Technical
University of
Madrid

Chapter 3

Climate Change and Waste Land Restoration

María Paz Arraiza
José Vicente López Álvarez
Belén Vázquez de Quevedo Algora
Ángela García de Arana

1 INTRODUCTION TO CLIMATE CHANGE AND WASTE LAND RESTORATION

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

Waste generation does not result in positive impacts on climate. Waste treatment and disposal can have both positive and negative climate impacts. Therefore, an increasingly key focus of waste management activities is to reduce GHG emissions.

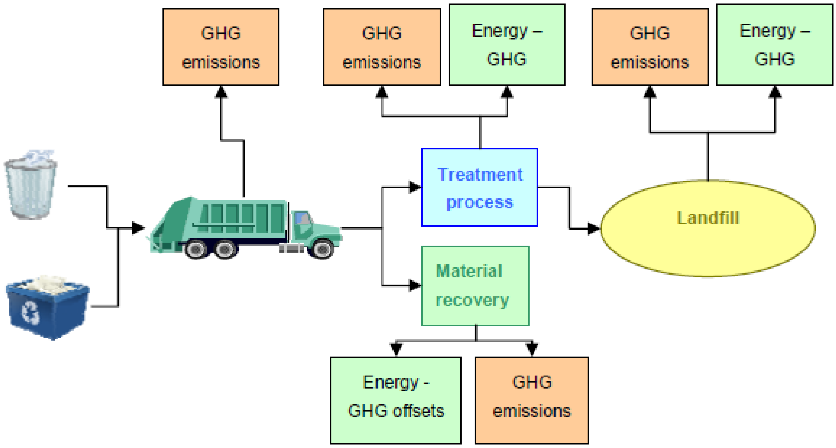


Figure 1. Simplified schematic of waste management system, and GHG emissions (applicable to urban waste management). Source: UNEP Waste and Climate Change Global Trends and Strategy Framework

2 WASTE MANAGEMENT AND GREEN HOUSE GASES (ghg)

2.1 Background

The waste management sector is in a unique position to move from being a comparatively minor source of global greenhouse gas (GHG) emissions to becoming a major contributor to reducing GHG emissions. Although minor levels of emissions are released through waste treatment and disposal, the prevention and recovery of wastes (i.e. as secondary materials or energy) avoids emissions in other sectors of the economy. A holistic approach to waste management has positive consequences for GHG emissions from the energy, agriculture, transport, and manufacturing sectors. A recent report by the US EPA estimates that 42% of total GHG emissions in the US are associated with the management of materials (US EPA 2009). A number of international organisations include waste and climate change initiatives in their portfolio of activities, recognising the considerable climate benefit that could be achieved through improved management of wastes.

2.2 Sources of GHG

2.2.1 Landfill

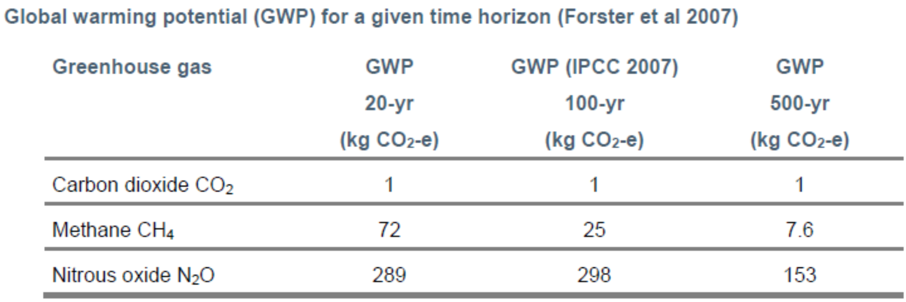
Methane emissions from landfill are generally considered to represent the major source of climate impact in the waste sector (this impact is quantified in later sections). It is worth noting that, if a broader view of waste management were taken, which included materials management, landfill methane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

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

As with any ecological system, optimum conditions of temperature, moisture, and nutrient source (i.e. organic waste) result in greater biochemical activity and hence greater generation of landfill gas.

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

Methane and carbon dioxide (CO_2) are greenhouse gases (GHG), whose presence in the atmosphere contribute to global warming and climate change. Methane is a particularly potent GHG, and is currently considered to have a global warming potential (GWP) 25 times that of CO_2 when a time horizon of 100 years is considered; the GWP is much higher (i.e. 72) when a 20-year time horizon is applied. See the table below:



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

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

Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

Evidently, the choice of time horizon can have a dramatic effect on the estimated climate impact of methane emissions. Ideally, and in-line with IPCC guidance (1995), the choice of time horizon should reflect climate policy, or the climate effect of most concern. For example if the aim of a policy is to reduce the immediate or nearfuture levels of GHG, or minimise the rate of climate change, then a 20-year horizon is most appropriate. However, if the focus is on minimising the 'risk of long-term, quasi-irreversible climate or climate-related changes', then a 100 or 500 year time horizon is most suitable (Fuglestveldt et al 2001). However, as noted by an IPCC scientist: 'the time horizons tend to be misused or even abused. Industries tend to pick the horizon that puts their 'product' in the best light' (Fuglestveldt et al 2001).

In terms of reporting landfill emissions, the Intergovernmental Panel on Climate Change (IPCC) has set an international convention to not report CO_2 released due to the landfill decomposition or incineration of biogenic sources of carbon – biogenic carbon is accounted for under the 'land use / land use change and forestry' (LULUCF) sector (see discussion below, and refer to IPCC (2006) for accounting methodologies). Therefore, where landfill is concerned, only methane emissions are reported, expressed as tonnes of CO_2 equivalent (i.e. 1 tonne of methane is expressed as 25 tonnes of CO_2-e). In practice, methane emissions from landfill are rarely measured, but rather estimated for reporting (United Nations Environment Programme, 2010).

2.2.2 Aerobic composting

Aerobic composting processes directly emit varying levels of methane and nitrous oxide, depending on how the process is managed in practice. Closed systems, such as enclosed maturation bays or housed windrows, reduce emissions through use of air filters (often biofilters) to treat air exiting the facility.

Compost plants require varying, but usually small, amounts of energy input (with associated 'upstream' GHG emissions). Further GHG emissions occur 'downstream', depending on the application of the compost product – CO_2 will be gradually released as the compost further degrades and becomes integrated with soil-plant systems.

2.2.3 Anaerobic composting

Anaerobic digestion (AD) systems are enclosed in order to capture and contain the biogas generated by the digestion process. GHG emissions from AD facilities are generally limited to system leaks from gas engines used to generate power from biogas, fugitive emissions from system leaks and maintenance, and possible trace amounts of methane emitted during maturation of the solid organic output.

Such systems also consume energy, however plants are generally self-sustaining if appropriately operated (i.e. a portion of the biogas output generates energy for use in-plant). 'Downstream' GHG emissions will depend on the application of the matured digestate (as per aerobic compost product). (United Nations Environment Programme, 2010)

2.2.4 Mechanical biological treatment (MBT)

Mechanical biological treatment (MBT) encompasses mechanical sorting of the mixed residual waste fraction, with some recovery of recyclable materials (limited due to contamination), and separation of a fine, organic fraction for subsequent biological treatment.

The biological component may include anaerobic digestion with recovery of biogas for energy/heat generation, or aerobic composting to produce a biologically stable product for either land application (limited applicability) or use as refuse-derived fuel

(RDF) to substitute fuel in industrial furnaces (i.e. coincineration in cement kilns). MBT facilities vary considerably in terms of sophistication, configuration, scale, and outputs. GHG emissions associated with MBT are due to energy inputs (although AD systems may be self-sustaining), direct process emissions (this will depend on the air protection control system, such as a biofilter, attached to the aerobic composting component), gas engine emissions (for AD), and use of the composted organic output (disposed of to landfill or applied to land). There is some use of composted MBT output to remediate contaminated land, however most OECD countries strictly regulate the use of compost derived from mixed waste, and the majority is disposed of in landfill, or used as cover material for landfill operations.

2.3 GHG savings

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

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

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

2.3.1 European Environment Agency (EEA)

Using a life-cycle perspective, this report analyses the greenhouse gas emissions from municipal solid waste management in the EU, plus Norway and Switzerland. Among other important conclusions, it finds that:

- improved municipal solid waste management in these countries has already cut annual net greenhouse gas (GHG) emissions by 48 million tonnes CO2-equivalent between 1995 and 2008;
- the two main factors responsible for this improvement are reduced methane emissions from landfill and increased avoided emissions through recycling;
- if all countries fully meet the Landfill Directive's waste diversion targets, potential life-cycle GHG emissions from municipal waste management in 2020 could be cut by a further 62 million tonnes, which equals 1.23 % of their total GHG emissions in 2008;
- a complete ban on landfilling could cut emissions even further, reducing potential net emissions from waste management in 2020 by 78 million tonnes compared to 2008 — an amount slightly greater than Hungary's total emissions in 2008.

As this report makes clear, better management of municipal solid waste can reduce greenhouse gas emissions significantly. But to tap this potential, the EU's waste directives must be implemented fully — in particular the Landfill Directive.

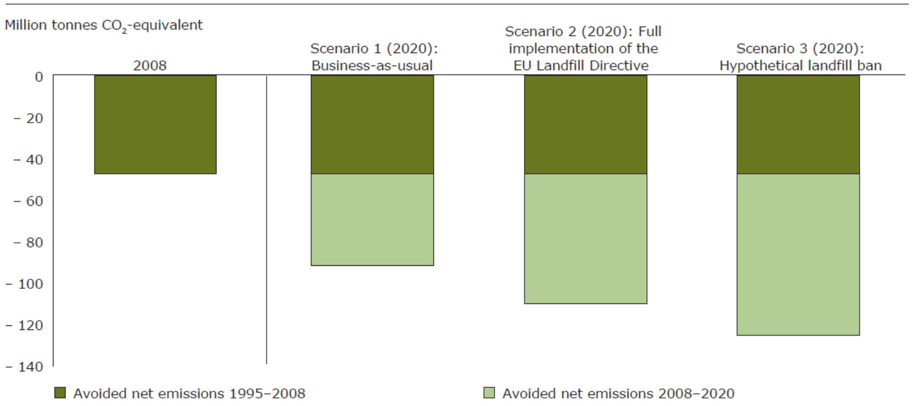
Beyond the progress so far, there is significant further potential to mitigate GHG emissions through better MSW management in the years to 2020.

In order to explore the potential effects on GHG emissions of new waste policies, the EEA and its ETC/SCP developed three scenarios on possible future paths for European MSW management:

- scenario 1 assumes business-as-usual (as presented in Figure 2.1);
- scenario 2 implies full implementation of the EU Landfill Directive;
- scenario 3 models a hypothetical landfill ban on all MSW by 2020 in all countries.

The next figure illustrates the net emission reduction achieved in the period 1995–2008 (in the first column) and the net GHG emission reductions in 2020 compared to 1995 for all three scenarios (in columns two, three and four). The net emission reduction is calculated as the difference between net emissions in 1995 and net emissions in 2008 or 2020, as appropriate.

Net emission reductions from MSW management in the EU (excluding Cyprus) plus Norway and Switzerland in 2008 and 2020 compared to 1995



Source: ETC/SCP. The European Topic Centre on Sustainable Consumption and Production.

2.3.2 European Commission

A resource-efficient Europe is one of seven flagship initiatives as part of the Europe 2020 strategy aiming to deliver smart, sustainable and inclusive growth 1. This is now Europe's main strategy for generating growth and jobs, backed by the European Parliament and the European Council. Member States and the EU institutions are working together to coordinate actions to deliver the necessary structural reforms.

This flagship initiative aims to create a framework for policies to support the shift towards a resource-efficient and low-carbon economy which will help us to:

- boost economic performance while reducing resource use;
- identify and create new opportunities for economic growth and greater innovation and boost the EU's competitiveness;
- ensure security of supply of essential resources;
- fight against climate change and limit the environmental impacts of resource use.

Increasing recycling rates will reduce the pressure on demand for primary raw materials, help to reuse valuable materials which would otherwise be wasted, and reduce energy consumption and greenhouse gas emissions from extraction and processing.

Improved waste management could cut significantly CO_2 emissions. For example, each year the EU disposes of 5.25 billion euro worth of recyclables such as paper, glass, plastics, aluminium and steel.

If this was recycled, the equivalent of 148 million tonnes of CO_2 emissions could be avoided annually. Improved management of municipal waste could result in 92 million tons of greenhouse gas emissions avoided in 2020 compared with 1995. At least 500 000 new jobs would be created in Europe if countries recycled 70% of their waste.

2.3.3 German Federal Ministry for the Environment

Following the entry into force of the Waste Management and Product Recycling Act in 1996, the practice of depositing untreated organic waste as landfill was gradually abandoned in the period up to June 2005.

