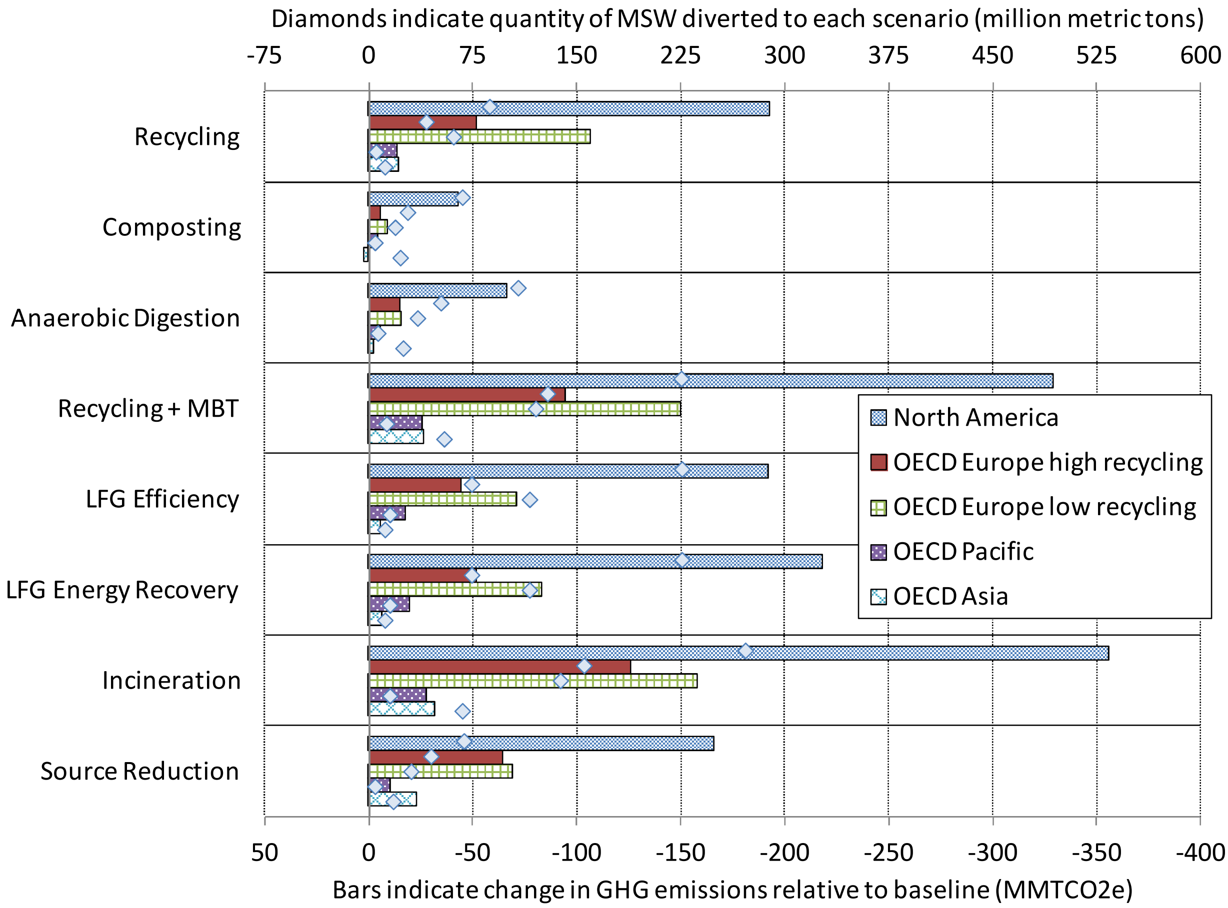
123. The variation in the effectiveness of each waste management practices across the different regions in Figure 12 is driven by the different baseline practices in each region. For example, OECD Pacific and North America achieve a higher reduction per ton of MSW diverted than other regions largely because more MSW is currently sent to landfills without gas capture in these regions; as a result, each metric ton of MSW diverted to alternative MSW practices provides a larger reduction in GHGs than in OECD Europe and OECD Asia.

124. Figure 13 provides the *absolute* GHG reduction potential for each technically-achievable alternative MSW management scenario, relative to baseline practices in each OECD region in 2030. The results of Figure 13 are not meant to imply a ranking of the different scenarios and management practices; this is represented by the *effectiveness* of each scenario, as shown in Figure 12.

[31] Refer to Appendix C for a list of key assumptions that influence the results in each scenario.

125. Instead, Figure 13 incorporates both the GHG reductions per metric ton of MSW diverted and the total amount of MSW diverted in each scenario to yield a range of *absolute* GHG reductions achievable across the scenarios. The result is an order-of-magnitude estimate of the life-cycle GHG reductions achievable from implementing alternative MSW management practices.

Figure 13. Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030 across OECD Regions[32]



126. Interestingly, the incineration, recycling + MBT, and LFG energy recovery scenarios in Figure 13 achieve large reductions in GHG emissions, even though these scenarios were less effective on a per-metric ton basis in Figure 12. The driver behind this counter-intuitive result is that these practices act upon a large portion of MSW, whereas source reduction and recycling materials are constrained by our assumptions of technically-achievable waste prevention and recycling rates in each scenario.

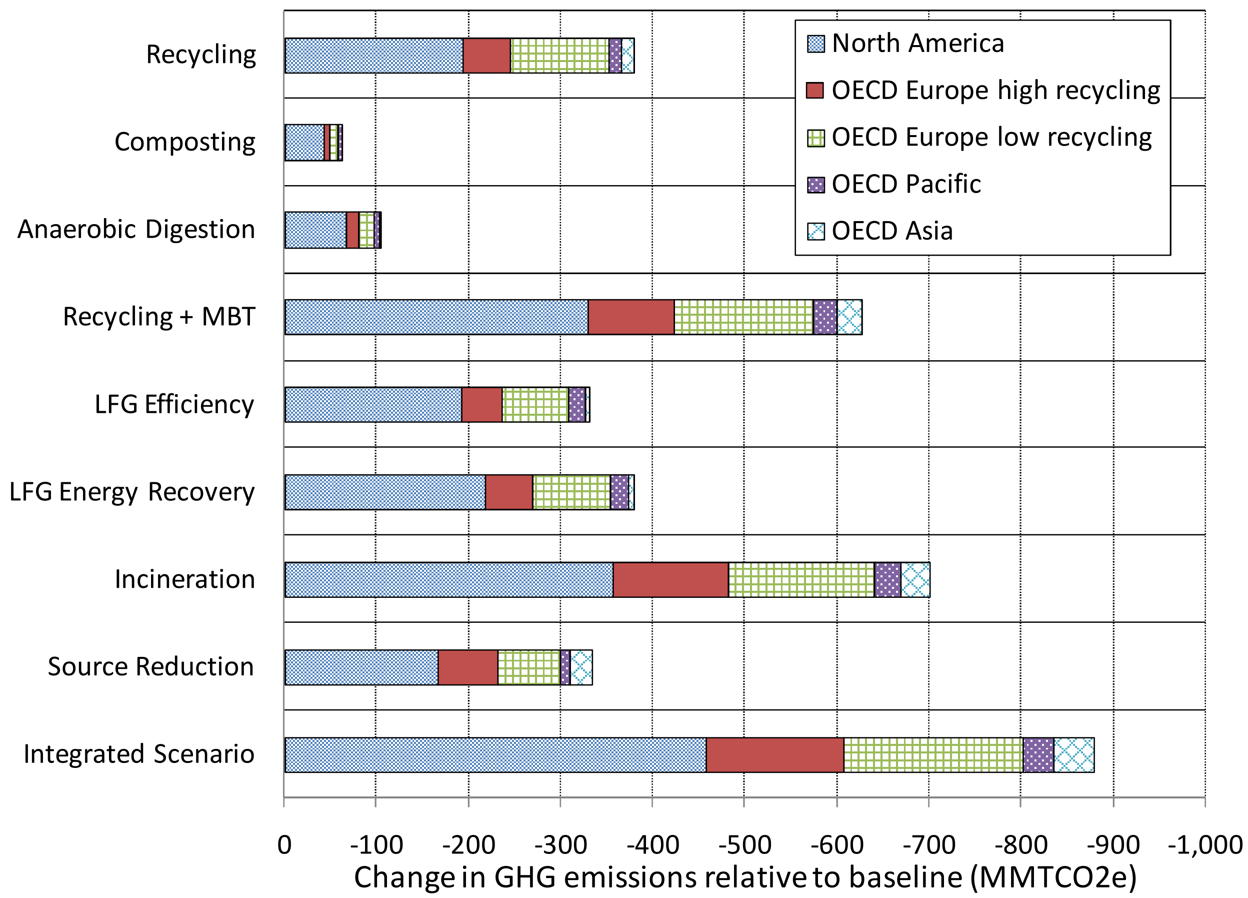
127. This result does not suggest that incineration is the best waste management option to achieving GHG reductions from MSW management practices. It does, however, highlight that scenarios which affect

[32] The results shown in Figure 13 account for both the potential GHG reductions per metric ton of MSW diverted and the total amount of MSW diverted in each scenario. Since different scenarios act on different shares of total MSW, absolute GHG mitigation potentials are larger for practices that act on a large share of MSW. This does not mean that practices that yield large reductions are the most *effective* at reducing GHG emissions. The *effectiveness* of each option is shown in Figure 12.

a wide range of materials can achieve large absolute GHG reductions by acting on fractions of MSW that other, more *effective* practices may not be able to recover due to technical limitations.

128. To demonstrate this point, we developed a final integrated scenario. In this integrated scenario, MSW generation is reduced by 30 percent across all OECD regions in 2030. Recycling and composting are maximised,[33] and the remaining fraction is sent to highly-efficient incineration facilities with energy recovery. This integrated scenario represents a combination of the most *effective* management practices (i.e., source reduction and recycling), and practices that reduce GHG emissions by acting on the remaining MSW (i.e., incineration). The GHG reductions from the integrated scenario are shown in Figure 14 relative to the other scenarios; each bar represents total GHG reductions in each scenario, with the reductions in each region shown in different shading within each bar. In the integrated scenario, life-cycle GHG emissions are reduced by 878 MMTCO2e relative to the 2030 baseline, which is 177 MMTCO2e—or 16 percent—greater than the 700 MMTCO2e reduction achieved by the incineration scenario across all OECD regions. In this scenario, an integrated combination source reduction, recycling, composting, and incineration achieves a larger reduction than any individual practice.

Figure 14. Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030 across OECD Regions



[33] The technical potential recycling rates are adjusted by 30 percent from the values in Table 15 to account for source reduction in the integrated scenario. In each region the recycling rates for paper/cardboard, wood, textiles, plastics, ferrous metals, aluminium and glass are: 58, 41, 34, 27, 65, 59, and 58 percent. Food and garden waste composting rates are 80 percent in each region.

129. Also, it is important to note that the relative magnitude of mitigation between the different regions is a consequence of the volume of waste generation in each region. Other regional differences, such as baseline waste management practices have a much smaller effect. This doesn't mean that the opportunity for GHG reductions is lower in these regions—indeed Figure 14 shows that diverting one metric ton of MSW to recycling in the OECD Pacific yields the highest reductions of all OECD regions. For example, mitigation potential is the highest in North America, but this is the result of its total waste generation being the highest of the five regions. At 389 million metric tons, North America's projected waste generation is 63 percent higher than that of OECD Europe high recycling countries, and nearly 18 times that of Australia and New Zealand (i.e., OECD Pacific) combined.

130. Key findings from the results presented in Figure 12 and Figure 13 include the following. Note that these findings are subject to several assumptions and caveats that are summarized in further detail in section 4.6.2 and Appendix C.

a) Source reduction and recycling are the most effective way of reducing GHG emissions per metric ton of MSW diverted from baseline practices. This result is driven by the GHG emission factors compiled for the MSW management practices in each region. These factors are provided in Appendix D, and the sources of these factors are discussed in Section 4.3. On average, the increasing energy recovery from LFG collection and incineration scenarios provide moderate GHG reductions per-metric ton, while the composting and anaerobic digestion scenarios provide the least amount of reductions.

b) Scenarios affecting a wide range of material types can have a large impact on GHG mitigation potential by managing the remaining fraction of MSW alongside aggressive diversion to the most effective practices such as recycling and source reduction. Incineration, for example, is a scenario that encompasses all combustible waste fractions, and, accordingly, presents extensive mitigation potential. Recycling and MBT, similarly, encompass all waste fractions and present GHG mitigation potential close to that of incineration. This does not imply that these practices are the best waste management options to achieving GHG reductions from MSW management practices, but it highlights that scenarios that affect a wide range of materials can achieve large GHG reductions by acting on fractions of MSW that other, more effective practices may not be able to recover due to technical limitations.

c) **The combined life-cycle reduction in GHG emissions from alternative MSW practices relative to baseline practices in 2030 across OECD member countries ranges from 701 $MMTCO_2e$ in the incineration scenario to 331 $MMTCO_2e$ in the landfill gas efficiency scenario.** Separately, the composting scenario achieves 61 $MMTCO_2e$ in reductions across all regions, while the anaerobic digestion scenario achieves 105 $MMTCO_2e$ in reductions. Alongside the recycling scenario, these scenarios separately achieve 440 $MMTCO_2e$ and 484 $MMTCO_2e$ respectively.[34] [35] [36]

[34] The estimated reductions in GHG emissions do not include landfill carbon storage. As a result, we may underestimate the GHG benefits provided by landfilling relative to other practices. See Box 4.1 for a discussion of carbon storage issues.