Thanks to a marked increase in separate collection and processing, and also to waste avoidance and more efficient waste treatment and disposal methods, it has been possible to replace fossil fuels and raw materials. These improvements are entered as credits n the climate balance, where they lead to significant reductions in climate-relevant emissions and savings in fossil fuels.

The balance for 1990 was dominated by methane emissions from landfill sites. Since the balance for 2005 is drawn up without landfill, emission reductions and balance sheet results between 2005 and 2020 are no longer possible on the scale seen between 1990 and 2005. But a potential of over 5 million t CO_2 equivalent remains as an important contribution to the German climate protection target.

On the whole, the disposal paths of waste incineration plants and co-incineration display the greatest potential for reducing emissions of greenhouse gases. Waste paper recycling is also of great importance, while all other paths make smaller contributions to climate protection, and even the expenditure involved in the collection of waste is relatively insignificant, as it is shown in the table below:

Greenhouse gas emissions and remaining reduction options in the scenario period up to 2020, figures in million CO_2 equivalenmt

Disposal path	Emissions 1990	Emissions 2005	Emissions 2020-optimised	Reduction potential from 2005 to "2020-optimised"
Waste incineration	-1.00	-2.47	-5.42	-2.95
Co-incineration	-0.05	-2.16	-3.55	-1.39
Biowaste	0.10	0.19	-0.06	-0.25
Lightweight packaging	0	-0.54	-0.63	-0.09
Waste paper	-0.31	-1.71	-1.65	0.06
Waste glass	-0.39	-0.61	-0.61	0
Bulky waste/waste wood	-0.005	-0.27	-0.3	-0.03
Metals	-0.28	-0.78	-1.55	-0.77
Collection	0.48	0.36	0.36	0
MBT	0	0.21	0.19	-0.02
Landfill	39.23	0.09	0.02	-0.07

Emissions preceded by a minus sign mean that the CO_2 emissions for this disposal path (debit) are smaller than the credit for the processes replaced

Source: German Federal Ministry for the Environment.

2.4 Biogenic carbon

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

- Climate change is time-critical – it is widely accepted that immediate reductions in global GHG emissions are essential to reduce the impact of climate change, immediate efforts should be made to minimise emissions of all CO_2, regardless of source.
- Plant growth – particularly of trees and longer-lived species – does not occur evenly over years and seasons, and the initial up-take of carbon by a seedling is far less than the uptake of carbon by a mature plant. Therefore it could be several

years before a flux of biogenic CO_2 emitted instantaneously from a process (i.e. combustion of biogenic carbon) is re-captured through plant growth.

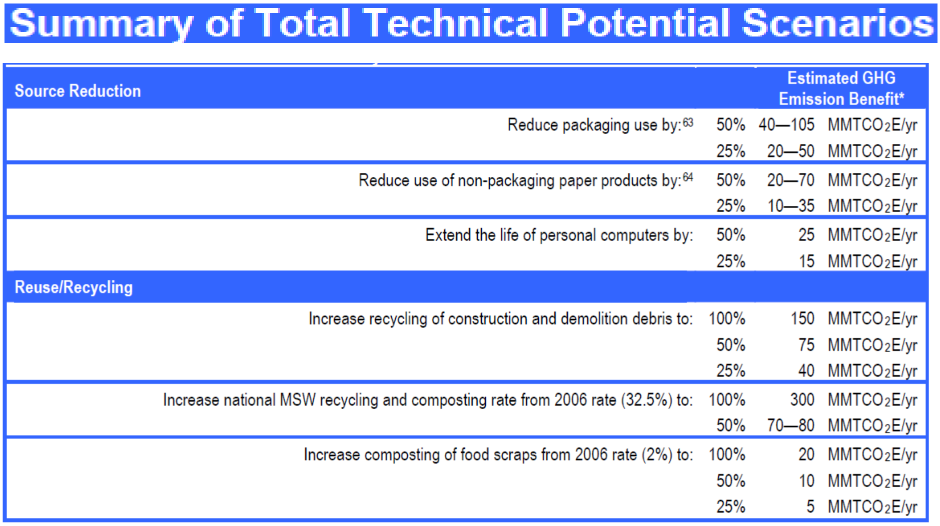
- The majority of wood, paper, and agricultural materials that enter the waste stream have not been produced through sustainable forestry/land practices – unsustainable practices deplete the carbon stored in forests and soil over time. According to IPCC methodologies for reporting national GHG inventories, if any factor '...is causing long-term decline in the total carbon embodied in living biomass (e.g., forests), this net release of carbon should be evident in the calculation of CO_2 emissions described in the Agriculture, Forestry and Other Land Use (AFOLU) Volume of the 2006 Guidelines'. However, it is unclear how and whether this information is being recorded in all cases.
- In a national GHG inventory for IPCC purposes, where deforestation and re-growth is accounted for in the land-use category (LULUCF), there may be an argument for ignoring biogenic carbon. However, in an examination of the GHG impact of waste management systems, where solutions are being sought to reduce emissions in the waste sector, there is justification for including all sources of GHG.
- The benefits that accrue from a reduction in total CO_2, irrespective of the source, would seem to be the best indicator of the consequences of the different options. The key theme is climate change and how to mitigate it, not differentiation of carbon sources.

3 CLIMATE IMPACT OF WASTE

3.1 Potential GHG emissions reductions from materials management

Improved materials management practices throughout the material flow can have a significant impact on Green-House Gas (GHG) emissions. These materials management total technical potential scenarios include life cycle GHG emissions. These scenarios represent the estimated emission reductions that would occur if the scenarios presented were achieved, setting aside economic or practical limitations.

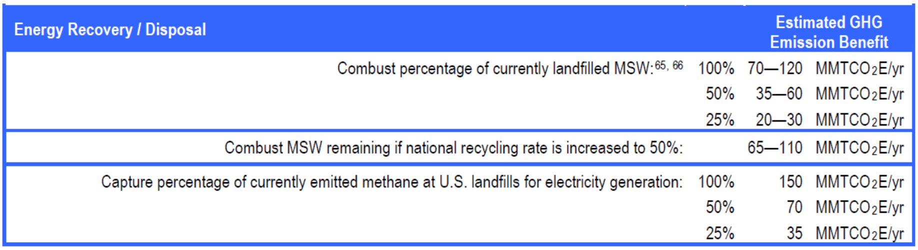
The total technical potential scenarios provided here are not representative of all possible approaches to reduce GHG emissions through materials management. Many of these scenarios focus on the waste stream because the data are limited on materials management strategies that focus on other points in the materials flow. As further research is completed, additional total technical potential scenarios will be developed to understand the GHG emission reductions that could be achieved throughout the materials flow. Potential reductions from some activities are summarized in the next boxes:



Summary of Total Technical Potential Scenarios

Source Reduction		Estimated GHG Emission Benefit*
Reduce packaging use by:[63]	50%	40—105 $MMTCO_2E$/yr
	25%	20—50 $MMTCO_2E$/yr
Reduce use of non-packaging paper products by:[64]	50%	20—70 $MMTCO_2E$/yr
	25%	10—35 $MMTCO_2E$/yr
Extend the life of personal computers by:	50%	25 $MMTCO_2E$/yr
	25%	15 $MMTCO_2E$/yr
Reuse/Recycling		
Increase recycling of construction and demolition debris to:	100%	150 $MMTCO_2E$/yr
	50%	75 $MMTCO_2E$/yr
	25%	40 $MMTCO_2E$/yr
Increase national MSW recycling and composting rate from 2006 rate (32.5%) to:	100%	300 $MMTCO_2E$/yr
	50%	70—80 $MMTCO_2E$/yr
Increase composting of food scraps from 2006 rate (2%) to:	100%	20 $MMTCO_2E$/yr
	50%	10 $MMTCO_2E$/yr
	25%	5 $MMTCO_2E$/yr

Source: EPA, United States Environmental Protection Agency. Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices, 2009.



Energy Recovery / Disposal		Estimated GHG Emission Benefit
Combust percentage of currently landfilled MSW:[65, 66]	100%	70—120 $MMTCO_2E$/yr
	50%	35—60 $MMTCO_2E$/yr
	25%	20—30 $MMTCO_2E$/yr
Combust MSW remaining if national recycling rate is increased to 50%:		65—110 $MMTCO_2E$/yr
Capture percentage of currently emitted methane at U.S. landfills for electricity generation:	100%	150 $MMTCO_2E$/yr
	50%	70 $MMTCO_2E$/yr
	25%	35 $MMTCO_2E$/yr

Source: EPA, United States Environmental Protection Agency. Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices, 2009.

3.2 Reducing or avoiding GHG emissions through land management practices

Land management has three key components: land protection, sustainable land use, and land revitalization. Similar to the materials management approaches that can be used in the material flow, land management approaches can be used to reduce GHG emissions by improving practices within or across each of these components. Land protection practices limit how much land is contaminated each year. When land is contaminated, it should be cleaned up to levels protective of human health and the environment.

Sustainable land use practices include those that promote the sustainable use and development of land (including managing land for agricultural and forestry purposes), and minimizing greenfield development. Land revitalization practices promote the cleanup and reuse of contaminated land. By considering the impact of land management throughout its life cycle, this implies significant reductions in GHG emissions. Decisions at the local, or national level related to the cleanup, restoration and/or reuse of contaminated land (i.e., land revitalization) can also reduce GHG emissions.

Many organizations involved with cleaning up contaminated land may find opportunities to employ cleanup techniques that provide an equivalent level of environmental and human health protection while emitting lower amounts of GHGs through:

1. Optimizing remedies and treatment systems both for new and existing remedies;
2. Using alternative energy derived from cleaner and renewable energy sources; and
3. Accounting for the technical needs of potential reuse options and incorporating them throughout the cleanup processes to facilitate sustainable reuse of the property and preservation of greenfields.

Sequestering carbon on these sites is another potential benefit from some cleanup and reuse activities—particularly on former mine lands. At some sites, organic soil amendments can be used to remediate the site, boosting the amount of carbon sequestered in the soil and enhancing vegetation growth. This remediation approach also provides a use for some organic soil amendments such as biosolids which may otherwise be a waste product.

Land cleanup activities may also provide recycling opportunities to further bolster EPA's approaches to materials and land management. For example, reusing and recycling construction and demolition debris from buildings on contaminated land is another effective materials and land management practice; this practice not only reuses both materials and land, but also prevents other land from being used for the disposal of construction and demolition debris.

After cleanup is complete, sustainably reusing land protects the land based carbon sink, by providing sites that can be reused for development, instead of developing greenfields. Reusing these restored properties can also reduce GHG emissions associated with the infrastructure expansion needed to connect newly developed greenfields to already developed areas. Policies that promote land reuse in place of new land development and denser mixed use development—key aspects of smart growth—will avoid the majority of infrastructure and bio-carbon emissions. Sites can also be ecologically restored to increase the amount of undeveloped land and expand the land-based carbon sink. These are some examples of land management approaches that help reduce GHG emissions:

Carbon Sequestration: EPA is studying the potential carbon sequestration that occurs when soil amendments are used to remediate sites.

Land Revitalization: To date, EPA has helped make more than 917,000 acres of previously contaminated lands ready for anticipated use, reducing pressure on greenfields and helping preserve the land-based carbon sink. EPA is promoting the development of renewable energy resources as one particularly promising land revitalization strategy with multiple environmental benefits.

Smart Growth: Smart growth has been shown to reduce household vehicle miles traveled by 20-40% compared with conventional development practices. For example, residents of Atlantic Station, a noted smart growth development, drive an average of 13.9 miles per day, compared to a regional average of 33.7 miles per day.

Green Remediation: Green remediation practices are being employed at contaminated sites, which can reduce GHG emissions. For example, some remediation projects use solar energy to operate ground water pump and treat systems; others are reducing construction engine idling time, and using alternative fuels to reduce GHG emissions.

3.3 Trends in waste generation and management

The long-term vision for the waste sector is to establish a circular global economy in which the use of materials and generation of waste are minimised, any unavoidable waste recycled or remanufactured, and any remaining waste treated in a way that causes least damage to the environment and human health or even creating additional value by recovering energy from waste. To achieve this vision, radical changes to supply-chain management, especially to the product and industrial design part of the supply chain, are needed. Specifically, the 3Rs need to guide industrial design – with implications for materials at all stages – and be overlaid on the entire supply chain. This requirement is, in turn, expected to motivate innovation. The chapter on manufacturing further elaborates on life-cycle approaches, including closed loop and circular systems in manufacturing.