[35] Although we have used a consistent methodology to ensure that the GHG emission factors for each practice across the different regions are generally comparable, they have been drawn from different sources representing the different regions in our study. Care should be taken in comparing these emission reductions across regions, acknowledging that there may be methodological differences in the calculation of emission factors for each region.

d) **Integrated MSW management practices achieve the largest GHG reductions—larger than any single practice.** An integrated scenario that maximised source reduction and recycling (i.e., the most *effective* MSW management practices at reducing GHG emissions per ton of waste diverted) and diverted the remaining MSW to highly-efficient incineration facilities with waste-to-energy recovery achieved a total GHG reduction of 878 $MMTCO_2e$. This is 177 MMTCO2e—or 16 percent—higher than the largest GHG reduction achieved by individually implementing MSW practices to their technical potential limit.

e) **A substantial share of the total reduction in GHG emissions provided by the incineration scenario results from the assumed efficiency increases in energy recovery.** We assumed that the baseline incineration plants achieve a 10 percent efficiency for electricity generation and a 30 percent efficiency for heat production (Prognos, 2008, p. 44; CEWEP, 2006, p. 22), and that optimised combined heat and power plants could achieve efficiencies of 16 percent for electricity production and 50 percent for heat production (eunomia, 2008, p. 39).[36] [37] This assumption influences roughly a quarter of the total GHG reductions from incineration in North America, low-recycling OECD Europe, and OECD Pacific. For high-recycling OECD Europe and OECD Asia, where landfilling is less dominant, energy recovery from incineration represents a larger share of the total GHG benefits; consequently the assumed increase in incinerator energy-recovery efficiencies provides 40 and 75 percent of the total GHG reduction benefit in high-recycling Europe and Asia, respectively.

f) **Although anaerobic digestion and composting appear to have relatively less impact on GHG mitigation, these two scenarios can each be added separately to the recycling scenario because they affect entirely different streams of MSW.** When added to recycling, the total GHG reductions from these options are comparable to the other scenarios, but still less than the reductions achieved by recycling and MBT.[38]

g) **Recycling rates in the recycling scenario are 40 to 45 percent of total MSW generation; the variation in these rates is largely a result of different waste compositions across the five regions.** This scenario does not include an increase in the biological treatment of organic waste by composting or anaerobic digestion. Combining either one these processes at their technically-feasible recovery levels with recycling would raise the total recycling rate to 64 to 74 percent.[39]

h) **Nearly all of the scenarios result in GHG emission reductions; that is, they are beneficial strategies.** Only one exception stands out, and that is the composting scenario in OECD Asia, which leads to an increase in emissions of 2 $MMTCO_2e$ as a result of MSW being diverted away from incineration with energy recovery. This result is largely due to two factors: (i) WTE incineration in OECD Asia recovers a portion of the energy from combustion for electricity

[36] The emissions reductions estimated for management practices with energy recovery (i.e., landfilling with energy recovery, incineration, and anaerobic digestion) are influenced by the assumption that recovered energy offsets electricity generation at a marginal GHG emissions rate. See section 4.2 for details.

[37] The ability to use recovered heat depends on the availability of a nearby demand for heat; this may be challenging—particularly in warmer climates where there is less demand for space heating.

[38] The estimated reductions for composting exclude additional benefits provided by carbon storage in soils; as a result we may underestimate the full benefits of composting relative to other options. See Box 4.1 for a more detailed discussion of carbon storage issues.

[39] GHG benefits from recycling do not include additional benefits from forest carbon storage. As a result, we may underestimate the full benefits of recycling relative to other options. See Box 4.1 for more information.

generation, and (ii) the exclusion of soil carbon storage from the calculation of mitigation potential, as discussed in Section 4.3, reduces the GHG benefits from composting.

i) **Each scenario represents a dramatic break from current MSW practices for most regions**. For example, in the source reduction scenario, countries generate 18 percent less MSW in 2030 than in the baseline. This is only 6% higher than what they generate today, even with continued population and economic growth. These examples provide a sense of the stringency of these scenarios, although we have not assessed the economic costs and benefits associated with these efforts in this study.

4.6.1 GHG Mitigation Potentials by OECD Region

131. This section assesses the results of the model for each region, examining the scenario results in each region individually. The results are shown below in Figure 15 to Figure 19 and key findings are summarised below. The graphs show the contribution of the various waste management practices to the GHG reduction potential within each scenario and region. However, the graphs do not display the net reduction. For example, the source reduction scenarios do not subtract out the losses from recycling.

Figure 15. North America - Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030

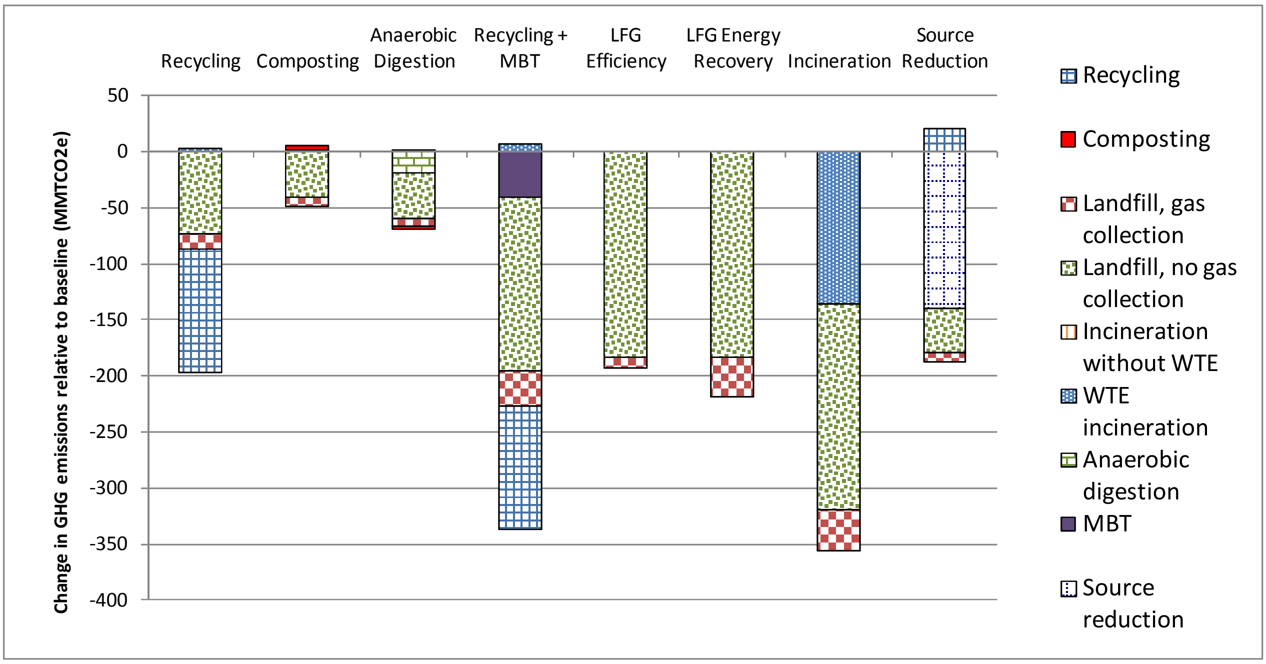


Figure 16. OECD Europe High Recycling Countries - Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030

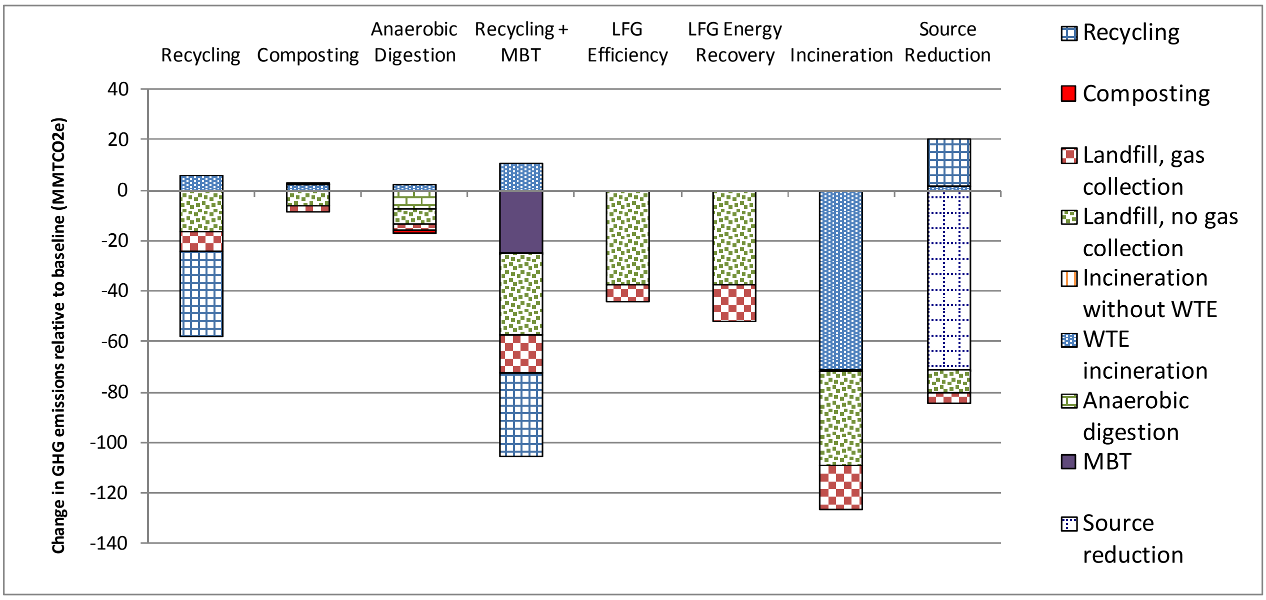


Figure 17. OECD Europe Low Recycling Countries - Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030

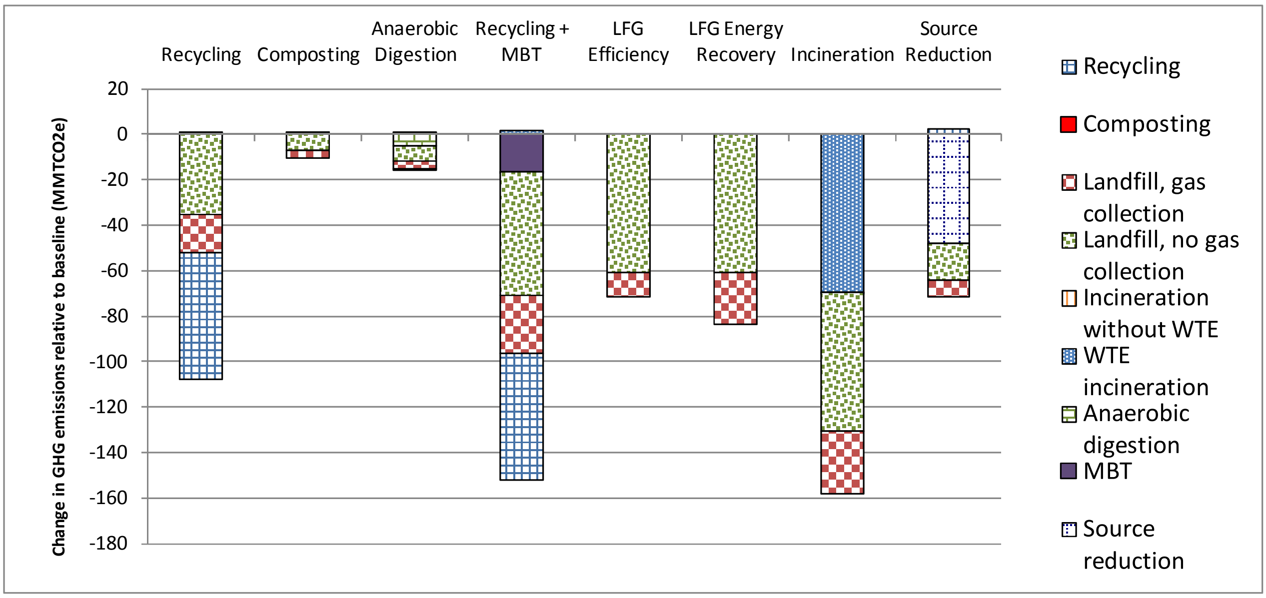


Figure 18. Australia and New Zealand (i.e., OECD Pacific) - Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030

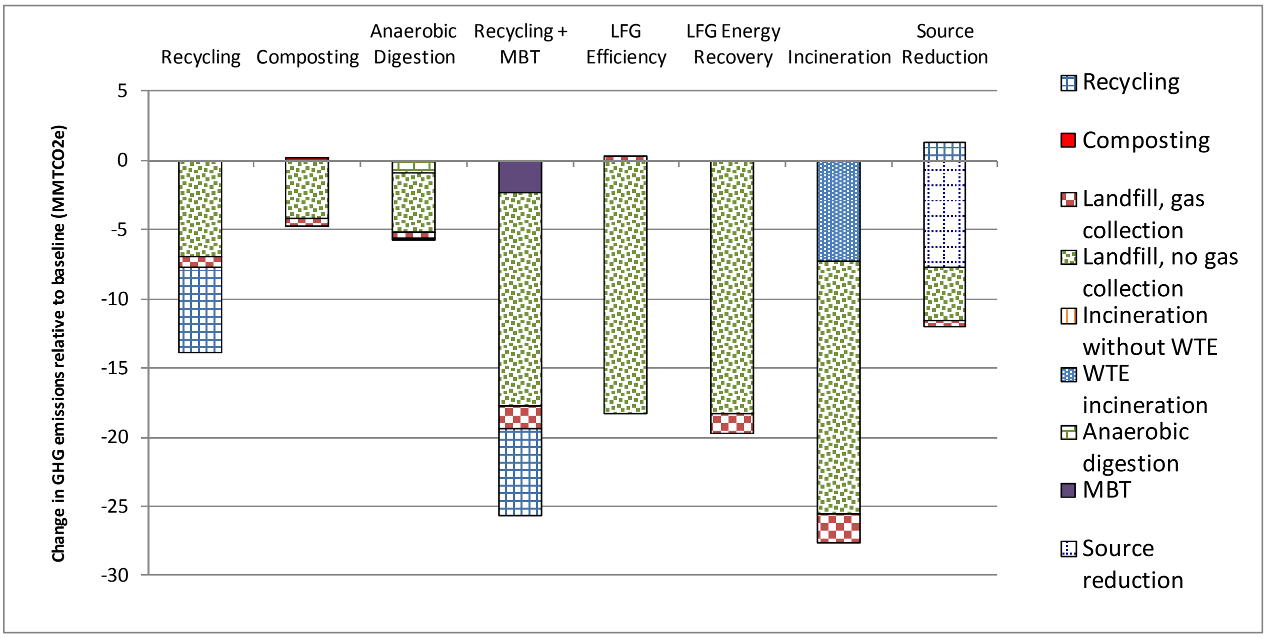
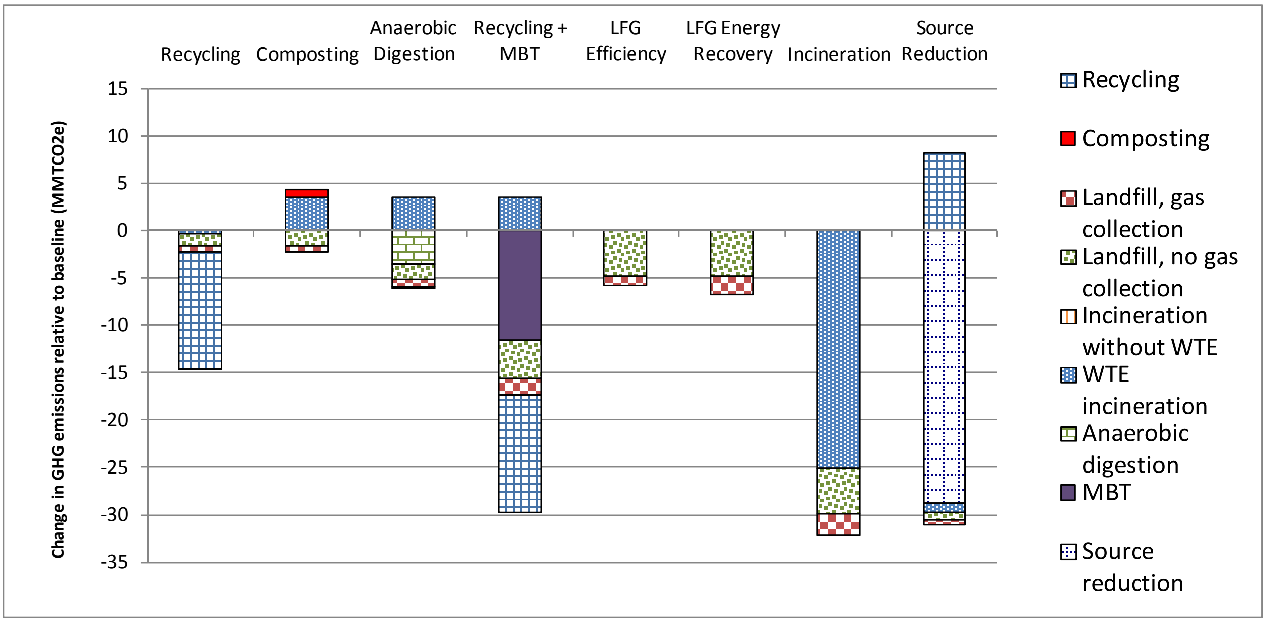