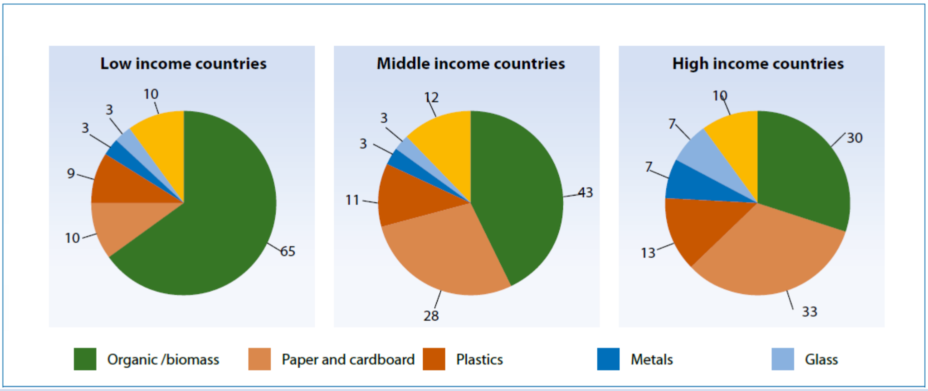
The waste sector is facing three sets of challenges:

1. Increasing growth in the quantity and complexity of waste streams associated with rising incomes and economic growth;
2. Increasing risk of damage to human health and ecosystems; and
3. The sector's contribution to climate change.

The exploitation of the earth's resources continues apace; material use increased eight-fold in the last century (Krausmann et al. 2009). According to the Wuppertal Institute, an average European consumes about 50 tonnes of resources a year, around three times the amount consumed per capita by emerging economies. Furthermore, on average, Europeans dispose twice as much as citizens from emerging economies (Bleischwitz 2009). Per-capita resource use in emerging economies is also increasing considerably while the world's Least Developed Countries (LDC) are beginning the transition towards an industrial type of societal metabolism, as incomes rise and purchasing power is deployed in consumer spending.

Currently, 3.4-4 billion tonnes of municipal and industrial waste are produced every year, of which non-hazardous industrial waste accounts for 1.2 billion tonnes (Chalmin and Gaillochet 2009). A major share of the waste generated is MSW originating from urban settlements (1.7-1.9 billion tonnes, or 46 per cent of the total waste generated) with 0.77 billion tonnes of this being produced by 25 Organisation for Economic Cooperation and Development (OECD) countries alone (UNEP 2010).

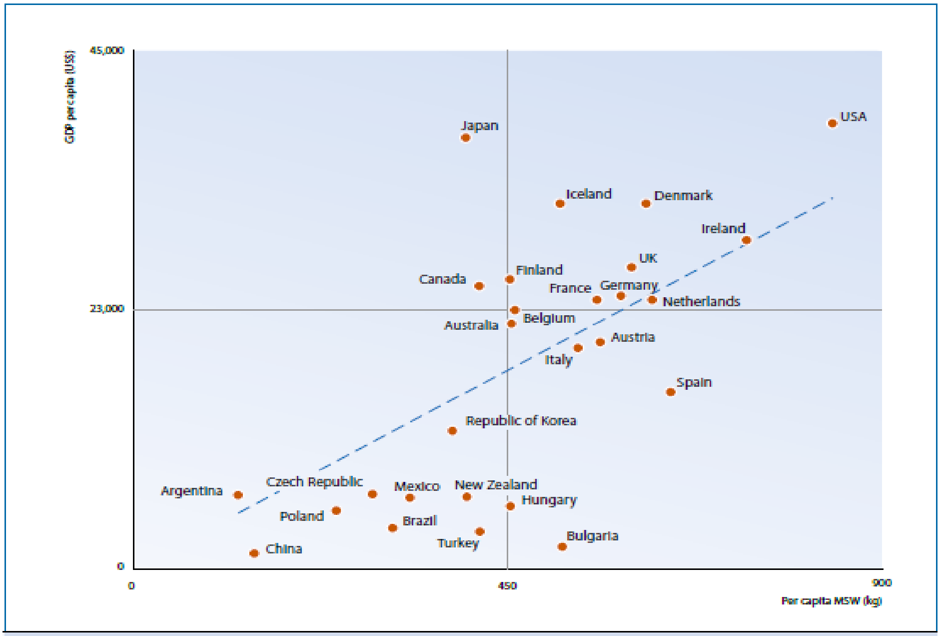
As a country develops and becomes wealthier, the composition of its waste stream typically becomes more varied and complex. The following figure illustrates the high proportion of organic-rich MSW in middle and lower income countries with a gross national income per capita of less than US$ 12,196, while the high-income countries' MSW streams contain a large proportion of paper and plastics.



Composition of MSW by national income

Source: Chalmin and Gaillochet (2009) and averaged

Waste generation is linked to both population and income growth. Of the two, income level is the more powerful driver. The following figure shows the correlation between MSW generation and GDP. In high-income countries, an urban population of 0.3 billion generates approximately 0.24 million tonnes of MSW (0.8 kg per capita per day), while in low-income countries around the same amount (0.26 million tonnes per day) is generated by 1.3 billion people (0.2 kg per capita per day), a quarter of the level high-income countries.



Quadrant	Economic status and waste generation	Country and year of data	
Q1	GDP: More than US$ 23,000 Waste: More than 450 kg per capita	USA: United States of America[a] (2006) IRL: Ireland (2004) DNK: Denmark (2005) ISL: Iceland (2004) GBR: United Kingdom (2004)	NLD: Netherlands (2004) DEU: Germany (2004) FRA: France (2004) BEL: Belgium (2002)
Q2	GDP: More than US$ 23,000 Waste: Less than 450 kg per capita	FIN: Finland (2004) CAN: Canada (2004)	JPN: Japan[e] (2007)
Q3	GDP: Less than US$ 23,000 Waste: Less than 450 kg per capita	BRA: Brazil[b] (2002) ARG: Argentina[c] (2002) CHN: China[d] (2004) POL: Poland (2005)	CZE: Czech Republic (2005) MEX: Mexico (2006) KOR: Republic of Korea (2002) NZL: New Zealand (1999) TUR: Turkey (2004)
Q4	GDP: Less than US$ 23,000 Waste: More than 450 kg per capita	AUS: Australia (2002) HUN: Hungary (2004) BGR: Bulgaria[f] (2003)	ITA: Italy (2004) AUT: Austria (2004) ESP: Spain (2004)

Note: US$ 23,000 represents the median point in the GDP data.

GDP per capita vs. MSW per capita[1]

Source: MSW data source from a EPA (2007), b Borzino (2002), c Methanetomarkets (2005), d World Bank (2005), OECD (2008) and e Yatsu (2010) and f GHK (2006); Population data available at http://esa.un.org/wpp/; GDP data sourced from World Bank.

The figure below shows estimates of MSW generation in different parts of the world. It rose in the US and the EU by 21 per cent and 14 per cent respectively from 1995 to 2007. However, due to increased awareness and policy interventions addressing waste management (for example, EU regulations stimulating recycling of obsolete vehicles since 2000 and electrical and electronic waste since 2002), the rate of MSW generation slowed in the EU and (to a lesser extent) in the US in the period from 2003 to 2007. The linkage between affluence and waste generation remains quite strong, in spite of improvements in efficiency, and represents a significant challenge for developing countries as they become wealthier, particularly in Asia (World Bank 1999).

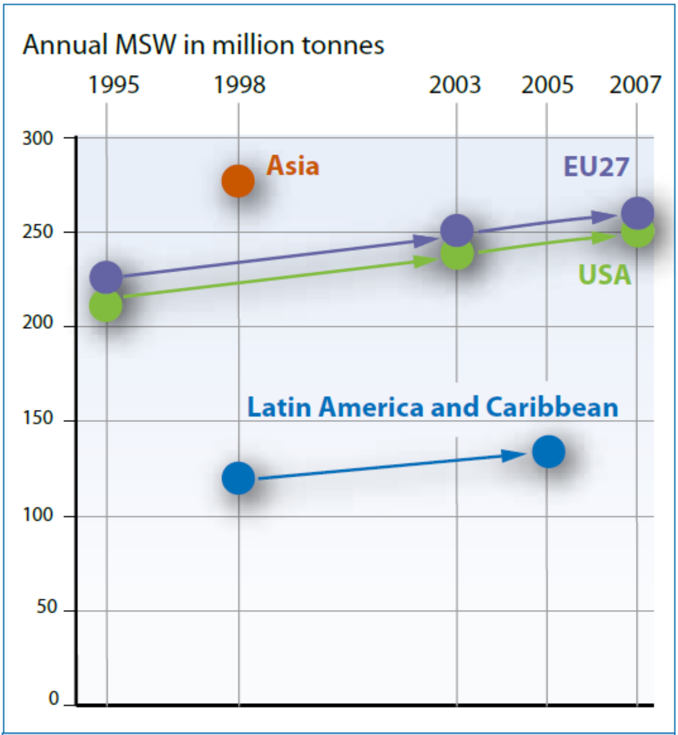


Figure 4: Estimated generation of MSW across regions of the world

Source: Acurio et al (1998), World Bank (1999), EPA (1999) and (2009), Hoornweg and Giannelli (2007) and Eurostat (2010)

At best, relative decoupling has begun in OECD countries, with a stabilisation of per-capita waste generation in the last decade, as shown in the next figure. The recent awareness on benefits of waste minimisation, but also the shifting of waste-intensive production to developing and emerging countries may have contributed to this development. Landfill remains the predominant method of disposal in these countries (OECD 2008).

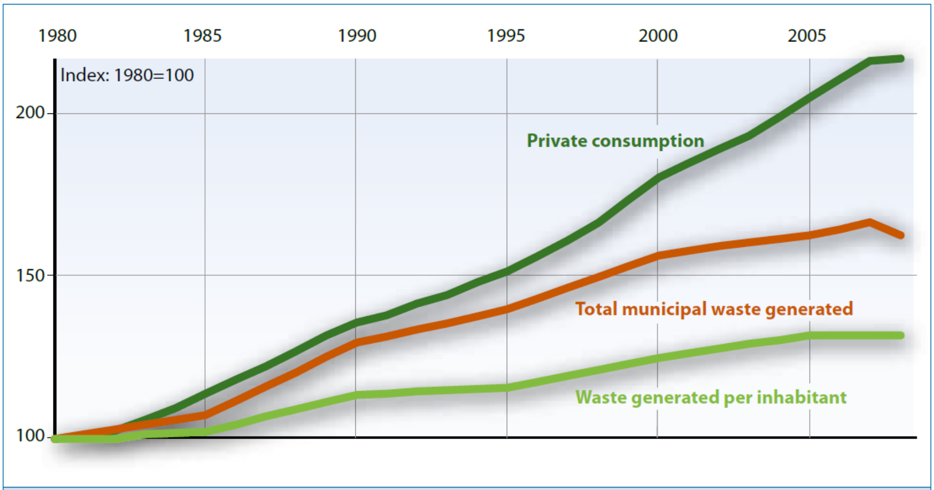


Figure 5: Relationship between private consumption and municipal waste in OECD countries
Note: The indicators presented here relate to amounts of municipal waste generated. They show waste generation intensities expressed per capita and per unit of private final consumption expenditure (which excludes public expenditures on education, health and similar categories) in 2006, and related changes since 1980.

Source: OECD (2008).

The rapid pace of industrialisation around the world has brought about increasing demand for metals, which are considered as core raw materials for infrastructure and manufacturing of products. The demand for metals is expected to maintain dynamic in the future: in developing countries due to economic growth, and in industrialized countries due to modern technologies with dissipative metal applications. Since metals are a finite resource, the potential challenge on metal supply could be addressed through recycling across the life-cycle.

Among the various steps of the metal life-cycle, societal or in-use metal stocks, which include all metals put into use and currently providing service, are the most relevant metal stocks to focus. On a global level, most of the world's in-use stocks reside in more developed countries. For instance, Japan and the United States posses the highest in-use stocks and exceed the value of China by 9 and 13 times. Moreover, data suggests that per capita inuse stocks in more-developed countries typically exceed those in less-developed countries by factors of 5 to 10.

One of the key strategies in meeting this increasing demand is to take advantage of anthropogenic mines, or urban stocks, which has a great potential to reduce dependency on virgin metal resources and mitigate the environmental degradation caused by mining activities. However, tremendous weak points have been found in global metal recycling. For instance, mass-scale use of specialty metals like gallium, indium, etc, in the last three decades and the lack of infrastructure for recycling in many developing countries has led to dissipative losses of such metals.

Thus, the recycling rates for some of the metals, especially specialty metals are relatively low. It has been recognized that creating a circular economy is key for increasing metal needs of the future. Setting of appropriate metal recycling infrastructure and services in urban areas - that are tomorrow's metal mines – is essential and should be given high priority.

The International Resource Panel decisively states that it is important to enhance capacity building, technology transfer and international cooperation in developing countries through international recycling conferences, technological implementation programmes and specific scientific exchange programmes.

The Panel also highlights three key issues that require urgent attention:

- Research & development. Data acquisition and analysis, recycling technologies research, and other research and development efforts should be a priority in the development process. Global data on a large variety of metals on equal spatial and temporal resolution is actually not available
- Stopping illegal waste transport. International organisations like UNEP and OECD have to multiply their engagement in the monitoring and controlling of illegal scrap exports.
- Continuous improvements of legislative systems. The more developed countries should reinforce their attempts to help the less developed countries install appropriate legislative systems and ensure their enforcement in order to take advantage of metal stocks in society.

Waste volumes are not necessarily the most important challenge ahead. Mixed MSW, hazardous health-care waste, and industrial waste streams can impose serious health and ecological risks if these wastes remain uncollected or dumped in uncontrolled and unsecured landfill sites. In low income countries, for example, collection rates are lower than 70 per cent, with more than 50 per cent of the collected waste disposed through uncontrolled landfilling and about 15 per cent processed through unsafe and informal recycling (Chalmin and Gaillochet 2009). Given the amount of valuable components in MSW, the mixing of wastes also means a lost opportunity to recover components that could be recycled and used as new resources.

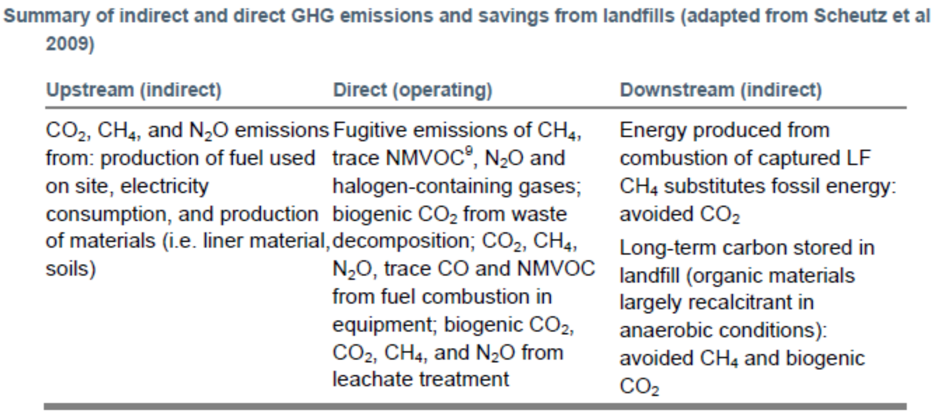
3.4 Climate impact of waste management practices

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

3.4.1 Landfill

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

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



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

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

NMVOC refers to non-methane volatile organic compounds.

Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

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

- Where landfill practices are informal and do not extend to site compaction and cover, the optimum anaerobic conditions for methane-production do not develop. Therefore less methane is produced per tonne of organic waste (compared to controlled sites). Degradation processes proceed under more aerobic conditions, generating larger quantities of biogenic CO_2.

- There is a trend towards more managed landfill practices in developing nations, which will somewhat ironically lead to enhanced anaerobic conditions and therefore generation of greater quantities of methane in the future. However, higher methane generation does mean that landfill gas capture systems become more economically viable.

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

Over a 100-year period, managed landfills of the type seen in developed countries may capture around 50 – 80% of methane generated (Manfredi et al 2009, Bahor et al 2009). Landfills in economies in transition regions are estimated to capture around 35% of methane generated.

Certain waste materials are largely recalcitrant in landfills – non-biodegradable materials (i.e. plastics), lignin and some lignin-bound cellulose and hemi-cellulose undergo minimal decomposition in the anaerobic conditions within managed landfills (Barlaz 2006). A high proportion of wood waste, for example, may be considered as carbon stored in landfills while anaerobic conditions prevail. It must be emphasized that, purely from a climate change perspective, burying wood in landfills may be part of the solution; however, there are myriad other reasons (i.e. ecological, resource use, land use) for not doing this.

Diversion of organic wastes from landfill and implementation of active systems for landfill gas extraction are complimentary to an extent: due to the gradual release of methane over many years, even if a ban on landfilling organic waste were implemented at a site today, there would still be an existing store of organic material releasing methane, that could be extracted into the future.

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

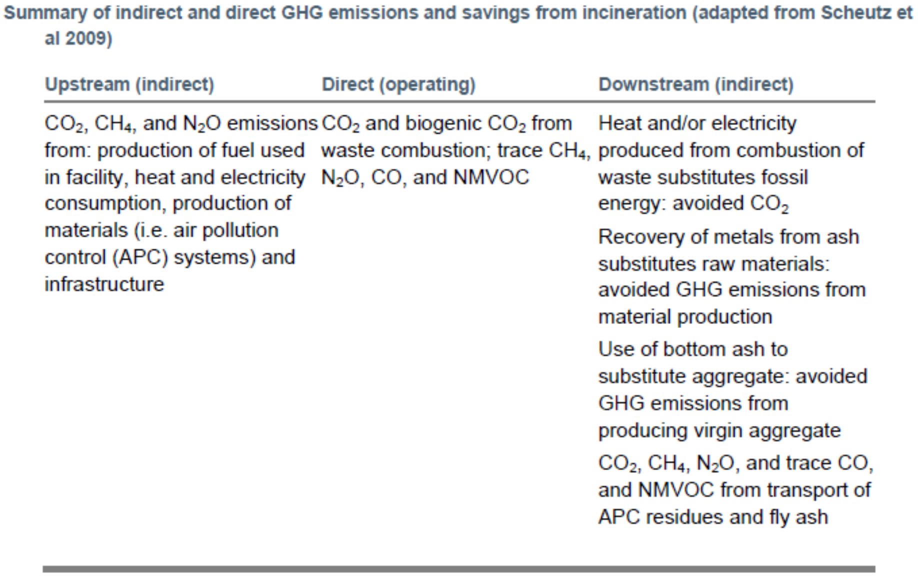
3.4.2 Thermal treatment

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

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

At the global level, the climate impact of incineration is minor compared to that of landfilling, contributing around 40 Mt CO_2-e in the current year (Bogner et al 2007). Typically only fossil CO_2 is counted as a GHG emission from incineration; therefore, the overall climate impact of incineration will be highly influenced by the fossil carbon content of the input waste. Downstream, indirect GHG savings due to energy generation may dominate an estimate of emissions from incineration, depending on the energy assumed to be replaced. The next table provides a qualitative summary of the indirect and direct GHG emissions and savings associated with incineration. To provide a complete picture, all GHGs are noted, including biogenic CO_2.

Thermal technologies could have a valuable role to play in the treatment of specific streams of wastes, or carefully prepared mixed residual wastes, as part of an integrated and future-thinking waste management system. In many countries, thermal treatment plants require long lead-times (i.e. >10 years) to meet planning approval, financing, construction, and commissioning. In addition, facilities will last for at least 25 years with limited flexibility for changing waste supply, which suggests that capacity needs to be planned for carefully. This suggests that such facilities may be part of a longer-term strategy for climate abatement.



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

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

Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

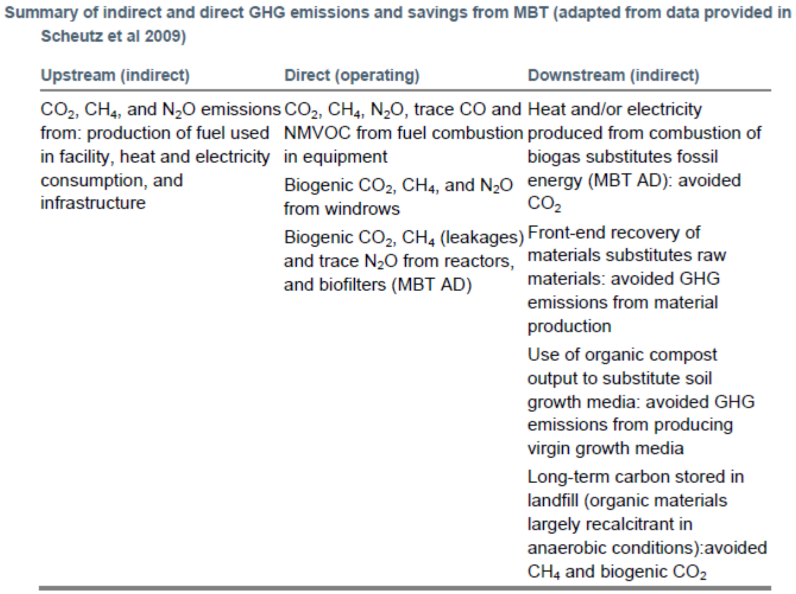
3.4.3 Mechanical biological treatment (MBT)

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

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

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

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



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

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

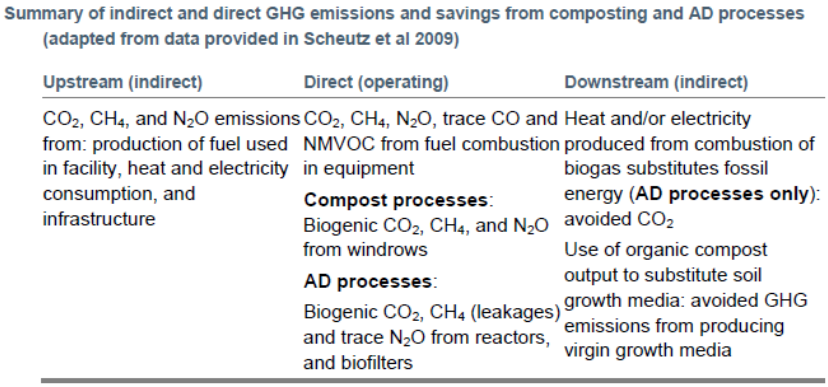
Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

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

3.4.4 Composting and anaerobic digestion

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

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



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

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

Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

Direct emissions from composting facilities result from fuel combustion in equipment (i.e. frontloaders) and from decomposition of the organic material. As composting produces CO2 from biogenic carbon sources, it does not contribute to national GHG inventories for the waste sector under IPCC accounting methods (IPCC 2006). CH_4 and N_2O emissions will depend on the type of organic waste input, the technology used (in particular, whether the process is open or enclosed), and how the process is managed (Boldrin et al 2009).

Once compost is applied to land, further, minimal emissions will be generated as organic compounds are gradually mineralised to biogenic CO_2. Therefore, compost applied to soil has a medium or long-term potential to store carbon; however, it does not represent a permanent solution for 'locking-up' carbon (Smith et al 2001; Favoino and Hogg, 2008). Quantifying the climate benefit of carbon storage is extremely difficult and will largely depend on how the soil landscape is managed (cropping, tillage, irrigation, compost application rate, etc), climate, and original carbon content of the compost and soil.

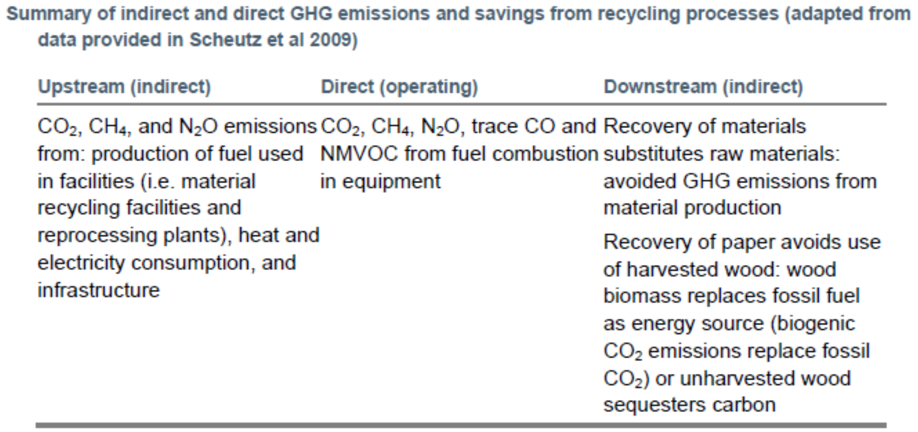
Anaerobic digestion (AD) of source-separated organic wastes is an alternative to aerobic composting systems; although AD tends to accept a smaller range of materials (i.e. materials with a high lignin content, such as woody garden wastes, are generally not suitable for AD in large quantities). The biogas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

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

3.4.5 Recycling

After waste prevention, recycling has been shown to result in the highest climate benefit compared to other waste management approaches. This appears to be the case not only in the OECD (i.e. ISWA 2009, Christensen et al 2009, US EPA 2006) but also in developing countries (i.e. Pimenteira et al 2004, Chintan 2009), although limited data is available. For example, in the US, recycling materials found in MSW resulted in the avoidance of around 183 Mt CO_2-e in 2006 (US EPA, 2009). Estimates of GHG savings are generally based on the premise that recycled materials replace an equal – or almost equal – quantity of virgin materials in a closed-loop recycling system (i.e. where material is reprocessed back into the same or a similar product). Industrial symbiosis involves the exchange of resources including by-products among industrial enterprises, which may form 'recycling clusters' to facilitate sharing resources.

The next table provides a qualitative summary of the indirect and direct GHG emissions and savings associated with recycling processes. To provide a complete picture, all GHGs are noted, including biogenic CO_2.



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

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

Source: UNEP. Waste and Climate Change Global Trends and Strategy Framework.