Figure 19. Japan and Korea (i.e., OECD Asia) - Change in GHG Emissions Relative to Baseline MSW Management Practices Resulting From Implementation of Alternative MSW Management Scenarios in 2030



a) In each region, the large reductions offered by the incineration and recycling and MBT scenarios reinforce the finding that scenarios which affect a wide range of MSW materials achieve large GHG reductions. These results do not imply that incineration is the most effective option for reducing GHG emissions from MSW. Instead, the results show that options which affect a large amount of waste can contribute to significant GHG reductions on remaining waste fractions alongside more effective options such as recycling and source reduction.

b) At a regional level, the sources of GHG reductions are influenced by baseline management practices. For example, in North America and OECD Pacific, diverting the waste that would have gone to landfills without LFG collection contributes to a large fraction of the GHG reductions across the different scenarios. This stems from the fact that, in the baseline, a large percentage of MSW in these regions is sent to landfills without LFG capture systems. On the other hand, in OECD Europe and OECD Asia, the reduction in landfill emissions is much lower, and the benefits from waste minimisation, resource recovery, and waste-to-energy recovery play a larger role. This is because relatively little waste is sent to landfills in the baseline in these regions.[40]

c) Source reduction offers a large potential for GHG reductions. In all regions, source reduction significantly reduces GHG generation by avoiding upstream extraction and manufacturing and landfilling emissions, even as the reduction in the volume of recycling actually appears as an increase in GHG emissions.[41]

d) Increasing recycling rates in regions with lower rates can provide a sizable reduction in emissions. For North America, OECD Pacific, and OECD Europe low recycling countries, the increase in recycling rates to the technical potential is significant, and results in extensive GHG reductions. Accordingly, increased recycling is more beneficial in these regions than source reduction (at the assumed technical potential limit of 32 percent).[42]

e) In most of the regions, paper and cardboard recycling generates most of the GHG mitigation of the recycling scenario. This is due in large part to paper and cardboard constituting a large fraction of MSW. Furthermore, in countries with high landfilling rates in the baseline, paper and cardboard generate high amounts of methane emissions in landfills. In contrast, plastic recycling is the largest source of GHG mitigation in OECD Asia's recycling scenario results, stemming from a low baseline recycling rate for plastics since most plastic in this region is incinerated in the baseline. This benefit would be even higher if forest carbon storage was included.[41]

f) In all regions, the anaerobic digestion scenario is shown to have more GHG mitigation potential than the composting scenario. While both scenarios divert organic waste from landfills[43] composting produces GHGs during the decomposition process. While these are lower emissions than would be produced by landfilling the waste, composting is a net GHG-generating process

[40] The estimated reductions in GHG emissions do not include landfill carbon storage to ensure consistency across the different data sources used to develop the emission factors (taken from box 4.3). As a result, we may underestimate the GHG benefits provided by landfilling relative to other practices. See Box 4.1 for a discussion of carbon storage issues.

[41] GHG benefits from source reduction and recycling do not include additional benefits from forest carbon storage. As a result, we may underestimate the full benefits of recycling relative to other options. See Box 4.1 for more information.

[42] It should be noted, however, that food waste, which can have a potentially large impact on this result could not be modelled due to a lack of data. The GHG emissions that are linked to the production of food are very significant and the inclusion of food waste into the model could therefore alter the result in favour of source reduction.

[43] Inert digestate from anaerobic digestion is landfilled after energy recovery. Therefore, although the digestate does not produce GHG emissions in the landfill, it does contribute some amount of the diverted material back to the landfill.

based on the exclusion of soil carbon storage. [44] In contrast, anaerobic digestion generates methane from decomposition to utilise in electricity generation, offsetting energy use elsewhere in the grid. It is thus a net GHG-reducing process.

g) The results show an increase in emissions from diverting MSW from incineration in the composting, anaerobic digestion, and recycling and MBT scenarios. This is because diverting organic waste from WTE incineration reduces the benefit of offsetting energy use through WTE, thus increasing emissions. This is most notable in OECD Asia, where a high percentage of MSW is sent to WTE incineration in the baseline. The slight increase in GHG emissions from reduced WTE incineration is more than made up for by savings in energy use from recycling, and energy recovery from anaerobic digestion, however.

132. Either of these options can be combined with recycling, since recycling and biological treatment affect completely separate waste streams. With recycling and anaerobic digestion implemented together, for example, absolute GHG mitigation reaches approximately 65 to 80 percent of what is possible through the recycling plus MBT scenario.

4.6.2 Considerations in Interpreting the Results of This Study

133. This analysis sought to establish an "order of magnitude" assessment of the GHG mitigation potential from MSW management practice across the OECD. Given the different categories and definitions of MSW across OECD countries and the data gaps—in particular between material-specific recycling rates and overall recycling rates in each region, and the need for consistent life-cycle boundaries and treatment of effects such as carbon storage—the results of this study are subject to a number of important limitations and caveats[45]. Even so, we have taken care to ensure that the results are consistent with the overall goal of evaluating the "order-of-magnitude" GHG potential.

134. The following caveats should be noted when interpreting the results of the model:

- The baseline in 2030 assumes no change in current waste management practices. We recognise that there are already policies and voluntary programs in place in OECD countries that will continue to increase the implementation of alternative or improved waste management practices. Our baseline therefore underestimates the extent to which alternative practices, such as recycling, composting, and waste-to-energy recovery, will be in place by 2030 even without any additional policies to promote these practices.

- The eight scenarios modelled are, for the most part, stand-alone waste management scenarios. Each scenario sets a specific management option to a technical potential level of adoption, and must thus be examined independently. The scenarios do not combine waste management strategies; nor should they be viewed additively because each works with the same quantity and composition of waste, distributed across the various waste management practices for each region depending on the scenario's technical potential. The exceptions to this are the composting and anaerobic digestion scenarios, which can each separately be added to the recycling scenario since they deal with entirely separate streams of MSW.

[44] The estimated reductions for composting exclude additional benefits provided by carbon storage in soils; as a result we may underestimate the full benefits of composting relative to other options. See Box 4.1 for a more detailed discussion of carbon storage issues.

[45] The main assumptions used in the analysis to determine the GHG abatement potential are presented in Appendix B.

- Each scenario models a waste management practice being set to a technical potential limit. We based these estimates on available literature and on bottom-up analyses of potential limits based on material-specific or—in the case of landfill gas collection and incineration—technology-based estimates and assessments. As the scenarios are based on technical potentials, we have not equalised scenarios for the level of effort involved. For example, the recycling scenario, combined with biological treatment of organics (composting or anaerobic digestion), achieves a recycling rate of 64 to 74 percent, while the incineration scenario results in up to 85 percent of MSW being incinerated. Both of these scenarios realise dramatic changes in MSW management practices from existing conditions in most OECD member countries, but we have not attempted to assess the economic or logistical feasibility of these scenarios or compare them because of the significant level of effort required for such an analysis. Both scenarios simply reach the technically potential limits that we have established.

- Although we have used a consistent methodology to ensure that the GHG emission factors for each practice across the different regions are generally comparable, they have been drawn from different sources representing the different regions in our study. To the extent that these factors' life-cycle boundaries are not entirely consistent, it may not be appropriate to compare these results directly to one another.

- Apart from the integrated scenario,[46] we assume that MSW materials that are not diverted to recycling or biological treatment (*i.e.*, composting, anaerobic digestion or MBT) are managed by landfilling (with and without gas collection) and incineration according to the relative proportion that MSW is landfilled or incinerated in the baseline. In other words, we did not make assumptions about which specific materials would be sent to incineration versus landfilling, nor did we combine scenarios—for example, assuming higher rates of recycling *and* incineration of the remaining waste fractions.

- We also assume that the same technically-achievable potentials are applicable across all OECD regions, because there should be little difference in technological limitations from region to region. Economic and policy-influenced drivers and barriers will likely differ across OECD regions, however, and these aspects will play a critical role in determining the future MSW management options eventually realised by these regions.

- Our emission factors assume that the GHG reductions from alternative MSW management practices scale linearly according to the quantity of MSW managed by each practice. It is likely that there will be non-linear effects and interactions among the broad changes in MSW management defined by our future scenarios. These effects will influence the GHG emission reductions achieved, but it is difficult to determine the extent to which these interactions will affect our GHG reduction estimates, and whether they will increase or decrease our results.

- Also, GHG emission factors for Europe are taken from Prognos (2008), a study produced by a coalition of European waste management associations, potentially involving commercial bias.

- The emissions reductions estimated for management practices with energy recovery (i.e., landfilling with energy recovery, incineration, and anaerobic digestion) are influenced by the assumption that recovered energy offsets electricity generation at a marginal GHG emissions rate. See section 4.2 for details. In addition, the ability to use recovered heat through combined

[46] The integrated scenario assumes that materials which are not reduced at source, recycled, or composted are diverted to highly efficient waste-to-energy incineration.

heat and power applications depends on the availability of a nearby demand for heat; this may be challenging—particularly in warmer climates where there is less demand for space heating.

- We did not locate a consistent data source for recycling and composting GHG emission factors for OECD Pac-Asia. Consequently, we applied recycling and composting emission factors that are representative of European practices to this region. This assumption will affect our results depending upon the extent to which recycling and composting practices or processes in OECD Pac-Asia are substantially different than Europe. Due to similarities in the level of economic development and infrastructure, we believe that this is an appropriate assumption for an "order-of-magnitude" assessment of the GHG reduction potential.

- We restricted our assessment to MSW management practices within OECD regions only and did not take into account the effect of future scenarios on international imports or exports of waste within or outside of OECD countries.

- We assessed the technical potential of source reduction as a steady decline in total MSW generation based on estimates from ISLR (2008). In our model, this reduction in waste is assumed to apply evenly to all material types, resulting in the same waste composition.

Box 3 briefly discusses the results as compared to those in related assessments.

Box 3. Comparison of the Results of this Study with Similar Assessments

The goal and approach of this study are similar to assessments performed by Prognos (2008), U.S. EPA (2009b), and the European Environment Agency (forthcoming), and this report incorporates data sources that were also used in these assessments. There are differences, however, in the scope, methodology, and assumptions of this study that make it difficult to draw direct comparisons with the results of these other assessments. Here, we summarise the key findings of each study and discuss some of the key differences and considerations in relation to this assessment.

Prognos (2008), in cooperation with IFEU and INFU, assessed potential GHG reductions from waste management options in Europe using a set of economic and policy-driven scenarios. The study found that "the total CO2 emission reduction achievable until 2020 in the four scenarios ranges between 146 and 244 million metric tons CO2e" (p. 12). These reductions are in addition to reductions in GHG emissions from existing baseline management practices. Key differences between the Prognos study and this report are that it assessed the reductions achievable from a total of 18 waste streams encompassing categories broader than MSW, and assumed that waste generation remains constant between 2004 and 2020 in order to assess reductions from equivalent amounts of waste. In addition, the scenarios developed in the Prognos study evaluated a mix of different practices under future economic and policy conditions, whereas our results consider technical potential reductions from different MSW practices separately.

EPA (2009b) evaluated the GHG reduction potential from a set of "technical potential" materials management scenarios in 2006, including source reduction, recycling, composting, and WTE recovery. The study found that increasing the national MSW recycling rate in the United States from 33 percent to 50 and 100 percent in 2006 could reduce life-cycle GHG emissions by 80 and 300 million metric tons CO2e, respectively. Incinerating all currently landfilled MSW could reduce GHG emissions by up to 120 million metric tons of CO2 in 2006, and capturing and recovering energy at all methane emitted from U.S. landfills in 2006 could reduce GHG emissions by up to 150 million metric tons CO2e.

Key differences between the EPA (2009b) study and this report include the following:

- EPA (2009b) assessed GHG emissions reductions from U.S. MSW generation in 2006, while this report evaluates reductions across a larger volume of MSW, encompassing all of North America in 2030.

- The recycling scenarios evaluated by EPA (2009b) assumed a different mix of materials recycled compared to this report. For example, a smaller amount of paper recycling was assumed in the EPA's 50 percent recycling scenario; as a result, the benefits from avoided landfill methane emissions from recycling paper are likely much smaller relative to this study.

- The EPA (2009b) study included carbon storage estimates, while this report excluded landfill, soil, and forest carbon storage estimates to ensure consistency across the different data sources used to develop the emission factors.

- The landfill gas recovery scenario evaluated GHG reductions from recovering landfill gas emitted from U.S. landfills in the year 2006, while this study assesses the life-cycle GHG reductions from recovering landfill gas from materials that are sent to landfills in the year 2030.

The European Environment Agency (EEA) and its Topic Centre on Sustainable Consumption and Production are about to release a new study on MSW and GHG emissions. The study investigates the development of MSW generation, treatment and associated GHG emissions in the EU, Norway and Switzerland in the years between 1990 and 2020.

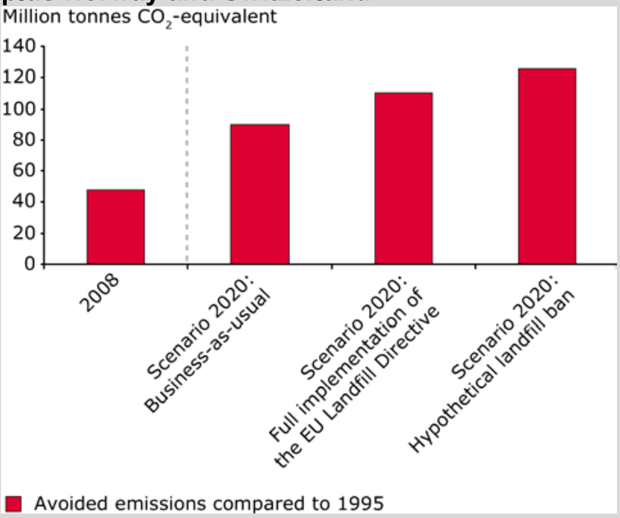
The study adopts a life-cycle perspective on waste management: The model used takes into account direct GHG emissions arising from MSW management activities like incineration, landfilling, recycling, waste transport, as well as GHG emissions that are avoided because recycled materials and energy recovered from the MSW replace virgin materials and energy. The model is based on reported data on MSW generation and management in Europe.

The results of this modelling exercise show the considerable relevance and potential of good MSW management for GHG mitigation: the policies put in place in the EU, promoting better waste management (increased recycling, reduced landfilling) are also responsible for a significant reduction in MSW-related GHG emissions. According to the baseline scenario that takes into account only existing policies and current trends, the net (direct + avoided) GHG emissions are reduced by 92 million tonnes of CO_2-eq between 1995 and 2020. Emissions avoided through recycling and the reduction of methane emissions from landfills contribute most to this development. Two more scenarios, one assuming the full implementation of the EU Landfill Directive, and the other one assuming a total landfill ban for all MSW by 2020 across the EU, show even higher reduction potentials.

The life-cycle approach to waste management shows that the environmental influence of MSW management in other sectors of the economy is substantial. The implemented or planned European waste policies improve not only the MSW management but help also to achieve the commitments for GHG reduction. Given the fact that MSW in Europe represents only about 8-9 % of all waste, the potential for climate change mitigation through improved management of all waste becomes even more important.

The methodology of this report was not assessed, but it appears that the orders of magnitude of GHG reductions that it provides are broadly in line with the findings of this report.

GHG emissions avoided due to better management of municipal waste in the EU27 (exc. Cyprus[47]) plus Norway and Switzerland



Source: European Environment Agency (2011), Waste opportunities - Past and future climate benefits from better municipal waste management in Europe

As a result of the differences between these three these studies relative to the analysis in this report, it is difficult to directly compare the results. Given that the goal of this study was to establish an order-of-magnitude estimate of potential reductions, however, the overall findings of this study are roughly of the same order of magnitude as the results of the Prognos, EEA and EPA studies. By applying a similar methodology of evaluating life-cycle GHG reductions from waste management activities, this study contributes a broader assessment across regions and management practices that complements the results of these previous studies.

[47] Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus" issue.

Footnote by all the European Union Member States of the OECD and the European Commission: The Republic of Cyprus is recognized by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

4.7 Discussion of Costs

135. This section briefly discusses the cost implications of implementing the various waste management alternatives discussed in the previous sections. Although a rigorous quantitative analysis of economically efficient options for mitigating GHG emissions from waste management alternatives is beyond the scope of this report, it is useful to describe the costs associated with waste management alternatives across different regions. The goal of this discussion is to provide useful information that could support further economic analyses of the GHG mitigation potential from MSW management practices.

136. Costs of waste management options vary considerably even within a region and are affected by markets for secondary materials and the status of the global economy. However, Table 16 presents a snapshot of the costs of current practices based on an investigation across relevant literature.

Table 17. Range of costs associated with implementation of waste management options; all values shown per metric ton of waste managed

Source	Landfilling	Composting[1]	Incineration	MBT	Anaerobic Digestion	Recycling[1]	Region
eunomia (2002)[2]	€6-164	€0-189	€21-326	--	€35-109	--	EU15
IPCC (2007), pp. 603-604[3]	€10-160 ($9-147) €56 ($52) avg	€20-170 ($18-156); €35 ($32) - open-windrow operations; €50 ($46) - in-vessel processes	€20-150 ($28-140); €64 ($59) - avg	€90 ($83)	--	--	EU
IFEU (2009)[4]	€3-5 without gas collection; €12-20 with gas collection; €15-25 BS + landfill	€20-40	€90-150	€40-60 - MBT + further treatment + landfill;	€60-90 ("digestion")	€0-5 (of dry waste)	EU
EPA (2008b)[5]	--	--	--	--	--	$115-155 two-sort collection; $100-300 single stream collection	United States

[1] For both recycling and composting, note that the revenue from the sale of recycled materials and finished compost can offset the costs of collection and processing. The composting estimates for eunomia (2002), for example, include revenue from the sale of compost.

[2] eunomia (2002) attempted to summarise cost of MSW management options (i.e., actual costs to managers, not gate fees or tipping fees charged by these operators) for each EU 15 country. The wide ranges in the estimates result from varying local conditions in different countries and different assumptions, boundaries, annual amount of MSW managed. For composting, for example, the lower bound is for composting garden waste in Denmark (including revenue from sale of compost); the upper bound is for composting using a drum reactor for biowaste in Finland at 13,000 metric tons/year, excluding revenue.

[3] IPCC (2007) is based on EC (2001). According to IPCC (2007), these estimates reflect "fees (including taxes) for countries with data" (p. 603).

[4] IFEU (2009) is based on data from Eunomia (2002). BS = biological stabilisation.

[5] EPA (2008b) is an example of average costs of curbside collection of recyclables to a typically community. Two-sort collection involves source separation of recyclables into two streams (typically containers and paper fractions) at the source of waste generation (e.g., household or commercial institution). Single-stream collection involves collection of all recyclables in a single, commingled stream. Range in costs reflects different diversion estimates and frequency of collection. Does not include processing costs at the Material Recovery Facility Estimates are in U.S. dollars.

137. As shown in the table above, the boundaries of the relative waste management options affect the ultimate cost of a particular option. Table 16 captures the wide range of costs across various regions and MSW management practices, but it is difficult to characterise the costs of particular MSW practices. A number of factors influence cost estimates across regions, management practices, and over time in response to changes in other sectors. The estimates in Table 16 provide representative estimates drawn from a few recent studies, but detailed economic assessments of the GHG benefits from MSW and other waste management practices will require more sophisticated economic models that account for complex interactions between costs, benefits, and the implementation of alternative waste management practices. Some of the most important considerations in future economic analyses include:

a) **Scope and type of costs.** The cost of MSW management will depend upon a number of factors including the stakeholders involved in the management process, the cost and revenue structure for each stakeholder, and the contractual arrangements between stakeholders. Consequently, the costs to a municipality may not be equivalent to the actual costs of processing MSW, and, similarly, the gate fees (or tip fees) charged by a private waste manager (*e.g.*, a landfill or incinerator operator) may be higher or lower than the marginal cost of processing additional waste.[48] As a result, it is important to determine whose costs are being modelled in economic analyses, and to ensure that representative cost data is used.

   It is also important to ensure that costs reflect consistent cost and revenue components across different management practices. Including or excluding revenue from the sale of products produced from MSW management practices (*e.g.*, recycled materials, electricity or heat recovered from waste-to-energy practices) will influence the estimate cost per ton. For example, the range of costs for composting in Table 4.8 reflects both estimates that have included revenue from the sale of finished compost, and estimates that have not included revenue.

   Finally, although MSW is encompasses wastes that are produced from residential, commercial, institutional, and certain industrial sources (e.g., packaging and administrative wastes that are sent to MSW landfills), most municipalities are not responsible for collection and management of non-residential wastes. Commercial, institutional, and industrial sources will typically contract separately with private waste haulers and/or recyclers to handle this waste. Therefore, the waste management costs borne by municipalities may only reflect residentially-generated waste, while commercial, institutional, and industrial sources of MSW are handled separately.

b) **Regional differences, including geographic characteristics and existing domestic policies or voluntary programs.** Regional characteristics can influence the economics of waste management options. For example, alternative waste management practices may be more competitive in areas with greater population density since landfill costs are higher in areas with high population densities and low land availability. National or regional fiscal and regulatory policies can also influence the costs of management practices through mechanisms such as taxes, incentives, and permitting requirements.

c) **Dynamic economic effects.** Large-scale changes in waste management practices—such as the scenarios introduced in this study—will have broad economic effects that will influence the net costs of waste management practices. Modelling these effects can be challenging, but they may have important implications for economic assessments. Examples of these dynamic effects include the following:

   i. Changes in the quantity of waste set for disposal in landfills and incinerators will affect the fees charged by operators of these facilities;

   ii. Recycling rates in OECD countries affect the supply of secondary materials and the prices for these materials on secondary materials markets;

   iii. The economics of waste-to-energy recovery systems will be affected by changes in electricity prices;

[48] See eunomia (2002, pp. 7-9) for a discussion of factors that can influence gate fees relative to the costs of providing waste management services.

iv. Waste imports and exports will be affected by the availability of alternative management options in other countries and global demand for materials.

d) **Technological innovation and market penetration.** Waste management technologies will continue to improve over time, lowering the costs of collection and processing MSW streams, or improving the performance and efficiency of certain technologies. The results of this study showed the significant GHG reductions achievable from efficiency improvements in incinerators and landfill gas capture plants, for example (see section 4.6). The availability and rate of adoption of new technologies will depend upon factors such as facility and equipment lifetimes, rates of turnover, the availability of new technologies at a commercial scale, and the level of investment available for new capital equipment and research and development. Over time, improvements in performance and efficiency can help lower costs and increase the competitiveness of MSW practices that realise GHG benefits, and these improvements will be important to capture in economic models of future MSW management opportunities. For example, advancements in screening equipment and optical sorting technologies may also help improve the efficiency and the quality of recyclables processed in Material Recycling Facilities (MRFs) (Egosi and Weitzman, 2010)

e) **The timing of GHG emissions resulting from waste management practices.** Due to the integrated nature of GHG emissions from waste management practices, it is important to evaluate reductions over the life-cycle of materials and end-of-life management pathways. Often, however, GHG emission reductions that result from a change in waste management practices do not occur within the same year as the change in practice (*e.g.*, avoided landfill methane emissions from recycling or composting MSW instead of landfilling). Since some of the benefits from implementing alternative waste management practices accrue in the future, it may be important to account for the timing future GHG reduction benefits in economic models. (Egosi and Weitzman, 2010).

138. Although this study has not attempted to evaluate the economic potential for life-cycle GHG emission reductions from MSW management practices, a recent study by Monni *et al.,* (2006) evaluates the relative benefits of various waste management alternatives in terms of costs and mitigation potentials with respect to methane emissions from landfills. This study evaluated emissions reductions in the waste sector (which are primarily a result of landfill methane emissions) using two different modelling approaches to develop future MSW management scenarios. First, the authors developed a set of dynamic emissions scenarios that considered existing policy measures and changes in waste management systems, as well as the timing of GHG emissions from landfills. Second, they use a partial-equilibrium economic model[49] (the Global TIMES model) to develop economic potential scenarios that optimise emissions reductions in 15 world regions in 2030.[50]

139. A summary of their study is shown in the following table from Monni *et al.,* (2006) (Table 17). Monni *et al.,* (2006) calculated the maximum landfill gas mitigation potentials of different waste management options at five different marginal emission reduction cost levels. The table evaluates reductions from a baseline scenario that assumes (1) waste generation will increase with growing

[49] A partial equilibrium model seeks to adjust prices until supply equals demand for one specific market (in this case, the waste sector) in isolation from other sectors of the economy.

[50] This second approach defines maximum economic potentials for each country, and does not consider increased recycling options (Monni *et al.*, 2006, p. 30) or the time lag in methane generation from landfills (p. 37).

population and GDP (using SRES scenario A1 data[51]), (2) waste management practices will not change significantly, and (3) landfill gas recovery and utilisation will continue to increase at the historical rate of 5 percent per year in developed countries. The estimates were generated using the Global TIMES model, with data taken primarily from EPA (2006a).

140. The table displays the reduction potential of landfill methane emissions by measures whose unit cost is below the overall marginal emission reduction cost level ($0, $10, $20, $50, or $100 per metric ton of CO_2 equivalent). The quantity of emission reductions possible is categorised by waste management option and region, where "OECD" designates OECD countries not included in the economies in transition category, "EIT" designates economies in transition, and "Non-OECD" designates countries included in neither the OECD nor the EIT category (*i.e.* developing countries). For example, the table shows that a reduction of 43 $MMTCO_2e$ of methane is possible in OECD countries using Landfill Gas Recovery for energy at costs below $10 per metric ton of CO_2e reduced.

141. The figures indicate that substantial emission reductions can be achieved at low or zero costs. More significant reductions would be possible at higher marginal costs, due mostly to the additional mitigation potential of thermal processes for waste-to-energy. The model indicates that a 535 $MMTCO_2e$ global reduction is possible at a marginal carbon cost of $0, and a 1,369 $MMTCO_2e$ global reduction is possible at costs at or below $100 per ton of CO_2e.

[51] Data on population and GDP projections were taken from IPCC's Special Report on Emissions Scenarios' Scenario A1, which is described as a future world with very rapid economic growth and a global population that peaks in mid-century and declines thereafter.

Table 18. GHG reduction potential of landfill methane emissions by waste management alternative and by various marginal costs in year 2030

Waste management practice	Region	MMTCO_2e of CH_4 reduced USD/metric ton CO2e $0	$10	$20	$50	$100
Anaerobic digestion	OECD	0	0	1	5	5
	EIT	0	0	0	20	24
	Non-OECD	0	0	30	68	95
	Global	0	0	31	94	124
Composting	OECD	0	0	0	0	3
	EIT	0	0	0	6	19
	Non-OECD	0	0	0	58	81
	Global	0	0	0	64	102
Mechanical biological treatment	OECD	0	0	0	0	0
	EIT	0	0	0	0	0
	Non-OECD	0	0	0	0	19
	Global	0	0	0	0	19
LFG recovery - energy	OECD	27	43	41	23	22
	EIT	56	29	15	0	0
	Non-OECD	328	368	306	138	43
	Global	411	440	362	162	65
LFG recovery - flaring	OECD	0	6	1	0	0
	EIT	0	17	0	0	0
	Non-OECD	0	12	0	0	0
	Global	0	34	1	0	0
Waste incineration with energy recovery	OECD	124	222	237	266	266
	EIT	0	101	156	156	140
	Non-OECD	0	0	166	515	653
	Global	124	323	558	936	1,059
Total	OECD	151	270	280	295	296
	EIT	56	147	171	182	182
	Non-OECD	328	380	501	779	890
	Global	535	797	953	1,255	1,369

142. It is important to note that the results generated by this model incorporate different boundaries than the mitigation potential results we show in Section 4.6 since Monni *et al.,* (2006) only incorporates avoided landfill methane emissions from disposal of municipal solid waste. Therefore, the GHG mitigation potential shown in Table 4.9 is not directly comparable to the results shown in Section 4.6.