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

- On average, virgin production of paper followed by incineration with energy recovery consumes twice as much energy as paper recycling; however, the GHG benefit of recycling paper depends largely on the system boundaries adopted by the individual LCA studies (in particular, whether the GHG 'cost' of using timber to produce paper is accounted for)

- Closed-loop recycling of glass results in net climate benefits compared to incineration. There is insufficient data on open-loop recycling (i.e. glass recycled into aggregate, insulation, or other secondary product) to determine the net GHG impact
- - Where recycled plastic replaces virgin plastic of the same kind in ratio of 1:1 (by weight), recycling of plastic was found to have a net environmental benefit compared to incineration. For every kg of plastic recycled, around 1.5 – 2 kg CO_2-e is saved.
- Production of virgin aluminium requires 10-20 times more energy than recycling aluminium. Although regional differences in energy sources cause large variations in the extent of GHG savings, there is a universal climate benefit in recycling aluminium.
- Production of virgin steel requires around two times as much energy as production of steel from recycled scrap. As above, regional differences in energy sources may cause variations in the extent of GHG savings; however there is a universal climate benefit in recycling steel.

The role of the informal recycling sector should not be underestimated in developing nations. The World Bank estimates that around 1% of the urban population in developing countries (approximately 15 million people) earns their livelihood from waste-picking and the informal recycling sector (Medina 2008).

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

3.5 Waste prevention

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

Since the early 1990s, the EU has been actively developing waste-related policy measures. The following EU Directives and Strategies have been instrumental in greening the region's waste management industry: Packaging (1994), Waste Communication Strategy (1996), Landfill (1999), End of Life Vehicles (EoLV 2000), Waste Electrical and Electronic Equipment (WEEE 2002), the Thematic Strategy on Waste Prevention and Recycling of Waste and Sustainable Use of Natural Resources (2005), the EU's revised Waste Framework Directive (2008) and the Raw Material Initiative (2008).

Meeting the 85 per cent EoLV target by 2006 had the potential to reduce the landfilling cost for the EU by € 80 million per year, which is a cost saving of 40 per cent, compared to the cost that prevailed prior to the directive. Meeting the 95 per cent target by 2015 will reduce the cost further by 80 per cent (GHK and Bio Intelligence Service 2006).

Individual countries have also moved forward with waste related regulations and their enforcement. The German Packaging Ordinance introduced in 1991 helped encourage recycling of packaging waste which is collected through a third party organisation. British Columbia Recycling Regulation of 2004 brought about a considerable increase in the proportion of recycled waste in Canada.

Developing-country examples include the Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution adopted in 1995, South Africa's National Waste Management Strategy in 1999, India's Municipal Waste Management and Handling Rules in 2000, the Philippines's Ecological Solid Waste Management Act in 2000, Malaysia's Solid Waste and Public Cleansing Management Act in 2007 and

Indonesia's Act regarding Waste Management in 2008. Although the real effects of such measures will come from implementation, the existence of these instruments provides a signal of political commitments to greening the waste sector.

In terms of climate change impact, the benefits of waste prevention generally outweigh benefits derived from any other waste management practice: not only are net GHG emissions avoided from treatment and disposal of the waste, but there is also a noteworthy benefit in avoided GHG emissions from less raw resource extraction and manufacturing.

A US EPA study found that, generally, the net GHG emissions for a given material are lowest for source reduction and highest for landfilling (US EPA, 2006). This is especially true for prevention of paper waste where GHG savings are attributed to increases in forest carbon sequestration (i.e. less use of virgin forest materials to produce paper products equates to less deforestation). A recent report produced by the US EPA Office of Solid Waste and Emergency Response (US EPA 2009) examines how GHG emissions could be prevented through alternative management of materials (US EPA, 2009). An estimated 42% of total US GHG emissions are due to materials management. Strategies discussed in the report include source reduction through improved product design and cleaner production, increasing product durability, and maximising the ease of product disassembly (for recycling).

3.5.1 European Union: The Landfill Directive

Issued in 1999, the Landfill Directive was a milestone in EU waste policy. It marked a decisive shift from landfill towards the EU's new waste hierarchy, which prioritizes waste prevention, followed by re-use, recycling and recovery, and seeks to avoid landfilling wherever feasible.

Determining the extent to which EU policies have effected change in national waste management practices is a complex task. The process of diverting biodegradable municipal waste from landfill commenced at different times in the countries and region studied and has proceeded at varying speeds. In addition, urbanization and population density are obviously important socio-economic drivers for diverting waste from landfill.

The Landfill Directive's success is based on two core factors. First, its combination of long-term and intermediate targets has provided a good framework for countries to landfill less biodegradable municipal waste. In particular, the targets have helped governments and the European Commission measure progress and keep attention on the core issues. Second, the directive's flexibility has been an important asset, affording Member States the space to try out alternative policies, adjust measures to match national and regional realities (including existing waste management practices, institutional structures and environmental conditions), and adapt policies in the light of experience. Evidently, the Landfill Directive has had the greatest impact in locations where the process of shifting away from landfill was not already under way.

The strategies usually include a combination of recycling, incineration, and/or mechanical-biological treatment:

- Closing landfills is an important driver for adopting new waste treatment options. The number of landfills in the countries and region studied decreased significantly in the last 10–15 years, mostly through the closure of dumpsites and other low standard sites. Although this probably implies a reduction in total landfill capacity, data on current waste generation and landfill rates indicate that existing capacity in most countries is sufficient for many years to come.
- Incineration capacity has increased significantly as governments have tightened emissions standards.
- Separate collection of biodegradable municipal waste fractions (mainly paper and cardboard, packaging waste, and food and garden waste) is increasingly used to divert biodegradable waste from landfill.
- Mechanical-biological treatment is used as an alternative option to incineration to treat mixed municipal waste, in fact capacity for mechanical-biological treatment has doubled or tripled in some countries. The countries studied that use this treatment option all use or are planning to use dedicated incineration and co-incineration of the refuse-derived fuel produced to generate energy.
- Since 1999, capacity at composting and anaerobic digestion plants has increased in most countries.
- If composting is to play a role in diverting waste from landfill then a well-functioning market for compost is needed. This in turn necessitates that the products of biological treatment of biowaste are of good quality.

To comply with the provisions of the Landfill Directive, countries have introduced various measures to increase the cost of landfilling. The increasing gate fees mainly result from rising technical standards for landfills and implementation of the principle that gate fees should cover all costs involved in the setting up, operating and closing landfills.

It is important to note that when governments and competent waste management authorities set waste management objectives and targets these must be clearly defined. Governments also need to designate clearly the institutions and actors responsible for meeting them. Cooperation between municipalities or larger geographical units such as provinces or districts plays an important role in ensuring that necessary financial and human capacity is available to develop alternatives to landfill.

An often overlooked problem in waste recycling is the lack of acceptance of waste-derived products among potential users. Lack of public acceptance is also very often an obstacle for the introduction of waste incineration. People have tackled incineration's poor reputation in the past by setting ambitious emission standards. Policy measures and instruments that the public traditionally regards positively; for example separate collection of waste paper, can be further strengthened. In addition, regular communication activities are important to keep households and others aware and active in separating waste and participating in home composting schemes.

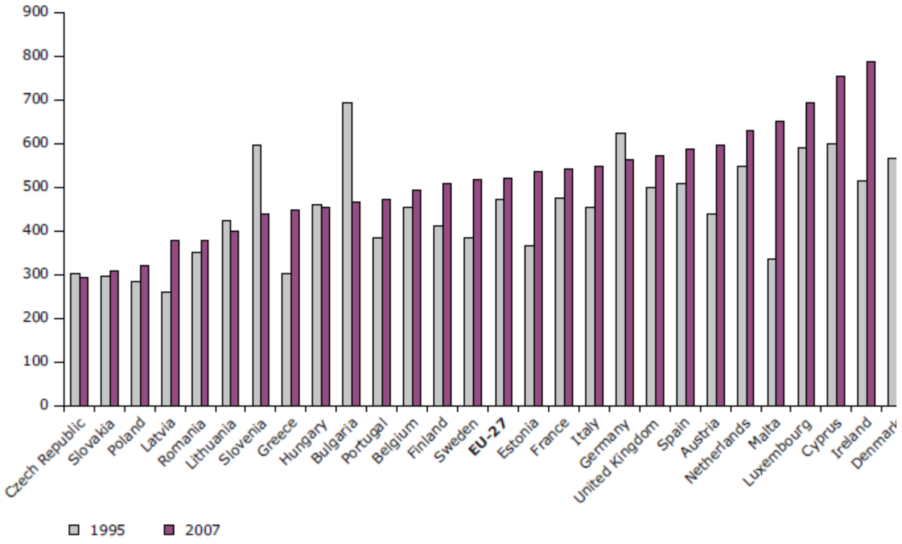
3.5.2 Waste management in the EU-27

The Sixth Environment Action Programme (2002–2012) sets out the EU's key environmental objectives. One of the overall goals is to decouple resource use and waste generation from the rate of the economic growth. The programme also targets a significant, overall reduction in the volumes of waste generated through waste prevention initiatives and a significant reduction in the quantity of waste going to disposal. It further encourages reuse and aims to reduce the level of hazard, giving preference to recovery and especially recycling, making waste disposal as safe as possible, and ensuring that waste for disposal is treated as close as possible to its source.

According to the new Waste Framework Directive (2008/98/EC), the European Commission will propose measures to support waste prevention activities, e.g. by setting prevention and decoupling objectives for 2020. Also by 2020, at least 50 % of waste materials such as paper, glass, metals and plastic from households and possibly from other origins must be recycled or prepared for re-use. The minimum target set for construction and demolition waste is 70 % by 2020.

On average (unweighted), the European citizen generated 10 % more waste in 2007 than in 1995 (Eurostat). The waste volume grew even faster (11.5 %) in the EU-15 Member States. As the next figure illustrates, these aggregated figures mask considerable differences between Member States.

Generation of municipal waste in the EU-27, 1995 and 2007



Source: Eurostat Structural Indicators

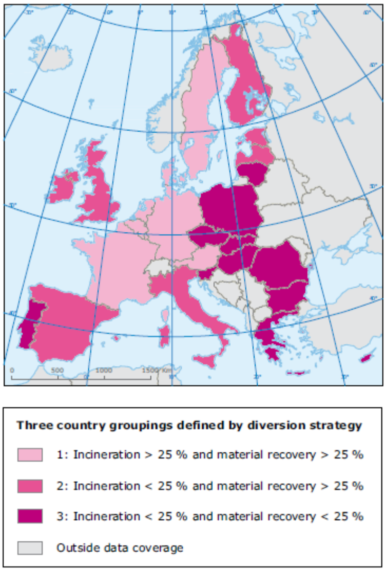
3.5.3 Development of municipal waste management

Broadly speaking, Member States can be categorised under three waste management 'groupings', clustered according to their strategies for diverting municipal waste away from landfill and their relative shares of landfilling, material recovery (mainly recycling and composting) and incineration (EEA, 2007a).

The first grouping comprises countries that maintain high levels of both material recovery and incineration, and have relatively low landfill levels. Countries in this group generally introduced several policy instruments early, often before the adoption of Directive 94/62/EC on packaging and packaging waste (hereinafter referred to as 'the Packaging Directive') and the Landfill Directive.

The second grouping brings together countries with high material recovery rates and medium levels of incineration, and with a medium dependence on landfill. In general countries in this grouping introduced policy instruments after adopting the Packaging Directive in 1994, and the Landfill Directive in 1999.

Three country groupings defined by diversion strategy



Source: EEA, European Environment Agency. Diverting waste from landfill — Effectiveness of waste-management policies in the European Union. 2009.

The third grouping contains those countries whose material recovery and incineration levels are both low and whose dependence on landfill is relatively high. This group comprises the majority of the EU-12 Member States in the process of implementing EU regulations and several, but not all Member States with a 4-year derogation from the Landfill Directive (i.e. Bulgaria, the Czech Republic, Greece, Lithuania, Poland, Romania, Slovakia and the United Kingdom) or from the Packaging Directive (Greece and Portugal). The geographical distribution of the three groupings is shown in this figure:

4 MANAGEMENT AND MINIMIZING OF LANDFILL GAS EMISSIONS

Landfill can be defined as "a site for the disposal of waste materials, depositing waste underground or on the surface for periods of time longer than one year for non-hazardous waste, and exceeding six months for hazardous waste."

From a technical point of view, waste disposal is defined as the ordered deposition of waste at locations properly built and prepared, following the corresponding environmental requirements. Waste disposal is the last option in the hierarchy of waste contained in the European Union management principles.

At the policy level, the general trend is to reduce landfill disposal, especially bio-recyclable materials (fully optimize waste resources), and to control environmental contaminants (pollutants in the atmosphere, leachate generation and treatment, distinction in the discharge of hazardous waste, inert or non-hazardous waste, etc..).