143. Studies on the abatement costs from implementing GHG reduction technologies in other economic sectors have also been performed, and can provide useful context for the cost estimates developed by Monni *et al.,* McKinsey (2009) evaluated global marginal abatements costs[52] in 2030 across a wide range of sectors encompassing power generation, fuel production, transportation, buildings, forestry and agriculture. The McKinsey report detailed all abatement options under a ceiling of €60 per tCO_2e. According to the report, many of the mitigation options that provide cost savings are efficiency options

[52] The McKinsey report presents cost estimates in 2005 euro using a 4% interest rate.

achievable in buildings (*e.g.*, switching to LEDs, lighting controls, retrofitting building envelopes – commercial and Heating, Ventilation and Air-Conditioning (HVAC)). The study found that measures in the land-use and forestry (*e.g.*, reduced deforestation and cropland afforestation) can reduce GHG emissions at moderate costs ranging from roughly one to about 27 €/tCO_2e. Higher abatement costs of 15 to 30 €/tCO_2e are seen for deployment of renewable energy such as wind and solar which require large up-front investment. Carbon capture and storage, however, is the most expensive abatement option (37-60 €/tCO_2e) under the McKinsey curve. In contrast with these options, the McKinsey study found that direct use of landfill gas, waste recycling, and electricity generation from landfilling also have significant cost savings of about 12 to 34 €/tCO_2e.

144. The IEA considered the costs of global energy emission reductions in the year 2050 (IEA, 2008).[53] The study found that significant reductions in emissions from buildings and appliances are easily achievable at zero or very low cost through efficiency improvements and retrofit technologies. For example, abatement options such as efficient lighting systems, energy efficient appliances, building insulation, hot-water cylinder insulation, and climate-specific and efficient HVAC systems, can reduce GHG emissions at net cost savings of between USD 0 to 150/tCO_2. Whereas, options in the power sector (*e.g.*, biomass co-firing, small hydro, improvements in grid efficiency and electricity storage) achieve significant reductions at moderate costs of $0 to $50 / t$CO_2$. Efficiency improvements in appliances and electronics alone can reduce about 550 MtCO_2e per year. Switching to renewable sources of power generation, such as wind, solar[54], and tidal energy require large investments and up-front capital costs but result in substantial reductions. Industrial fuel-switching, carbon capture and storage, and alternative transportation fuels are some of the most expensive abatement technologies at costs equal to or greater than $50 / t$CO_2$.

145. Direct comparison of these results with the estimates from Monni *et al.,* (2006) is difficult, because the analyses use different approaches, study boundaries, and—in the case of the IEA study—different time frames. These results are provided to illustrate a general range of cost projections for GHG reduction options in other economic sectors, rather than for direct comparison with the cost estimates developed by Monni *et al.,* summarised in this section.

4.7.1 Conjectures of the economic feasibility of MSW management scenarios

146. Although a thorough economic assessment is beyond the scope of this report, the following conjectures can be made about the economic feasibility of the mitigation scenarios introduced in Section 4. Landfill gas capture with energy recovery is a proven, well-established technology that offers a low-cost option for further abatement of GHG emissions from landfills within the current mix of materials management practices in OECD countries, predominantly in North America, OECD Europe, and OECD Pacific regions. The costs of waste-to-energy incineration are typically higher than landfilling MSW, and in areas with abundant landfill capacity (e.g., Canada), waste-to-energy incineration plants are economically justifiable in only a few municipalities. The results of this study suggest that incineration also offers GHG reduction opportunities, particularly if assumed efficiency improvements in waste-to-energy plants are realised on a large scale over the next one to two decades. In OECD Asia, waste-to-energy incineration is already the predominant practice for managing MSW.

147. The scenarios that divert MSW from disposal in landfills and incinerators tend to be higher cost, but offer opportunities to recover materials to reduce energy use and GHG emissions across industrial sectors, which provide additional benefits (WRAP, 2010). Recycling secondary materials, for example,

[53] Costs are reported in 2005 real U.S. dollars; transaction costs are not considered and policy costs are considered separately. Discount rates vary by sector and by country.

[54] Photovoltaic and concentrated solar power (CSP) combined

reduces the amount of virgin material required, and avoids disposal costs associated with landfilling or incinerating materials. Looking forward, there are considerable opportunities for innovation in the performance and efficiency of processing efficiencies through screen design, optical sorting, and residue reduction. These improvements may be challenged by changes in the composition of MSW, and by a wider range of materials, such as plastics, added to recycling programs. (Egosi and Weitzman, 2010). Given its small scale in the current mix of MSW management practices, the economic feasibility of MBT is particularly uncertain. Currently, it is relatively high-cost compared to other management alternatives, but future improvements may see the technology become more cost-competitive with other management practices (IPCC, 2007, p. 604).

148. Composting and anaerobic digestion can offer opportunities for biological stabilisation of food and garden wastes at reasonable costs, depending upon the application and local market conditions. Composting is an established MSW management option in most OECD countries, managing an estimated 10 percent of MSW in North America, OECD Europe, and OECD Pacific, although it is less prevalent in OECD Asia. Establishing local markets for compost products produced from the composting process can increase the cost-competitiveness of composting alongside other MSW management practices (IPCC, 2007, p. 603), although it is uncertain how large-scale implementation of composting and/or anaerobic digestion might affect market demand and the economics of these practices.

149. The economic feasibility of source reduction is difficult to evaluate alongside other MSW material management practices. It is equally difficult for municipalities to allocate budget to promote source reduction, since it is challenging to measure the benefits of such programs. Reusing products or avoiding the use of products in the first place avoids the cost of producing the materials and services used to manufacture, distribute, and manage those goods at end-of-life, potentially allowing these resources to be used more efficiently. Substituting one material for another, however, leads to source reduction of the original material but the net cost depends upon the differential between the materials involved. In some cases, source reduction can be a cost-effective practice when combined with other MSW diversion methods. For example, when residences are charged for waste collection based on the amount of waste they generate, known as variable-unit pricing (or Pay-As-You-Throw), waste is reduced through a combination of recycling and source reduction. (EPA 2009c, Skumatz 2008) By reducing a share of the MSW generated alongside increased levels of recycling, source reduction can provide cost savings that can, to some extent, offset increased costs associated with recycling.

5.0 CONCLUSIONS

150. The results of this study provide an initial level of insight into the importance of a systems-based, life-cycle perspective of GHG emissions in OECD countries, and an order-of-magnitude assessment of the GHG mitigation potential of integrated waste management practices in particular. These findings serve as a starting point for further analysis of the contribution of SMM practices in reducing GHG emissions across OECD member countries.

151. The contributions of this report include a methodology, two case studies and two additional country level systems reallocation to help OECD member countries estimate the share of their national GHG emissions that are associated with materials management activities. In addition, by estimating the mitigation potential of integrated MSW management practices, this report: (i) developed high-level, comprehensive estimates of existing MSW management practices in OECD regions, (ii) compiled a set of life-cycle GHG emission factors and described important considerations in applying and interpreting these factors (*e.g.*, life-cycle boundaries, sources of GHG emissions and emissions offsets, and treatment carbon storage), and (iii) consolidated economic data from existing literature to enable further economic analyses of MSW management practices.

152. Based on the contributions and results of this study, we conclude the following:

a) **Due to the integrated, cross-cutting stages of materials acquisition, production, consumption, and end-of-life management, a systems view of GHG emissions is needed to assess GHG emissions associated with materials management systems and activities.** Although GHG emissions from the waste sector typically account for 3 to 4 percent of total emissions in member countries' GHG emission inventories, this emission source only considers direct emissions primarily from landfill methane emissions and incinerators. In contrast, a life-cycle perspective of materials management-related GHG sources encompasses emissions from the production, consumption, and end-of-life treatment of physical goods in the economy. This perspective allows policy-makers to evaluate a more complete, systems-based understanding of the relationships between materials management activities and their associated environmental impacts.

b) **When viewed from a life-cycle perspective that includes the extraction and harvesting of resources, the production of goods (including crops and food), transportation of goods, and treatment of waste, GHG emissions arising from material management activities account for a significant share of national emissions in OECD member countries.** Case studies developed for Australia and Mexico in this report estimate that materials management activities account for roughly 60 percent of total national GHG emissions in both countries. Additional case studies developed for Slovenia and Germany similarly estimated the majority of total GHG emissions are associated with materials management in each country (55 percent in Slovenia and 54 percent in Germany). A similar study conducted by the U.S. EPA found that 42 percent of GHG emissions in the United States were attributable to materials management activities (EPA, 2009b).

c) **Integrated waste management practices are one set of SMM options available that can achieve GHG reductions in OECD member countries.** Given the broad, economy-wide nature of materials management activities and emission sources, there are also numerous policy levers and further opportunities for reducing GHG emissions across the life-cycle stages of materials. For example, product-specific management practices—such as the recycling of high-GWP refrigerants and foams from refrigerators and freezers—may yield additional opportunities for reducing GHG emissions (see Box 2).

d) **An order-of-magnitude estimate of life-cycle GHG reductions across future technical potential MSW management scenarios shows that achievable reductions are on the order of current annual emissions from the conventional waste sector quantified in OECD countries' GHG inventories**. Annual landfill methane emissions in North America and Europe are on the order of hundreds of million metric tons, in terms of CO_2e. For OECD Pacific and OECD Asia, annual landfill methane emissions are on the order of tens of millions metric tons CO_2e (IPCC, 2007, Figure 10.5, p. 597). The GHG reductions estimated by the scenarios summarised in this report are roughly the same magnitude as current annual landfill gas emissions in these regions.

e) **The potential for GHG emission reductions across the MSW management scenarios investigated in this report depends primarily upon existing management practices, the *effectiveness* of management practices at reducing GHG emissions, and the quantity and composition of MSW generation.** From a GHG emissions reduction perspective, effective waste management involves promoting *both* highly-effective waste management practices such as source reduction and recycling, as well as practices that reduce emissions and recovery energy on remaining waste fractions that are not recoverable. Together, this strategy can provide substantial GHG emission reductions that exceed the application of any single practice.

f) **Although this study did not explicitly evaluate these factors, economic and policy conditions will play an important role in determining the extent to which integrated MSW management practices are realised in the future.** Economic drivers and waste management policies will have a large impact on how management practices are implemented regionally. Accounting for these effects can be complex, and requires consistent definitions of the scope and type of costs included and should consider regional differences, future policy actions, dynamic economic effects, and technological innovation, among other factors.

153. In addition to these conclusions, the following findings are particularly relevant to OECD member countries in interpreting the results of this report:

a) **Evaluating the share of national GHG emissions attributable to materials management activities is a useful exercise in developing a systems-based view of national emissions**. Once established, this systems-view can provide important insights into the contribution of GHG emissions from various production, transportation, consumption, and end-of-life treatment activities to total national emissions. This perspective can help identify or prioritise stages of the life-cycle where SMM opportunities could mitigate emissions.

In developing a systems perspective of national inventories, member countries would benefit from clearly documenting the approach, assumptions, and definitions used in the life-cycle boundaries of the assessment. The same methodology used in this report can be applied to other OECD member countries.

b) The level of detail and accuracy of development of a systems-based perspective of national GHG emissions depends greatly upon the level of detail used to report national GHG inventories and the availability of secondary data sources.

i. In some cases, Tier 1 data from national inventories is sufficient; for example, the "waste" reporting category in national inventories is included in the definition of materials management activities. Other categories, such as the energy sector ideally require Tier 4-level data from national inventories to sufficiently determine which categories broadly include materials management activities.

ii. Secondary data sources are required to further reallocate national inventory categories into materials management-related activities. Data sources that can be used in this manner include: economy-wide energy balance tables that represent the flows of energy in and out of national industrial and economic sectors, freight and personal transportation statistics compiled by member countries, and sector-specific publications with information on energy use or GHG emissions.

c) The order-of-magnitude estimates of GHG reductions from future MSW management scenarios illustrate the significant GHG reduction potential from integrated MSW management practices. These results provide a rationale for OECD member countries to include consideration of MSW management practices in efforts to address GHG emissions reductions domestically.

d) Further research and analysis is required to assess the full potential from MSW management practices in OECD countries. OECD member countries may wish to undertake addition research and data-gathering efforts to develop more consistent life-cycle methodologies and emission factors across OECD regions. Areas where further work could be conducted to overcome key caveats and limitations to this analysis include:

iii. Accounting for region-specific characteristics in more detail, or including a more detailed assessment of the variation in MSW generation, composition, and baseline MSW management practices within the regions characterised in this study.

iv. Investigating the effects of landfill, soil, and forest carbon storage on estimated GHG reductions.

v. Developing a framework for detailed economic analysis of the costs, benefits, and cost of abating GHG emissions through MSW management practices.

vi. Incorporating estimates of dynamic effects associated with large scale changes in MSW management practices over medium- to longer-term timeframes. For example, modelling how GHG emission reductions from alternative MSW practices are likely to change as more and more MSW is diverted to these practices. Other dynamic effects include changes in the performance of technologies over time, and changes in costs in response to innovation and changes in MSW management practices.

vii. Expanding the scope of the GHG emissions assessment of integrated waste management practices to include other waste streams beyond MSW.

viii. Developing better insight into upstream SMM approaches to view their impact in GHG emissions. For example, the impact of providing services and leasing in place of product sales on GHG emissions. This could also include an evaluation of other SMM case studies where GHG emissions are already considered among environmental impacts. This analysis would help advance the concept of looking at GHG emissions from systems (not sectoral) approach and the large connection between materials management and GHG emissions as presented in the first section of this report.

154. Further research into these areas will improve the level of detail of the order-of-magnitude estimates presented in this paper. This will provide additional insights into the role of integrated waste management practices in reducing GHG emissions, as well as a better understanding of the drivers and barriers to implementing these practices in OECD member countries.