The characteristics of landfills depend on the methods of operation and management, as well as the main characteristics (waterways, water bodies and agricultural and urban areas, the existence of groundwater or natural reserves, geological and hydrogeological conditions, risks of flooding, subsidence, earth movement or landslides, protection of cultural heritage of the area where they will be located) and consider the distances between the boundary of the site and residential and recreational areas.

The following table shows the subdivision of the different types of waste-household origin in the different treatment streams. See the table below:

T/YEAR RATIO AND PERCENTARGE OF WASTE OF EACH FLOW TREATMENT OF MSW IN SPAIN.

Treatment system	t/year	%
Controlled waste	14.696.000	59,35
Triage + Composting	6.455.000	26,07
Incineration	1.915.000	7,73
Selectively collected packaging waste	331.000	1,33
Selectively collected organic waste	244.000	0,98
Triage + methanation	1.124.000	4,54
TOTAL	2.4765.000	100,00

Source: Spanish Ministry of Agriculture, Food and Environment, 2006.

4.1 Closure of landfills

A landfill may be considered sealed only if the competent authorities perform a final on-site inspection, assessing all the reports submitted and notifying the operator its approval for the closure. Then, the entity will be responsible for its maintenance; monitoring and control during the period required by the relevant authorities and in no case shall be less than 30 years.

This entity will also be responsible for monitoring and analyzing landfill gas and leachate, and the groundwater regime in the vicinity of the site. After the useful life of a landfill is over, it is important to consider the restoration of the area occupied. This restoration should be done with all environmental safeguards.

These are the stages for closure and landfill restoration:

1. Conduct a detailed site survey, in order to write a proper sealing project, as each landfill has particular characteristics.

2. Write the sealing project.

3. Once the landfill has received its final shipment of waste, it is still performed an access control, in order to prevent further discharges.

4. Conditioning discharge surfaces.

5. Sealing covers, used as a barrier to isolate the waste, prevent the filtration of river water and close the outlet passage of the vent gases through the exhaust system of gas. This includes revegetation of the surface. Sealing layers:
   - The top layer of waste is covered with a 0.5 m compacted clay mineral layer.
   - Layer of high density polyethylene (HDPE) that is covered by a geotextile.
   - Gravel drainage layer (not <50 cm), enabling the collection and channeling of rainwater.
   - Capa de tierra de 1m de espesor y de naturaleza adecuada a la vegetación que se prevea.
   - 1m thickness soil layer suitable for the vegetation.
   - Humus soil fertilized with appropriate vegetation to these conditions.
6. Control surface runoff to reduce the infiltration of water runoff flowing and decreasing landfill leachate production.
7. Control leachate extraction placing drainage systems leading to leachate storage ponds.
8. Controlling the extraction of gases and avoid its uncontrolled migration.
9. Monitoring of gas and leachate management during a period of 30 years after closure.
10. Protective measures to avoid possible effects in other areas.
11. Waste and soil treatment, as it must be conditioned for revegetation and reclamation.

4.2 Post-closure maintenance

4.2.1 Production of biogas

The absence of oxygen in a landfill favours anaerobic digestion of biodegradable waste producing gases such as methane, carbon dioxide and water vapor mainly, and other volatile organic compounds (hydrogen sulfide, ammonia, pectins, mercaptans, etc.)..

The volume and composition of gases generated depends, not only on the content of the organic waste disposal but also on the moisture, and the degree of waterproofing of the landfill.

Gas production is automatically controlled by the gas conduction to control stations which determine parameters such as flow, pressure and temperature. These data are centralized in a control center using a computerized system.

4.2.2 Exploitation of landfill biogas

The recovery of methane gas at a landfill, municipal waste involves the following actions:

- Preparation of wells or chimneys

Essential conditioning to hinder the introduction of air through the surface adjacent to each well, estimated at 15-20 m radius (area of influence from the aspiration). It basically consists of the isolation of the area adjacent to each well of capture, so that the aspiration of biogas does not cause unintended oxygenation and reduces landfill biogas production by aerobic conditions.

Each wellhead located on the surface of the landfill must be sealed as airtight as possible. The sealing of the wellhead can be ensured by the compaction of clay covering materials in the vicinity of the chimneys, complemented if necessary, placing a polyethylene film to cover surfaces between 200 and 300 m^2 around each well. This system is used to prevent the entry of air and thus oxygen, to the compacted waste.

- Uptake of gas and its conduction

Each wellhead is connected to pipes of high density polyethylene (HDPE) of 110 or 90 mm in diameter. These pipes in groups, will lead the gas with minimum slopes of 2% to regulation stations.

- Regulation stations

HDPE pipes from wells, form groups according to their closeness. Each set of pipes goes to a collector where the concentration of methane (CH_4) and oxygen (O_2) is continuously measured. Other devices measure the pressure, and a valve regulates the flow.

The collector of each station leads the gas mixture to the extraction plant; it is centralized in a picture-programmable computer control.

- Extraction system

Mixture gas pipes from regulation stations converge at the entrance of the extraction plant in a single intake manifold. The suction gas is sent to the delivery manifold where it is distributed for use (cogeneration or torch).

The amount of gas that is sent to cogeneration (CHP) must contain a minimum of methane in the mixture. Therefore, an automatic valve regulates the gas flow direction, depending on the indication of the methane analyzer.

- Cogeneration

Cogeneration is the alternating electric generation by a group of internal combustion engine-electric generator.

- Torch

This is a safety system which burns the excess of gas cogeneration. It must have sufficient capacity to burn 100% of the captured gas.

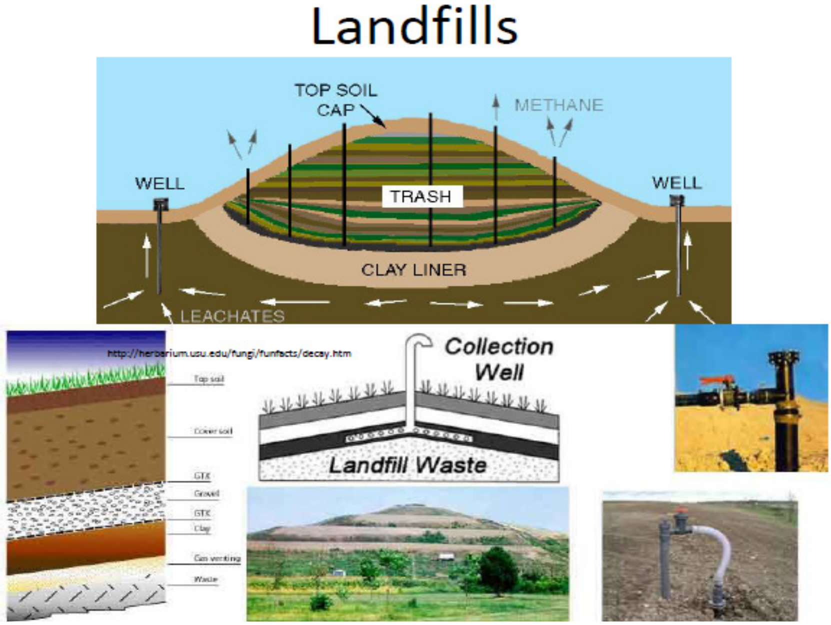
- Gas control

It provides control of gas collection facilities, the analysis, the control of cogeneration based on the quantity and quality of gas produced, and centralization of data in a control center with computer support.

4.3 Minimizing impacts on the atmosphere

- Improving landfill gas recovery and utilization:
  - 10% of the gas recovered is utilized for heat generation (direct use)
  - 40% is used for electricity generation
  - 60% is flared (burned)

- Diverting biodegradable waste from landfill:
  - 50% of the reduction is achieved through paper recycling
  - 15% is achieved using 'lower' cost techniques such as turned windrow Composting
  - 25% is achieved through 'medium cost' techniques such as incineration, and
  - 15% is achieved through higher cost techniques such as anaerobic digestion or more highly engineered composting schemes



Source: http://www.globalenergymanagement.com/Landfill-Gas-Capture.php

4.4 Landfill mining

As available land and resources become increasingly scarce, options to harness these from alternative sources become more sought after. One of the options available is Landfill Mining (LFM). LFM is commonly understood to be the extraction of waste from a landfill site after that site has closed and is no longer accepting waste. With a significant proportion of the world's waste still being disposed of in landfill, there is the potential for significant resources to be recovered post-disposal. In the future old landfills are likely to be considered as exploitable material stocks.

It appears that there are three main strategic reasons for LFM operations: Extraction recycling potential; extraction for energy recovery; and the reclamation of land. Whilst the first two are clear economic arguments about the potential income from the deposited wastes, the third has greater potential for considering environmental and wider sustainability drivers.

4.4.1 Advantages and disadvantages of landfill mining operations

The extraction of wastes for their recycling potential is highly likely to be driven by the material values in the market place for specific recyclates. Metals and plastics are those materials which have the highest values and the lowest level of degradation within a landfill site. These are, therefore, often cited as targets for LFM. However, there may be others that have a specific local value. The benefits to resource security need to be considered.

The reasons covered by the broad term 'land reclamation' may include one or a combination of the following:

- Landfill sites may be in locations that are, was it not for the landfill operations, ideal for traditional development purposes;
- The landfill site may form a physical barrier to a development that is planned, such as the Channel Tunnel Rail Link in the United Kingdom;
- It may be contaminating the groundwater or surrounding area and the source requires removal; or,
- There may be a need to reuse the available landfill space at that site for different kinds of wastes more suitable to long-term disposal, such as non-reactive hazardous wastes (e.g. asbestos).

Materials and energy recovery are likely to be primarily dependent on economic factors, land reclamation may be driven by environmental reasoning. When the widest range of benefits is considered, the greatest benefits can be driven from an LFM operation that can have significant costs and other impacts.

When the widest range of benefits is considered, the greatest benefits can be driven from an LFM operation that can have significant costs and other impacts.

On the other hand, it is only in recent years that accurate knowledge, and then only in broad terms, is available to assess what wastes a landfill site may contain. This lack of knowledge merely increases the risks that would otherwise be present during LFM operations.

The risks of excavation of a landfill site include:

- Nuisance caused during the LFM operation
- Potential for presence of hazardous materials
- Escope of leachate or landfill gas during LFM operations

Many of these risks are similar to traditional mining operations but are enhanced by the heterogeneous nature of the wastes in a landfill. They are also similar to the risks posed by landfilling operations but in reverse. If LFM were not to take place, the waste would remain contained and have limited opportunity to realise the hazards caused.

4.4.2 Technical requirements and considerations

LFM is a combination of processes. These can be broken down into:

1. Preliminary works
2. Extraction of waste
3. Processing of waste
4. End-markets
5. Remediation of land
6. Subsequent development

Following the preliminary works of site preparation, surveys, investigations and programming resources, the physical operation of LFM is a relatively simple one for an experienced landfill or mining operator. However, there are specific risks that need to be considered. The discovery and handling of hazardous materials within the landfill has the potential to hold up, and increase the costs of, LFM operations.

Once the waste is extracted, it needs to be processed according to the objectives of the scheme. This may be for recyclables recovery, where there will be specific standards depending upon material and the end-markets will have their own requirements. These will vary from place to place and may have specific regulatory controls.

Any form of energy recovery is likely to require pre-treatment shredding, trommel screens and metal extraction. It may also require drying to reduce moisture content. There will be significant variability in the composition and consistency of the waste through the different stages of the excavation and the pre-treatment systems need to be able to provide a homogenous output for a waste-to-energy plant to deal with. This may need to be completed on site prior to transportation so that only a stabilised product is being moved and the associated haulage costs and risks reduced.

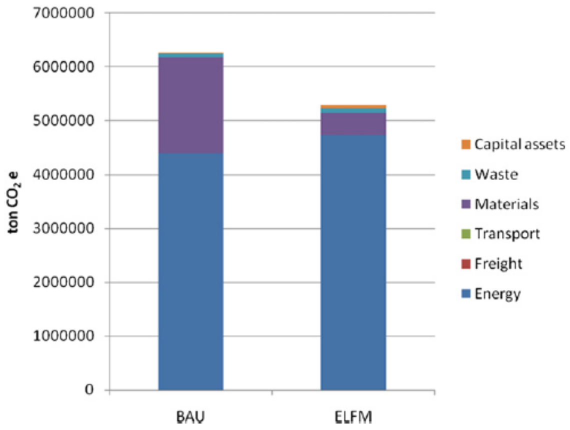
Once the site has been completely excavated, there will be a requirement to remediate the land to remove any residual pollution if the intention is to develop the site for an alternative purpose or to remove the future burden. This will be a specific operation that will require intensive ground investigations and analysis of the groundwater and soils in the area. By removing the source, this part of the process becomes one of containment and decontamination. It is likely that this would be possible using traditional land remediation techniques.

The subsequent development of a landfill may be specified as part of the objectives of the scheme. Depending on the extent of the remediation, it is likely that a specialist operator would not be required at this stage and a construction contractor experienced in brownfield development may be sufficient.