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APPENDIX A: SYSTEMS-BASED EMISSIONS ALLOCATION FOR AUSTRALIA, MEXICO, SLOVENIA, AND GERMANY

Australia 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				**Non Materials Management**		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Public Electricity and Heat Production	45%	0%	1%	0%	1%	30%	23%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Petroleum Refining	12%	0%	6%	0%	79%	1%	2%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Manufacture of Solid Fuels and Other Energy Industries	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.2. Manufacturing Industries and Construction	Manufacturing Industries and Construction	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Civil Aviation	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Road Transportation	0%	23%	0%	0%	77%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Railways	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Navigation	0%	100%	0%	0%	0%	0%	0%

Australia 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	UNFCCC Tier 2	UNFCCC Tier 3	UNFCCC Tier 4 or Tier 5, varies by country	Production of Goods and Fuels	Transportation of Goods	Crop and Food Production and Storage	Disposal of Food and Waste	Passenger Transportation	Residential Energy Use	Commercial Energy Use
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Other Transportation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Commercial/ Institutional	0%	0%	0%	0%	0%	0%	100%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Residential	0%	0%	0%	0%	0%	100%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Agriculture/ Forestry/ Fisheries	0%	0%	100%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.5. Other (not previously identified)	Other (Fuel Combustion)	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Coal Mining and Handling	93%	0%	0%	0%	4%	0%	3%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Oil	12%	0%	6%	0%	79%	1%	2%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Natural Gas	68%	0%	0%	0%	3%	22%	7%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Venting and Flaring	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Other (Fugitive)	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.A Mineral Products		Mineral Products	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.B Chemical Industry		Chemical Industry	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.C. Metal Production		Metal Production	100%	0%	0%	0%	0%	0%	0%

Australia 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				**Non Materials Management**		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
2. Industrial Processes	2.D Other Production		Other Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.E. Production of Halocarbons and SF6		Production of Halocarbons and SF6	100%	0%	0%		0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.1 Refrigeration and AC Equipment	Refrigeration and AC Equipment	4%	12%	33%	0%	47%	1%	4%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.2 Foam Blowing	Foam Blowing	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.3 Fire Extinguishers	Fire Extinguishers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.4 Aerosols/Metered Dose Inhalers	Aerosols/ Metered Dose Inhalers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.5 Solvents	Solvents	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.6 Other applications using ODS subs	Other applications using ODS subs	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.7 Semi conductor manufacture	Semi conductor manufacture	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.8 Electrical Equipment	Electrical Equipment	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.9 Other	Other (Consumption of Halocarbons and SF6)	100%	0%	0%	0%	0%	0%	0%
2.G Other	2.G Other		Other (Industrial Processes)	100%	0%	0%	0%	0%	0%	0%
3. Solvent and Other Product Use			Solvent and Other Product Use	100%	0%	0%	0%	0%	0%	0%
4. Agriculture			Agriculture	0%	0%	100%	0%	0%	0%	0%

Australia 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	UNFCCC Tier 2	UNFCCC Tier 3	UNFCCC Tier 4 or Tier 5, varies by country	Production of Goods and Fuels	Transportation of Goods	Crop and Food Production and Storage	Disposal of Food and Waste	Passenger Transportation	Residential Energy Use	Commercial Energy Use
6 - Waste			Waste	0%	0%	0%	100%	0%	0%	0%
7. Other			Other (All)	100%	0%	0%	0%	0%	0%	0%

Mexico 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	UNFCCC Tier 2	UNFCCC Tier 3	UNFCCC Tier 4 or Tier 5, varies by country	Production of Goods and Fuels	Transportation of Goods	Crop and Food Production and Storage	Disposal of Food and Waste	Passenger Transportation	Residential Energy Use	Commercial Energy Use
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Public Electricity and Heat Production	58%	0%	4%	0%	1%	25%	11%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Petroleum Refining	9%	0%	4%	0%	76%	10%	2%
1. Energy	1.A. Fuel Combustion -	1.A.1. Energy Industries	Manufacture of Solid	100%	0%	0%	0%	0%	0%	0%

Mexico 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
	Sectoral Approach		Fuels and Other Energy Industries							
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.2. Manufacturing Industries and Construction	Manufacturing Industries and Construction	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Civil Aviation	0%	19%	0%	0%	81%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Road Transportation	0%	30%	0%	0%	70%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Railways	0%	98%	0%	0%	2%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Navigation	0%	97%	0%	0%	3%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Other Transportation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Commercial/ Institutional	0%	0%	0%	0%	0%	0%	100%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Residential	0%	0%	0%	0%	0%	100%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Agriculture/ Forestry/ Fisheries	0%	0%	100%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.5. Other (not previously identified)	Other (Fuel Combustion)	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Solid Fuels	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Oil and Natural Gas	24%	0%	3%	0%	62%	9%	2%

Mexico 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
1. Energy	2.A Mineral Products		Mineral Products	100%	0%	0%	0%	0%	0%	0%
1. Energy	2.B Chemical Industry		Chemical Industry	100%	0%	0%	0%	0%	0%	0%
1. Energy	2.C Metal Production		Metal Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.D Other Production		Other Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.E Production of Halocarbons and SF6		Production of Halocarbons and SF6	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.1 Refrigeration and AC Equipment	Refrigeration and AC Equipment	6%	19%	54%	0%	14%	1%	6%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.2 Foam Blowing	Foam Blowing	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.3 Fire Extinguishers	Fire Extinguishers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.4 Aerosols/Metered Dose Inhalers	Aerosols/ Metered Dose Inhalers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.5 Solvents	Solvents	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.6 Other applications using ODS subs	Other applications using ODS subs	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.7 Semi conductor manufacture	Semi conductor manufacture	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.8 Electrical Equipment	Electrical Equipment	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.9 Other	Other (Consumption of Halocarbons and SF6)	100%	0%	0%	0%	0%	0%	0%

Mexico 2007 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
2. Industrial Processes	2.G Other		Other (Industrial Processes)	100%	0%	0%	0%	0%	0%	0%
3. Solvent and Other Product Use			Solvent and Other Product Use	100%	0%	0%	0%	0%	0%	0%
4. Agriculture			Agriculture	0%	0%	100%	0%	0%	0%	0%
6 - Waste			Waste	0%	0%	0%	100%	0%	0%	0%
7. Other			Other (All)	100%	0%	0%	0%	0%	0%	0%

Slovenia 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Public Electricity and Heat Production	49%	0%	0%	0%	2%	25%	24%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Petroleum Refining	5%	0%	4%	0%	72%	12%	7%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Manufacture of Solid Fuels and Other Energy Industries	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.2. Manufacturing Industries and Construction	Manufacturing Industries and Construction	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Civil Aviation	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Road Transportation	0%	31%	0%	0%	69%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Railways	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Navigation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Other Transportation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Commercial/Institutional	0%	0%	0%	0%	0%	0%	100%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Residential	0%	0%	0%	0%	0%	100%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Agriculture/Forestry/ Fisheries	0%	0%	100%	0%	0%	0%	0%

Slovenia 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	UNFCCC Tier 2	UNFCCC Tier 3	UNFCCC Tier 4 or Tier 5, varies by country	Production of Goods and Fuels	Transportation of Goods	Crop and Food Production and Storage	Disposal of Food and Waste	Passenger Transportation	Residential Energy Use	Commercial Energy Use
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.5. Other (not previously identified)	Other (Fuel Combustion)	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Coal Mining and Handling	100%	0%	0%	0%	0%	0%	0%
	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Solid Fuel Transformation	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Oil	5%	0%	4%	0%	72%	12%	7%
	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Natural Gas	85%	0%	0%	0%	0%	14%	2%
	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Venting and Flaring	100%	0%	0%	0%	0%	0%	0%
	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Other (Fugitive)	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.A Mineral Products		Mineral Products	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.B Chemical Industry		Chemical Industry	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.C. Metal Production		Metal Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.D Other Production		Other Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.E. Production of Halocarbons and SF6		Production of Halocarbons and SF6	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.1 Refrigeration and AC Equipment	Refrigeration and AC Equipment	4%	12%	33%	0%	47%	1%	4%

Slovenia 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
2. Industrial Processes	2.F Consumption of Halocarbons and SF7	2.F.2 Foam Blowing	Foam Blowing	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF8	2.F.3 Fire Extinguishers	Fire Extinguishers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF9	2.F.4 Aerosols/Metered Dose Inhalers	Aerosols/Metered Dose Inhalers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF10	2.F.5 Solvents	Solvents	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF11	2.F.6 Other applications using ODS subs	Other applications using ODS subs	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF12	2.F.7 Semi conductor manufacture	Semi conductor manufacture	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF13	2.F.8 Electrical Equipment	Electrical Equipment	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF14	2.F.9 Other	Other (Consumption of Halocarbons and SF6)	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.G Other		Other (Industrial Processes)	100%	0%	0%	0%	0%	0%	0%
3. Solvent and Other Product Use			Solvent and Other Product Use	100%	0%	0%	0%	0%	0%	0%
4. Agriculture			Agriculture	0%	0%	100%	0%	0%	0%	0%
6 - Waste			Waste	0%	0%	0%	100%	0%	0%	0%
7. Other			Other	100%	0%	0%	0%	0%	0%	0%

Germany 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	UNFCCC Tier 2	UNFCCC Tier 3	UNFCCC Tier 4 or Tier 5, varies by country	Production of Goods and Fuels	Transportation of Goods	Crop and Food Production and Storage	Disposal of Food and Waste	Passenger Transportation	Residential Energy Use	Commercial Energy Use
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Public Electricity and Heat Production	46%	0%	2%	0%	3%	27%	23%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Petroleum Refining	21%	0%	0%	0%	52%	17%	9%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.1. Energy Industries	Manufacture of Solid Fuels and Other Energy Industries	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.2. Manufacturing Industries and Construction	Manufacturing Industries and Construction	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Civil Aviation	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Road Transportation	0%	26%	0%	0%	74%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Railways	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Navigation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.3. Transport	Other Transportation	0%	100%	0%	0%	0%	0%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Commercial/Institutional	0%	0%	0%	0%	0%	0%	100%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Residential	0%	0%	0%	0%	0%	100%	0%
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.4 Other Sectors	Agriculture/Forestry/Fisheries	0%	0%	100%	0%	0%	0%	0%

Germany 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
1. Energy	1.A. Fuel Combustion - Sectoral Approach	1.A.5. Other (not previously identified)	Other (Fuel Combustion)	0%	0%	0%	0%	100%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Coal Mining and Handling	79%	0%	0%	0%	0%	17%	4%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Solid Fuel Transformation	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.1 Solid Fuels	Other Solid Fuel Fugitive Emissions	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Oil	21%	0%	0%	0%	52%	17%	9%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Natural Gas	33%	0%	7%	0%	0%	49%	11%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Venting and Flaring	100%	0%	0%	0%	0%	0%	0%
1. Energy	1.B. Fugitive Emissions from Fuels	1.B.2 Oil and Natural Gas	Other (Fugitive)	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.A Mineral Products		Mineral Products	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.B Chemical Industry		Chemical Industry	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.C. Metal Production		Metal Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.D Other Production		Other Production	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.E. Production of Halocarbons and SF6		Production of Halocarbons and SF6	100%	0%	0%	0%	0%	0%	0%

Germany 2008 systems-based GHG allocation by percent

				Systems Level Categories						
				Materials Management				Non Materials Management		
UNFCCC Tier 1	**UNFCCC Tier 2**	**UNFCCC Tier 3**	**UNFCCC Tier 4 or Tier 5, varies by country**	**Production of Goods and Fuels**	**Transportation of Goods**	**Crop and Food Production and Storage**	**Disposal of Food and Waste**	**Passenger Transportation**	**Residential Energy Use**	**Commercial Energy Use**
2. Industrial Processes	2.F Consumption of Halocarbons and SF6	2.F.1 Refrigeration and AC Equipment	Refrigeration and AC Equipment	4%	12%	33%	0%	47%	1%	4%
2. Industrial Processes	2.F Consumption of Halocarbons and SF7	2.F.2 Foam Blowing	Foam Blowing	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF8	2.F.3 Fire Extinguishers	Fire Extinguishers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF9	2.F.4 Aerosols/Metered Dose Inhalers	Aerosols/Metered Dose Inhalers	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF10	2.F.5 Solvents	Solvents	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF11	2.F.6 Other applications using ODS subs	Other applications using ODS subs	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF12	2.F.7 Semi conductor manufacture	Semi conductor manufacture	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF13	2.F.8 Electrical Equipment	Electrical Equipment	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.F Consumption of Halocarbons and SF14	2.F.9 Other	Other (Consumption of Halocarbons and SF6)	100%	0%	0%	0%	0%	0%	0%
2. Industrial Processes	2.G Other		Other (Industrial Processes)	100%	0%	0%	0%	0%	0%	0%
3. Solvent and Other Product Use			Solvent and Other Product Use	100%	0%	0%	0%	0%	0%	0%
4. Agriculture			Agriculture	0%	0%	100%	0%	0%	0%	0%
6 - Waste			Waste	0%	0%	0%	100%	0%	0%	0%
7. Other			Other (All)	100%	0%	0%	0%	0%	0%	0%

APPENDIX B: LULUCF REALLOCATION FOR AUSTRALIA CASE STUDY

Emissions and Sinks in the LULUCF Category

155. The systems reallocation of the UNFCCC emissions categories does not include the Land Use, Land Use Change and Forestry (LULUCF) UNFCCC category. The LULUCF category provides an estimate of the carbon sink for land management practices and is usually reported separately within GHG Inventories. However, for countries that do calculate LULUCF emissions, we provide a methodology to apportion emissions within each UNFCCC sub category into a simple two-tiered framework to highlight emissions associated with materials management. There are several intersections between land management and materials management. This analysis identified the following materials management sources and sinks that fall under the definition of materials management:

- Material management practices such as paper recycling and source reduction can result in decreased forest logging and increased carbon sequestration in forests.
- Land converted from other uses to the production of food (*i.e.* land converted to cropland) results in changes in carbon sequestered, particularly if the conversion is from forestland to cropland.
- Emissions from agricultural practices on the cropland, such as the application of lime to soils, results in emissions associated with food production.
- Harvested wood products sequester carbon during the life time of the wood product and are considered an emissions sink.

156. Of the LULUCF materials management sources and sinks listed above, this methodology does not provide a means for separating out the forest carbon sequestration associated with recycling. Apportioning the amount of forest sequestration that results from recycling policies would require a sophisticated analysis that is beyond the scope of this analysis. While the LULUCF analysis detailed here could be applied to any OECD country, in practice only some of the OECD countries report LULUCF sources and sinks. For example, while Australia does report LULUCF emissions, Mexico does not. The figure below illustrates that most of the emissions in the LULUCF sector for Australia in 2007 are not associated with materials management and are instead a result of soil emissions, fires, and other land management sources. These emissions are considered to be influenced by land management policies, such as land development, reuse, and restoration, rather than materials management policies (EPA, 2009b).