4.4.3 Costs and benefits to society

According to a study conducted by Van Passel, S., et al. (2012), show that Enhanced Landfill Mining (ELFM) projects have a clear private economic potential when adequate regulation and support policies are in place. This is important because it shows that there is scope for private entrepreneurs to invest profitably in ELFM projects. In this section we broaden the scope of analysis by including also some of the most significant external effects of ELFM projects for the society. In particular, we want to explore the environmental impact of ELFM projects. In a first step we focus on the carbon footprint of the "Closing the Circle" case study. The footprint will be assessed and later monetized. In a second step the analysis of impacts for society is extended to the valuation of other benefits to society.

Van Passel, S., et al. (2012) performed the carbon footprint analysis for two scenarios assuming a time frame of 20 years. In this way, they investigated which scenario is the most beneficial in terms of climate change mitigation. The Remo site (Flanders, Belgium) is an existing landfill containing historical waste with energy recovery from methane. The energy recovery from methane would last for about 15 years, using a combined heat and power (CHP) cycle. This will generate an amount of electricity and an amount of recoverable heat. Keeping the situation unchanged 'forever' is called the Business as usual (BAU) scenario. No incoming materials, no outgoing materials. In a second scenario (ELFM) most of the historical waste from the Remo site would be recovered as energy and materials. As in the BAU scenario, energy recovered from methane would last for about 15 years. In the ELFM scenario, however, a waste-to-energy (WtE) plant and a sorting and recycling plant (WtM) need to be built on the Remo site. All operational emissions of the six categories mentioned are taken into account (see the next figure). It was assumed that biogenic emissions do not generate any net addition to global warming.

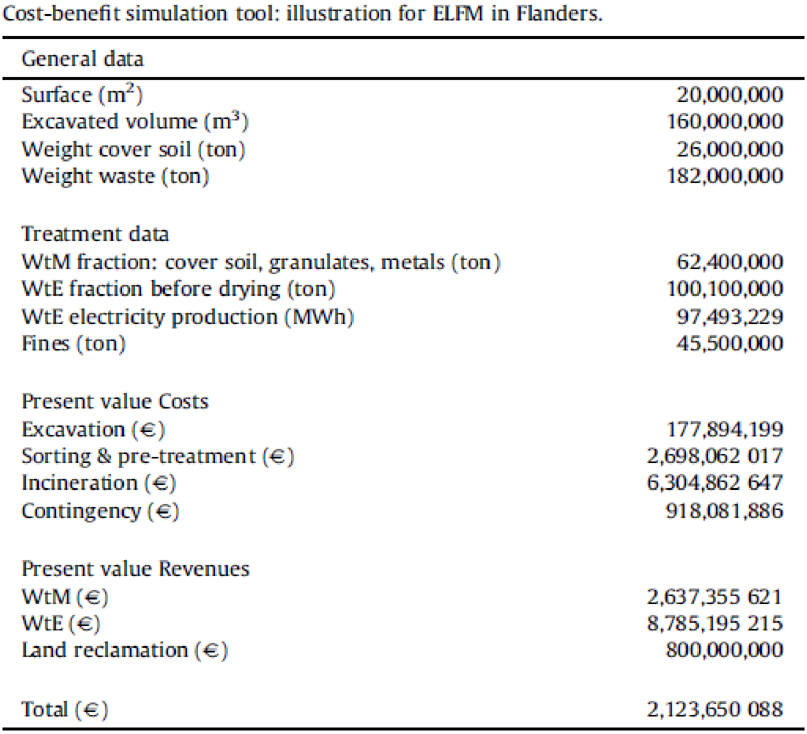


Carbon footprint of BAU and ELFM scenario.

Source: Van Passel, S., et al., The economics of enhanced landfill mining: private and societal performance drivers, Journal of Cleaner Production (2012), doi:10.1016/j.jclepro.2012.03.024

The BAU scenario would only produce a small amount of energy (from methane recovery), and not producing any materials. Therefore, the difference in materials and energy will be purchased on the market in the case of the BAU scenario. Greenhouse gas emissions of conventional market production methods will be accounted for in the BAU carbon footprint. Comparing the footprints of both scenarios; gives us an idea of which scenario is more beneficial towards greenhouse gas mitigation.

The summarized output data in the next table show that, under current conditions, WtE constitutes the most important cost (about 60% of all costs) as well as the most important benefit (more than 70% of all benefits). The development of innovative technologies (and especially Waste-to-Energy technologies) is an important aspect to improve the feasibility of ELFM practices. Logically, market prices also have an impact on the economic performance of ELFM.



Cost-benefit simulation tool: illustration for ELFM in Flanders.

General data	
Surface (m^2)	20,000,000
Excavated volume (m^3)	160,000,000
Weight cover soil (ton)	26,000,000
Weight waste (ton)	182,000,000
Treatment data	
WtM fraction: cover soil, granulates, metals (ton)	62,400,000
WtE fraction before drying (ton)	100,100,000
WtE electricity production (MWh)	97,493,229
Fines (ton)	45,500,000
Present value Costs	
Excavation (€)	177,894,199
Sorting & pre-treatment (€)	2,698,062 017
Incineration (€)	6,304,862 647
Contingency (€)	918,081,886
Present value Revenues	
WtM (€)	2,637,355 621
WtE (€)	8,785,195 215
Land reclamation (€)	800,000,000
Total (€)	2,123,650 088

Source: Van Passel, S., et al., The economics of enhanced landfill mining: private and societal performance drivers, Journal of Cleaner Production (2012), doi:10.1016/j.jclepro.2012.03.024

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Chapter

4

Water Management and Planning

Authors

Juan C. Santamarta Cerezal

Jonay Neris

Axel Ritter

Luis E. Hernández-Gutiérrez

University of La Laguna

Viana nº 50, planta baja, 38071,

La Laguna - Tenerife

Spain

University of
La Laguna,
Tenerife, Spain

Chapter 4

Water Management and Planning

Juan C. Santamarta Cerezal
Jonay Neris
Axel Ritter
Luis E. Hernández-Gutiérrez

ABSTRACT

Water is life, sustaining ecosystems and regulating our climate. But it's a finite resource, and less than 1% of the world's fresh water is accesible for direct human use. The field of water resources covers a wide range of topics and subject matter. It is well recognised that water planners require a broad set of inter-disciplinary skills to engage effectively with the multi-faceted, complex nature of contemporary water management challenges. Solving water-related problems, requires scientific expertise and skills for engaging with communities and the ability to integrate environmental, social and political considerations into planning practice. The 21st century will be an era of increased global concern regarding the availability of water.

Besides, climate change has become a hot topic both for the scientific community and the population in general. Despite the climate pattern has been changing continuously during the Earth´s history due to changes in the atmosphere, topography, volcanic activity, and other natural factors, this change seems to have been exacerbated recently due to the alteration of the greenhouse gases content in the atmosphere by the humanity. Nowadays, the extent of this change and its effects on the environment have got relevance due to its influence on disaster risks and its effects on properties and population. It is easy to understand why the water cycle is one of the most environmental drivers affected by climate change. Global warming, leaded last century by the climate change, has involved alterations in the temperature, precipitation and evaporation patters. From the point of view of

the water resources, these changes include an increase in the freshwater losses from terrestrial sources (glaciers, ice and snow, lakes, soil moisture, swamps, groundwater, marches and rivers) by evaporation and sublimation from fresh water deposits and transpiration from the vegetation, but also changes in the rainfall quantity and patterns. As a result, climate change has leaded short and long-term alterations in the frequency of extreme water-related events such as floods of droughts which directly impact on, among others, the quantity but also quality of water resources.

This module focuses on one of those, the issue of water supply planning and resource management, in particular, the planning process, systems analysis methods; institutional framework for water resources engineering; comprehensive integration of engineering, economic, environmental, security, legal, and political considerations in water resources development and management. It further discusses the environmental, economic, and social implications of floods, droughts, dams, and water usage as well as current issues in water quality, water pollution, and water resource regulation.

The overall aim of the module is to develop the skills of the students to know how to plan, develop and manage water resources.

1 WATER PLANNING

1.1 Introduction

Water is an increasingly critical issue at the forefront of global policy change, management and planning. There are growing concerns about water as a renewable resource, its availability for a wide range of users, aquatic ecosystem health, and global issues relating to climate change, water security and water trading.

Water Resources Management Plans should ensure an efficient, sustainable use of water resources. They should focus on delivering efficiently the outcomes that customers want, while reflecting the value that society places on the environment, also considers how water resources can become more integrated and sustainable.

1.2 Water plans

Water plans must include recommended alternatives for regional water resources management, water conservation, protection of the regional public welfare, and time lines for implementing the water plan. The primary factor that was taken into consideration was rainfall which is an important influence on the availability of water resources, such as boreholes, rivers or springs.

The water budget begins with the amount of water provided by precipitation as the total available water in the watershed.The plan will be reviewed and updated every five years. This will allow incorporating any refinements in climate change and population forecasts into the forecasts.

Figure 1: Lake in Azores Island, San Miguel (Santamarta-Cerezal, 2013).

According to Loucks and van Beek (2005), planning and management activities should pay attention to these possible negative consequences of industrial development, population growth and the intensive use of pesticides and fertilizers in urban as well as in agricultural areas. Issues regarding the environment and water quality include:

- Upstream versus downstream conflicts on meeting water quality standards
- Threats from aquatic nuisance species
- Threats from the chemical, physical and biological water quality of the watershed's aquatic resources
- Quality standards for recycled water
- Non-point source pollution discharges, including sediment from erosion
- Inadequate groundwater protection compacts and concerned institutions

1.3 Water plans objectives and strategies

The water plans objetives include;

To introduce a Water Act as well as revise existing laws and regulations to serve as principal legislation for efficient management of national water resources.

To establish a national level organization responsible for policy formulation; oversee implementation of the policy by concerned agencies; and establish basin-level and local level organizations with supporting laws.

Appropriate water allocation for all user sectors at the national and basin levels:

- Define rights and responsibility of the various user sectors
- Prioritize water use for the various sectors, i.e., agriculture, domestic, industry, conservation of ecosystem etc
- Promote conjunctive use of surface and groundwater
- Set water-use criteria/proportions for the various sectors from national to basin level
- Prepare emergency plans (drought, flood and wastewater)

Improvement of water-use efficiency:

- Apply economic and financial tools for water allocation, fee collection, the creation of a water market, compensation, taxes and allow users to be responsible for paying for service, wastewater treatment etc

- Campaign to create awareness of users about the necessity to share costs and use water efficiently
- Set up a water resources management fund
- Introduce water reuse/recycling
- Introduce water saving technologies

To increase water management efficiency:

- Rehabilitate existing infrastructures
- Develop a water network/grid both within and among basins, and a distribution system to serve as many users as possible
- Improve the organizational structure and management system

To develop water resources in accordance with potential and needs of various activities, both in terms of quantity and quality with due consideration of the environment. To ensur sufficient and equitable water for the various basic needs:

- Set clear direction for water resources development both within and outside the country by emphasizing development of water resources within the country to their full potential

To create awareness of the importance of water resources and efficient utilization:

- Include water related topic at all levels of educational curriculum
- Promote public awareness and understanding of the importance and maintenance of water sources and efficient utilization

To have a clear flood, drought and water quality protection plan and introduce an efficient flood and drought protection system:

- Formulate flood and draught protection and rehabilitation master plans, employing bothstructural and non-structural measures
- Promote and support local organizations to be capable of reduce and solve flood anddrought problem
- Develop a preparatory process for protection and rehabilitation operations prior, during and

- after disasters
- Set up a forecasting and warning system
- Set guidelines and procedure for water related disaster warning

1.4 Water budget

Water covers 70% of the earth's surface, but it is difficult to comprehend the total amount of water when we only see a small portion of it. The oceans contain 97.5% of the earth's water, land 2.4%, and the atmosphere holds less than 0.001%, which may seem surprising because water plays such an important role in weather. The annual precipitation for the earth is more than 30 times the atmosphere's total capacity to hold water. This fact indicates the rapid recycling of water that must occur between the earth's surface and the atmosphere.

Knowledge of the water balance is needed to define the lack and excess water and it applies to the climatic classifications, defining an island hydrology and water planning. A water balance analyzes the input and output of water in an area of a watershed over time, taking into consideration changes in the internal storage under different scenarios, such as the effects of climate change.

The importance of water balance is that it is a study that helps us define deficit or surplus water in a watershed taking parameters like rainfall, relative humidity, temperature, evaporation, evapotranspiration and the main flow of the drainage network of the watershed.

The continuity equation is based on the difference that occurs between the inputs and outputs of water mean water that is stored.

Inputs - Outputs = Change in Storage

Applying these concepts, precipitation is expressed as:

$$P = E + R + I + e$$

Being e the error in the estimates or closing error, E evapotranspiration, R runoff and I infiltration.

The usefulness of the knowledge of the water balance is that it allows us to perform a hydrological planning in accordance with the data coming out in the survey results, essential for integrated water management in the islands.

In relation to the water balance of the islands, especially oceanic the following singularities must be taken into account (Santamarta, 2013).

- High demand for water resources for agriculture
- Overpopulation
- Scarce water resources in general
- Significant seasonal tourism
- Isolated systems
- Binomial water-energy

Figure 2: Rain over forest in Hierro Island, Canary Archipielago (Santamarta-Cerezal, 2013).

Natural watershed systems maintain a balance between precipitation, runoff to lakes, rivers and wetlands, etc., infiltration to the groundwater system, and water which either evaporates (from open water surfaces) or transpirates from vegetation (evapotranspiration), completing the natural cycle back into atmospheric moisture and precipitation. It is necessary to understand this balance or water budget in order to sustain the resource and its environmental and human connections in the watershed. The understanding of the hydrologic cycle on a watershed basis is essential for development and implementation of appropriate watershed management policies and procedures.

A water budget analysis is a computational technique that balances water input and output while accounting for change in storage. On a watershed scale knowledge of these relationships can be used in addressing major decisions relating to such issues as:

- Land use and watershed planning
- Ensuring sustainable development
- Determining the receiving stream capacity for waste discharge
- Assessing risk exposure;
- Evaluating economic benefit to the community
- Reporting environmental conditions and status.

1.5 Water planning and climate change

The most important impacts of Climate Change will be on the Earth's water cycle. Understanding the water cycle and how it will be modified by climate change is a real challenge. The water cycle describes the constant movement of water from ocean to atmosphere to the land surface and back to the ocean. On a global scale the total amount of water does not change but where it is distributed does.

Water scarcity is expected to become an ever-increasing problem in the future, for various reasons. First, the distribution of precipitation in space and time is very uneven, leading to tremendous temporal variability in water resources worldwide (Oki et al, 2006).

Second, the rate of evaporation varies a great deal, depending on temperature and relative humidity, which impacts the amount of water available to replenish groundwater supplies. The combination of shorter duration but more intense rainfall (meaning more runoff and less infiltration) combined with increased evapotranspiration (the sum of evaporation and plant transpiration from the earth's land surface to atmosphere) and increased irrigation is expected to lead to groundwater depletion (Konikow and Kendy 2005).

As climate change warms the atmosphere and alters the hydrological cycle, we will continue to witness changes to the amount, timing, form, and intensity of precipitation and the flow of water in watersheds, as well as the quality of aquatic and marine environments, Already, water-related climate change impacts are being experienced in the form of more severe and more frequent droughts and floods. Higher average temperatures and changes in precipitation and temperature extremes are projected to affect the availability of water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows; these factors are expected to lead to further deterioration of water quality as well.

The premises that water planning is best done on a regional level is due to the many variables in climate, water supply, water demand, and legal and institutional constraints to water resources management.

1.6 Water management on islands

Water problems on islands are mainly related to the limited water resources. Due to the limited water resources, water related problems that are common elsewhere as well, such as pollution by wastewater and inadequate water supply systems (mainly huge leakages) become more acute on islands and thus require special attention and appropriate management (Hophmayer, 2012).

Islands depend, as other mainland countries, upon the quality and quantity of their water for their existence and economic activities. However, water management on islands is unique as it is constrained by their size, isolation from the mainland, fragility, and limited human, natural and financial resources (Pacific Islands Forum, 2005).

Small islands frequently have a relatively limited capacity to store water for use in the dry season, and the construction of large reservoirs is often prohibited by the requirement to flood scarce land. In addition, torrential rains, coupled with steep topography, short river channels and easily eroded soils, can cause siltation of reservoirs, further decreasing storage capacity (Khaka, 1998).

Figure 3: Landscale in Hawaii islands (Santamarta-Cerezal, 2013).

1.7 Useful links

- WATER - Environment - European Commission
- Climate Change and Water - US Environmental Protection Agency
- Water resources systems planning and management
- Ground Water Development, Sustainability, and Water Budgets
- Climate Uncertainty: What it Means for Water Planning and Policy
- Water Resource Planning Options for Climate Change

2 WATER USES

2.1 Introduction

An adequate supply of water is essential to ensure continued economic vitality and quality of life. Water use must generally respond to two needs: the need to satisfy the growing demand for water used for human consumption and for production processes (industry, agriculture, recreation), and the need to preserve water quality and protect the environment. This requires the identification, characterization, management and protection of water resources.

The most important water uses are;

- For drinking purpose
- For washing, bathing and cooking etc
- For building construction
- For the generation of steam for industrial use and electricity generation
- For generating hydroelectricity
- As a solvent
- For irrigation purposes

Water is crucial for the economy. Virtually every industry from agriculture, electric power and industrial manufacturing to beverage, apparel, and tourism relies on it to grow and ultimately sustain their business. Generally, the largest percentage of water consumption is attributed to agriculture.

Accounting for water is an essential step toward ensuring that a water utility is sustainable. This is best accomplished when water systems meter use by their customers. Metering helps to identify losses due to leakage and also provides the foundation on which to build an equitable rate structure to ensure adequate revenue to operate the system.

Options for water demand reduction:

- More efficient fixtures for new developments

- Landscaping and storm water management
- Grey water use
- Revised irrigation strategies and technologies
- Water pricing
- Education
- Incentives
- Retrofitting

Two-thirds of the world's population is projected to face water scarcity by 2025, according to United Nations (2006). Factors Affecting Population Trends:

- Birth rate
- Death rate
- Immigration
- Emigration
- Government policies
- Religious and societal beliefs
- Catastrophes
- State of the Economy

2.2 Water footprint

The water-footprint concept was coined in 2002 by Arjen Hoekstra, a professor of water management at University of Twente in the Netherlands. Using data from the UN's Food and Agricultural Organization, Mr. Hoekstra and other researchers gauged the water content that went into the making of various products and applied those statistics to people's consumption patterns to get a rough water footprint for average individuals and nations as a whole.

People use lots of water for drinking, cooking and washing, but even more for producing things such as food, paper, cotton clothes, etc. The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business.

2.3 Agricultura water uses

Water constitutes a key component in food production. Agricultural use of water accounts for nearly 70% of the water used throughout the world, and the majority of this water is used for irrigation. On the negative side, irrigation of land causes salinization of the land that is being irrigated, mostly in arid and semi-arid regions. Irrigation of cropland can increase the possibility fertilizers and pesticides will infiltrate into the groundwater or runoff into nearby streams. Along with the irrigation of crops, the farmers that have livestock must provide clean water for the livestock to drink.

Figure 4: Pineapple crops in Hawaii Islands (Santamarta-Cerezal, 2013).

2.4 Industrial uses

It is estimated that 15% of worldwide water use is industrial. Major industrial users include power plants, which use water for cooling or as a power source (i.e. hydroelectric plants), ore and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent.

Some power plants use cooling systems that draw water from a lake, river, aquifer, or ocean to cool steam and then return virtually all of it, although at higher temperatures, to the source. Such systems, known as once-through cooling systems, have high withdrawals but low consumption.

Reusing and recycling industrial water can ease the pressure on water resources and avoid the need to discharge to the sewer and/or environment. With appropriate management, which may include treatment, industrial water can be used for a wide range of purposes including industrial uses (e.g. cooling or material washing) or non-industrial uses (e.g. irrigation or toilet flushing).

2.5 Useful links

- What's your water footprint?
- The EU's Water Footprint - Institute for Environment and Sustainability
- Water resources across Europe - European Environment Agency
- TEDxOslo - Angela Morelli - The Global Water Footprint of Humanity
- Water Footprint and Conservation projec

3 SURFACE WATER EXPLOTATION

3.1 Precipitation

The part of the hydrologic cycle that is of most relevance to water planning is the precipitation;

- Some precipitation that falls on land seeps (infiltrates) into the ground to become soil moisture, part of which is taken up by plant roots and returned to the atmosphere through the process of transpiration
- Precipitation that is not intercepted or infiltrated flows across the land surface and through channels, from which it may be diverted for various consumptive uses or used to fill reservoirs, where it is stored until used or evaporated
- When soil moisture storage capacity is exceeded, recharge to groundwater occurs

When rainfall falls on the land surface, typically, depending on the intensity of the rainfall and the permeability and wetness of the soils, some of the rainfall infiltrates into the ground, and the remainder becomes runoff and flows overland to reach the nearest stream channel, thus contributing to river flow or streamflow.

The factors which control runoff generation are rainfall intensity and the permeability of the soil. Since both soil properties and rainfall intensity can vary significantly in space, it is easily possible that runoff generation does not occur uniformly across the catchment.

Surface water budget analyses rely heavily on estimates of components instead of actual measurements. Although precipitation and streamflow are measurable water sources, they are typically measured at only a few locations. Evaporation, evapotranspiration by plants, infiltration, return flows, and spring and seep discharges are generally not measured directly and are therefore estimated. Consequently, the surface water budget calculations presented here have a high degree of uncertainty and should be used with caution.

Figure 5: Surface water catchment (Santamarta-Cerezal, 2013)

3.2 Reservoir related issues

The river yields in semi-arid zones show major fluctuations, both on a seasonal and annual basis. Dam building, or other hydraulic works, is the way usually to control water quantity, as far as meeting demands is concerned.

Reservoir is a natural or artificial lake, storage pond or impoundment from a dam which is used to store water. Reservoirs may be created in river valleys by the construction of a dam or may be built by excavation in the ground or by conventional construction techniques such as brickwork or cast concrete.

The ecological quality of rivers must be maintained by maintaining a minimum flow. Rivers must not dry-up or have their physical regimes significantly altered in order to conserve the hydrological and ecological functions of their drainage networks.

Degradation of the riverbed upstream of reservoirs may increase the risks of flooding in those areas. Reservoir construction inevitably results in loss of land and forces the evacuation of residents due to impoundment

Water stored here during wet times is used during dry times, making the region's water supply more drought resistant, reliable and flexible.

The reasons for constructing reservoirs are ancient in origin, and initially focused on the need of humans to protect themselves during periods of drought or floods. Accordingly, reservoirs are usually found in areas of water scarcity, or where a controlled water facility was necessary.

3.2.1 Dams

A dam is any barrier that holds back water; dams are primarily used to save, manage, and/or prevent the flow of excess water into specific regions. In addition, some dams are used to generate hydropower. There are several different kinds of dams. Some dams are called embankment dams. Embankment dams are called either earthfill dams or rockfill dams, depending on what material is used most in the dam. Earthfill dams are made mostly of soil, or earth. Rockfill dams are made mostly of rocks. Other dams are made of concrete. Concrete dams can be either gravity dams or concrete arch dams, depending on how they are built.

Dams and reservoirs serve a number of different functions but one of the largest is to maintain an area's water supply. Many of the world's largest urban areas are supplied with water from rivers that are blocked via dams. Another major use of dams is power generation as hydroelectric power is one of the world's major sources of electricity. Hydropower is generated when the potential energy of the water on the dam drives a water turbine which in then turns a generator and creates electricity. To best make use of the water's power, a common type of hydroelectric dam uses reservoirs with different levels to adjust the amount of energy generated as it is needed. When demand is low for instance, water is held in an upper reservoir and as demand increases, the water is released into a lower reservoir where it spins a turbine. Some other important uses of dams and reservoirs include a stabilization of water flow and irrigation, flood prevention, water diversion and recreation.

3.2.2 Water storage ponds

The demand for water has increased tremendously in recent years, and ponds are one of the most reliable and economical sources of water. Ponds are now serving a variety of purposes, including water for livestock and for irrigation, fish production, field and orchard spraying, fire protection, energy conservation, wildlife habitat, recreation, and landscape improvement.

Water storege ponds are a key component in the treatment, storage and distribution of potable water. Built in many sizes and shapes they serve as repositories for the regions water.

Figure 6: Water reservoir (Santamarta-Cerezal, 2013)

3.2.3 Water supply and transport

The functions of the formal urban water supply and wastewater sector include storage, supply, distribution, and wastewater treatment and disposal systems that provide organized water services to established urban areas. The infrastructure generally includes water and wastewater utility systems with large raw-water storage facilities, storm-water collection systems, trans-basin diversion structures, potable and wastewater treatment plant equipment, pipelines, local distribution systems, and finished-water storage facilities.

Some urban distribution systems also include secondary distribution systems for reuse of treated wastewater, advanced treatment systems such as reverse osmosis or filtration, and multiple types of storage systems. Treated wastewaters may be distributed to meet irrigation and other non-potable needs, and with adequate treatment can be used to augment some drinking water supplies provided that communities are willing (Hurliman, 2007).

Figure 7: Water channel in Canary Islands (Santamarta-Cerezal, 2013)

Water leaking from water company pipes is wasteful of water and energy if the benefits of reducing it would outweigh the costs.