Figure 20. LULUCF Emissions and Sinks for Australia in 2007

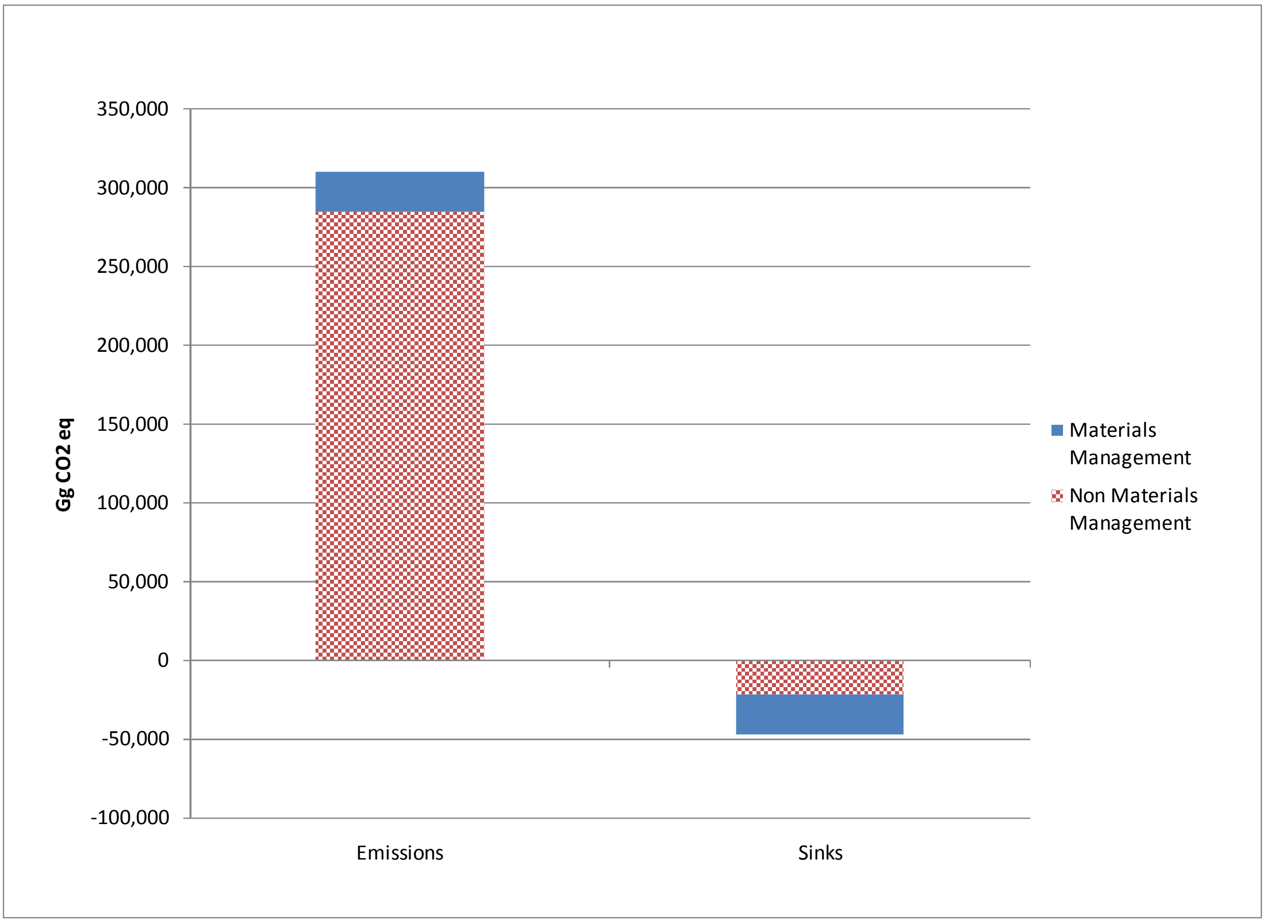


Table 19. LULUCF Emissions Sources and Materials Management Classification for Australia in 2007

Category	Total MMT of CO_2e	% of Gross Emissions	Overall Classification
Carbon Stock Decreases Due to Land Converted to Cropland	7	2%	Materials Management
Emissions from Cropland Remaining Cropland	17	5%	Materials Management
N_2O emissions from disturbance associated with land-use conversion to cropland	<1	0%	Materials Management
Agricultural Lime Application	1	0%	Materials Management
Carbon Stock Decreases Not Involving Cropland	70	23%	Non Materials Management
Carbon Flux from Land Remaining in the Same Land Use Category	215	69%	Non Materials Management
Materials Management LULUCF Emissions	25	8%	Materials Management
Non Materials Management LULUCF Emissions	285	92%	Non Materials Management
Total Emissions	310	100%	

Table 20. LULUCF Emissions Sinks and Materials Management Classification for Australia in 2007

Category	Total MMT of CO_2e	% of Gross Emissions Sequestered	Overall Classification
Harvested Wood Products	-4	17%	Materials Management
Carbon Stock Increases Not Involving Cropland	-21	83%	Non Materials Management
Total Sinks	-26	100%	

157. Although the majority of LULUCF emissions and sinks are not associated with materials management, the net emissions from LULUCF categories that are associated with materials management are slightly positive for Australia (using the typical emissions inventory sign convention that emissions are positive and sinks are negative). In other words, the carbon sequestered in harvested wood products offsets only a portion of the emissions associated with the conversion of land to cropland. Materials management policies that affect the agriculture sector and associated food products could intersect with land management policies that deal with cropland management and could ultimately reduce land management related emissions (*i.e.*, conversion to cropland).

APPENDIX C: TABLE OF ASSUMPTIONS FOR ANALYSIS OF GHG MITIGATION POTENTIAL FROM ALTERNATIVE WASTE MANAGEMENT PRACTICES

158. The table below presents the main assumptions the results for the life-cycle GHG mitigation analysis of the alternative MSW management scenarios presented in Section 4 of this report. The scenarios we developed are intended to be order-of-magnitude estimates of the life-cycle GHG emissions mitigation potential of different MSW management scenarios at "technically-achievable potential" limits. We recognise that there are many assumptions and boundaries inherent in our analysis that will ultimately affect the results in different ways. The goal of this table is to communicate key assumptions and provide the references upon which the assumptions are based.

Table 21. Main Assumptions in the Assessment of Life-Cycle GHG Mitigation from MSW Management Scenarios

Assumption	Effect of Assumption	Description/Rationale	Related References
Landfill carbon storage is excluded	Large. This assumption increases the GHG benefits of alternative practices relative to landfilling.	The landfill emission factors we developed from methodologies described in the IFEU model did not include landfill carbon storage. Although landfill carbon storage is included in the U.S. EPA's Waste Reduction Model (WARM), it was excluded in this analysis for consistency with the approach used across the other regions and the exclusion of other forms of carbon storage in forests and soils. See Box 1 in Section 4 for further details.	IFEU (Institut für Energie- und Umweltforschung). (2009). EPA. (2006b)
Forest carbon storage is excluded	Large. This assumption decreases the GHG benefits of recycling and source reducing paper and wood materials.	Forest carbon storage estimates depend upon harvesting practices and the relationship between decreased virgin paper demand and forest carbon stocks. Since this relationship will vary greatly across different regions, and no information was available for regions outside of the United States, forest carbon storage was excluded for consistency across regions. See Box 1 in Section 4 for further details.	EPA. (2006b)
Soil carbon storage in compost is excluded	Moderate. This assumption decreases the GHG benefits of composting food and garden waste.	Developing soil carbon storage factors requires modelling the flows through short-, medium-, and long-term pools of soil carbon storage, and will vary depending on local soil conditions and compost characteristics. Soil carbon storage estimates were not available in the data source used for non-U.S. composting emissions factors; thus, soil carbon storage was excluded for consistency across regions. Based on U.S. specific data, the benefit from soil carbon storage is typically smaller compared to landfill and forest carbon storage for most material types.	Defra (Department for Environment, Food and Rural Affairs). (2009)., EPA. (2006b)

Assumption	Effect of Assumption	Description/Rationale	Related References
Landfill-gas- and waste-to-energy recovery offsets fossil-fuel electricity generation	Moderate. This assumption increases the GHG benefits of landfilling and incineration.	Fossil-only power plants tend to be the "load-following" sources of electricity generation and are the first to respond to marginal changes in supply and demand of electricity whereas non-fossil fuel operations tend to supply baseload capacity. All OECD regions have less GHG-intensive "average grid mix" emission factors meaning that the landfill and incineration scenario benefits would be reduced if the average grid mix GHG-intensity was used to calculate the results. The offset for each region was calculated based on EIA emission factors for reduced emissions from avoided generation of electricity in OECD countries. It is important to note that increased shares of low-CO_2 electricity in the grid mix of OECD countries will lower the GHG benefit from electricity offset by waste-to-energy recovery. Given the scope, and resources available, however, a detailed analysis of future electricity grid mixes across all OECD regions was not possible in this study.	EPA. (2006b) EIA. (2010)
Waste-to-energy recovery through incineration is harnessed in combined heat and power units with 50% of the energy recovered for heat and 16% recovered for electricity Landfill gas capture efficiency increases to 87% in the alternative landfill scenarios	Moderate. These assumptions increase the GHG benefits of landfilling and incineration.	System efficiency increases in waste-to-energy incineration plants and landfill gas capture systems at landfills are based on technical potential improvements taken from literature. These estimates are aggressive and optimistic, but are consistent with the goal of this study, which was to define "order-of-magnitude" estimates of what is technically achievable in terms of GHG reductions from MSW management practices.	eunomia (2008) Barlaz et al. (2009)
Up to 85% of total MSW is diverted to incineration in the alternative incineration scenario	Large. This assumption influences the GHG benefits of incineration since each additional ton of waste sent to incineration will have a one-to-one effect on the total GHG benefits.	Based on "technical potential" estimate from literature.	Monni et al. (2006)
Technical potential MSW recycling rates: paper/cardboard: 85%, wood: 60%, textiles: 50%, plastic: 40%, ferrous metals: 95%, aluminium: 87%, glass: 85%	Moderate. These assumptions on recycling rates influence the overall GHG benefits from recycling since each additional ton of waste recycled will have a one-to-one effect on the total GHG benefits.	Based on "technical potential" available estimates from literature.	Prognos. (2008). EPA. (2009a).

Assumption	Effect of Assumption	Description/Rationale	Related References
Technical potential assumption for composting: 80% of food and garden waste is composted or anaerobically digested	Moderate. This assumption influences the overall GHG benefits for these alternative scenarios since the GHG benefits from composting and anaerobic digestion are directly proportional to the amount of materials composted or anaerobically digested.	Based on "technical potential" available estimates from literature	Warnken Ise (2007) Prognos. (2008).
Technical potential assumption for the recycling and MBT alternative scenario that 75% of MSW not recycled is processed by MBT	Moderate. The GHG benefits of MBT are directly proportional to the amount of materials recovered and processed by an MBT facility.	Based on available estimates from literature that indicates that 25% of MSW processed by MBT cannot be sorted and is sent for disposal in landfills.	IFEU (Institut für Energie- und Umweltforschung). (2009).
Technical potential assumption for source reduction: all MSW except for food and garden waste is source reduced by 30%	Large. The GHG benefits of source reduction are directly proportional to the amount of materials that are source reduced. The inclusion of source reduction of food and garden waste would increase the GHG benefits associated with the source reduction alternative scenario.	Based on rates from literature that indicate material consumption can potentially decrease by 1 percent annually. Thus, total source reduction between 2010 (baseline) and 2030 is 30 percent. The exclusion of food and garden waste materials from the source reduction scenario is due to a lack of information on upstream production of food and garden waste across all OECD regions. For example, U.S. EPA's Waste Reduction Model (WARM) does not include source reduction emissions estimates for food and garden waste due to data limitations and complexities with evaluating upstream emissions (i.e., food production and distribution).	ILSR (2008) EPA. (2009a).
Baseline practices remain the same in 2030 as they are today.	Moderate to large.	Due to the uncertainty in how MSW practices will evolve over time, this simplifying assumption implies that current waste management practices will persist through 2030 in the baseline. This allows us to evaluate the full range of future GHG benefits resulting from implementing the various alternative practices beyond the current baseline levels in 2030. The results show both the benefits of existing measures, plus an upper bound on the additional reductions that could be achieved within MSW streams We recognise that assuming baseline practices remain the same potentially underestimates the adoption and use of alternative practices in 2030.	Internal assumption.

Assumption	Effect of Assumption	Description/Rationale	Related References
MSW is diverted from baseline practices to alternative practices such that the relative proportion of landfilling to incineration remains the same in each region	Large. GHG emission benefits are calculated as the difference between the benefits provided by the alternative scenario minus the baseline scenario. As a result, the net benefits will be strongly influenced by assumptions of where the waste is diverted from in the alternative scenario.	MSW is diverted from landfilling and incineration so that the relative proportion of landfilling to incineration stays the same as in the baseline. This assumption was made in order to evaluate the effect of increasing each alternative waste management option to its technical potential in isolation, so that the efficiency and overall GHG mitigation in each scenario could be compared. We did not make assumptions about whether MSW was more likely to be diverted from one baseline practice than another. This assumption is not meant to imply that MSW practices should be applied in isolation (e.g., only emphasizing recycling or waste-to-energy recovery), but it does allow for the scenarios to be analysed separately so that the benefits of each can be assessed.	Internal assumption
MSW composition remains the same in 2030 as today.	Moderate.	Due to the uncertainty in how MSW composition will evolve over time, this simplifying assumption implies that the percent composition of the MSW stream in each region remains the same as the baseline. We recognise that the composition of MSW will change over time.	Internal assumption.
The recycling alternative scenario GHG benefits are shown separately from composting and anaerobic digestion alternative scenario GHG benefits	No change to results.	The results of these scenarios are shown separately because they are modelled as distinct and separate options. However, as we make clear in the report, these are the only scenarios that can be additively combined. The recycling and composting scenarios can be additively combined as well as the recycling and anaerobic alternative scenarios since they deal with entirely separate streams of MSW.	Internal assumption.
Division of Europe into “low recycling” and “high recycling” groups based on a recycling rate of 15%	No effect on results.	This assumption reflects the different mix of MSW management practices that are currently in place across many countries within Europe. The 15% recycling rate was selected as a natural break between European nations based on current practices—it is relevant to current conditions. The label was not meant to imply that a 15% recycling rate was “high”. The benefit of splitting Europe into these two groups is that it allows some regional detail that can provide insight into different options available within the European OECD region.	Internal assumption based on OECD (2008a)

APPENDIX D: MSW MANAGEMENT PRACTICE GHG EMISSION FACTORS

159. This appendix provides a summary of the GHG emissions factors used to estimate the changes in GHG emissions from OECD member countries as a result of implementing alternative MSW management practices. The life-cycle boundaries, data sources, and assumptions used to develop these estimates are included in Section 4.

North America									
metric tons CO_2e/ metric ton of MSW	Recycling	Composting	Landfill, gas collection	Landfill, no gas collection	Incineration without waste-to-energy	Waste-to-energy incineration	Anaerobic digestion	Mechanical-biological treatment	Source reduction or waste minimisation
Food waste	NA	0.05	0.26	1.39	0.00	-0.22	-0.17	NA	NA
Garden waste	NA	0.05	0.34	1.80	0.00	-0.22	-0.17	NA	NA
Paper/ cardboard	-0.50	NA	0.70	3.76	0.02	-0.61	NA	NA	-1.53
Wood	0.09	NA	0.73	3.90	0.00	-0.81	NA	NA	-0.20
Textiles	-2.82	NA	0.55	2.93	0.29	-0.50	NA	NA	-5.70
Rubber/ leather	-2.03	NA	0.77	4.13	0.41	-0.38	NA	NA	-4.42
Plastic	-1.68	NA	0.00	0.00	2.75	1.05	NA	NA	-2.28
Ferrous metals (steel)	-1.98	NA	0.00	0.00	0.00	0.00	NA	NA	-3.51
Aluminium	-15.02	NA	0.00	0.00	0.00	0.00	NA	NA	-9.12
Glass	-0.31	NA	0.00	0.00	0.00	0.00	NA	NA	-0.59
Other	NA	NA	0.00	0.00	0.10	-0.36	NA	NA	NA
Bulk MSW	NA	NA	NA	NA	NA	NA	NA	-0.29	NA

OECD Europe									
metric tons CO_2e/ metric ton of MSW	Recycling	Composting	Landfill, gas collection	Landfill, no gas collection	Incineration without waste-to-energy	Waste-to-energy incineration	Anaerobic digestion	Mechanical-biological treatment	Source reduction or waste minimisation
Food waste	0.00	0.03	0.28	1.39	0.00	-0.20	-0.14	NA	NA
Garden waste	0.00	0.06	0.36	1.80	0.00	-0.20	-0.14	NA	NA
Paper/ cardboard	-0.82	NA	0.74	3.76	0.02	-0.55	NA	NA	-1.00
Wood	-0.06	NA	0.77	3.90	0.00	-0.74	NA	NA	-0.41
Textiles	-2.82	NA	0.58	2.93	0.29	-0.42	NA	NA	-5.70
Rubber/ leather	-1.80	NA	0.81	4.13	0.41	-0.30	NA	NA	-4.42
Plastic	-1.06	NA	0.00	0.00	2.75	1.20	NA	NA	-2.03
Ferrous metals (steel)	-1.00	NA	0.00	0.00	0.00	0.00	NA	NA	-3.10
Aluminium	-11.10	NA	0.00	0.00	0.00	0.00	NA	NA	-11.80
Glass	-0.18	NA	0.00	0.00	0.00	0.00	NA	NA	-0.20
Other	NA	NA	0.00	0.00	0.10	-0.31	NA	NA	NA
Bulk MSW	NA	NA	NA	NA	NA	NA	NA	-0.29	NA

OECD Asia and Pacific									
metric tons CO_2e/ metric ton of MSW	Recycling	Composting	Landfill, gas collection	Landfill, no gas collection	Incineration without waste-to-energy	Waste-to-energy incineration	Anaerobic digestion	Mechanical-biological treatment	Source reduction or waste minimisation
Food waste	0.00	0.03	0.27	1.39	0.00	-0.20	-0.15	NA	NA
Garden waste	0.00	0.06	0.35	1.80	0.00	-0.20	-0.15	NA	NA
Paper/ cardboard	-0.82	NA	0.73	3.76	0.02	-0.56	NA	NA	-1.00
Wood	-0.06	NA	0.76	3.90	0.00	-0.75	NA	NA	-0.41
Textiles	-2.82	NA	0.57	2.93	0.29	-0.44	NA	NA	-5.70
Rubber/ leather	-1.80	NA	0.80	4.13	0.41	-0.32	NA	NA	-4.42
Plastic	-1.06	NA	0.00	0.00	2.75	1.17	NA	NA	-2.03
Ferrous metals (steel)	-1.00	NA	0.00	0.00	0.00	0.00	NA	NA	-3.10
Aluminium	-11.10	NA	0.00	0.00	0.00	0.00	NA	NA	-11.80
Glass	-0.18	NA	0.00	0.00	0.00	0.00	NA	NA	-0.20
Other	NA	NA	0.00	0.00	0.10	-0.32	NA	NA	NA
Bulk MSW	NA	NA	NA	NA	NA	NA	NA	-0.29	NA

APPENDIX E: MITIGATION POTENTIAL FROM MSW MANAGEMENT IN CONTEXT WITH MATERIALS MANAGEMENT GHG EMISSIONS

160. The first part of the report assessed the share of materials management activities from a broad set of activities representing total GHG emissions in OECD country economies. The second part of the report addressed GHG mitigation potential cutting across those various materials management activities, but with a focus on the waste sector as result of improved MSW management practices. This mitigation potential covered more than emission reductions at end-of-life because the approach for calculating the GHG mitigation potential considered life-cycle GHG reductions from shifting from baseline to improved practices.

161. It can be difficult to interpret the absolute abatement potentials estimates in Section 4. To provide some context to these numbers, we provide illustrative comparisons of the GHG emission reduction potential in relation to overall GHG emissions from MSW management in the baseline (Figure 13) to the systems-based view of GHG emissions associated with materials management for Mexico and Australia (Figure 5 and Figure 6).

162. The systems-based materials management GHG emissions profiles shown for Australia and Mexico in Section 3 illustrate the relative GHG impact of economic activities that span multiple sectors associated with materials management in recent Inventory years. The GHG mitigation potential of different MSW management options shown in Section 4 are assumed to be implemented by year 2030 and are relative to the current baseline assessed across five OECD regions.

163. As shown in, the OECD Pacific region includes Australia and New Zealand and the North America region includes Canada, Mexico, and the United States. In order to more appropriately compare GHG mitigation potential for Australia and Mexico specifically, we can scale the total GHG mitigation potential for each of the regions by the percentage of total waste generation of each country within the region (Table 9). Although this is a crude approximation which assumes that country-specific MSW waste management practices are similar across the different countries, it provides and order-of-magnitude comparison of the GHG mitigation potential for the different MSW management alternatives in 2030 to the GHG emissions associated with materials management from Australia and Mexico.

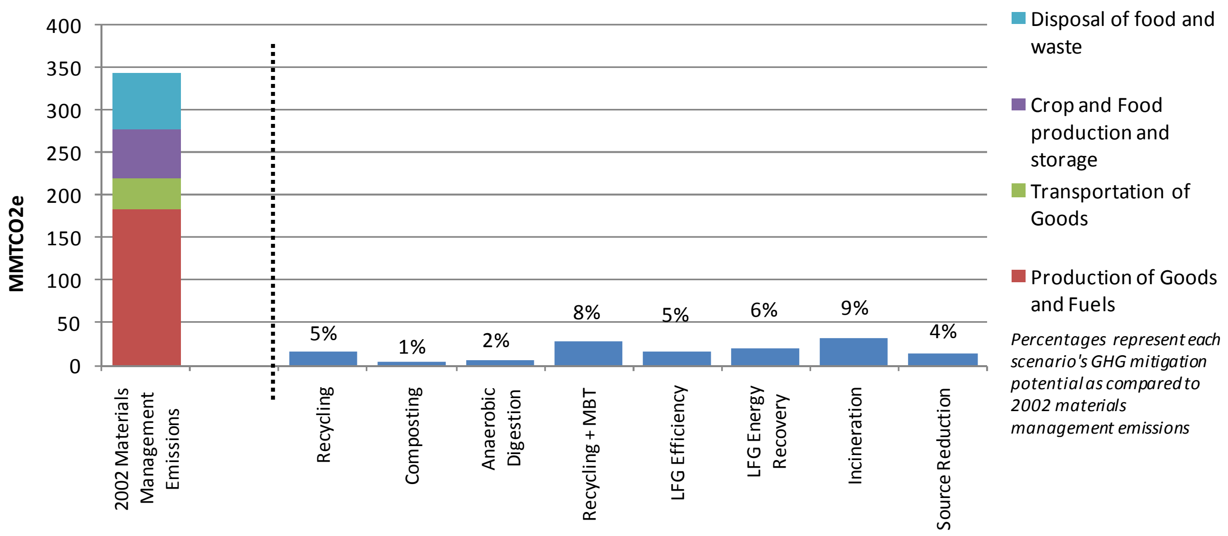
Table 22. Regional percentage of waste generation based on 2000

OECD North America		OECD Pacific	
United States	87%	Australia	83%
Canada	4%	New Zealand	17%
Mexico	9%		

164. The figures below show the comparison between the GHG emissions associated with materials management as described in Section 3 for Australia and Mexico, respectively, with the GHG mitigation potential across the eight modelled alternative MSW management scenarios. The GHG mitigation potential is shown as positive in these figures because it is meant to illustrate GHG *emission reductions* as compared

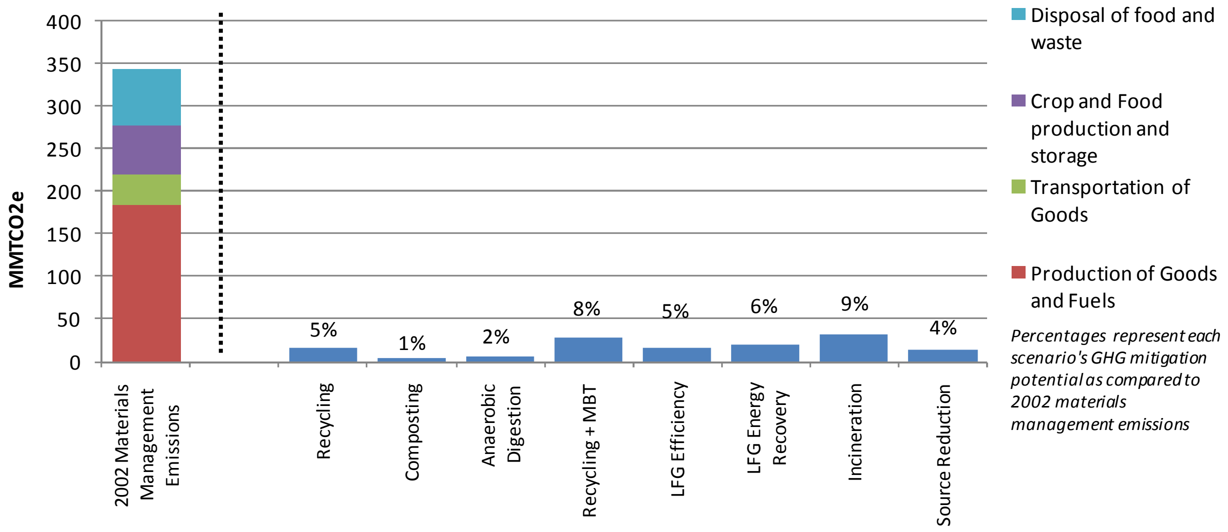
to GHG *emissions* from materials management. Note that the GHG mitigation potential across scenarios is not additive (i.e., scenario results cannot be summed to accurately portray the benefits from implementing multiple scenarios).

Figure 21. Year 2007 Australia GHG Emissions from Materials Management Compared Against scaled OECD Pacific Region GHG Reductions Potential Scenarios in 2030



165. The total GHG emission reductions across the various MSW management scenarios for the scaled OECD Pacific region as modelled in Section 4 represent approximately 1 to 9 percent of the total Australia year 2007 materials management emissions.

Figure 22. Year 2002 Mexico GHG Emissions from Materials Management versus scaled OECD North America Region GHG Reduction Potential Scenarios in 2030



166. The total GHG emission reductions across the various MSW management scenarios for the scaled OECD North America region as modelled in Section 4 represent approximately 1 to 9 percent of the total Mexico year 2002 materials management emissions.

167. The comparisons in Figure 21 and Figure 22 reveal that the total GHG mitigation potential across the different MSW management scenarios represents a narrower focus on MSW management practices relative to the broad scope of materials management activities. However, even within the relatively narrow context of MSW management practices, the life-cycle emission reductions from these scenarios are equivalent to five to ten percent of GHG emissions from materials management activities, and roughly on the order of emissions from the traditional waste sector in emissions inventories, which are estimated to cause three to four percent of anthropogenic GHG emissions globally (IPCC, 2007).

168. In addition to the MSW management practices evaluated in this study, there are other broader opportunities for end-of-life materials management outside of MSW management. These include the management of industrial wastes, agricultural wastes, and construction and demolition wastes as well as implications on land use changes (*i.e.*, landfill, forest and soil carbon storage) that are not addressed in this report. Other materials management opportunities, such as energy efficiency gains at production facilities, policies that reduce GHG emissions in the agricultural sector, and sustainable management of forests, all related to materials management, would further provide GHG mitigation potential related to materials management as well. In analysing the potential GHG mitigation potential through these additional opportunities, accounting for GHG emissions over the life-cycle of materials is instrumental to realising the full potential.

169. The comparison shown in this section should be taken as illustrative only because of a few important caveats:

- **Country versus regional estimates:** Figure 21 and Figure 22 compare scaled regional GHG emissions mitigation potential reductions versus individual country-specific GHG emissions.
- **Different timeframes:** The GHG mitigation emissions from potential MSW management alternatives are based on year 2030 emission reductions from an assumed MSW management

baseline in year 2010. In other words, the GHG benefits resulting from a change in MSW management practices in the year 2030. The estimate of the share of materials management emissions in national inventories refers to data for a single year.

- **Differences in inventory versus life-cycle GHG estimation approaches:** Although the GHG emissions mitigation potential is based on MSW management options, the GHG reductions incorporate life-cycle emissions that span across multiple sectors. For example, the GHG mitigation potential from the recycling MSW management scenario incorporates GHG emissions that are reduced through the displacement of virgin inputs in the manufacturing process, which lowers energy needs in the extraction of raw materials and processing. The share of emissions from materials management similarly takes into account emissions from activities occurring across the material life-cycle; however, it represents a single year (that does not consider the effect of an action today on upstream material production). The GHG mitigation potential, although provided as single values for each scenario, includes emission reductions that may occur over multiple years. In addition, the mitigation potential does not include all of the materials management activities (*e.g.*, crop and food production and storage).