POTENTIAL IMPACTS OF CLIMATE CHANGE ON WASTE MANAGEMENT

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The report will help inform policy and process development within the Agency Corporate Plan and Making it Happen process. The report will be distributed to senior Agency managers with responsibility for 'Limiting and Adapting to Climate Change' and for Waste Management Regulation/Policy. The report will also provide information for waste management businesses and the wider climate impacts research community.

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Executive Summary

This report starts the process of considering what climate change could mean for municipal waste management and how it could be addressed. The scope of the waste management techniques and activities addressed within the report is focused on the management of municipal and household waste. The management of other waste streams will also be impacted by climate change and although these have not been specifically addressed many of the issues raised will also be of relevance when considering their future management.

Climate Change

There is evidence that climate change is already happening and that it is due, at least in part, to human activities that give rise to emissions of greenhouse gases (GHG). Climate models suggest that in the future we could experience higher temperatures, changes in seasonal precipitation and a shift to more extreme rainfall events, rising sea levels and more frequent storms. These changes could have significant impacts on a range of social, economic and environmental processes that are affected by the weather.

Given the levels of GHGs that have been emitted in the past and their lifetime in the atmosphere, it seems likely that we will have to adapt to some level of climate change. It is therefore important to understand what the potential impacts of climate change could be, what the adaptation options are and their implications for policy makers, regulators, business and the public. As well as this, we will also need to substantially reduce the emissions of GHGs if we are to avoid the climate extremes that the climate models suggest.

Climate Change and Waste Management

The timescales for climate change and some of the consequences on how we mange our waste are similar. For instance, landfill sites can be operational for decades and still be active for decades following their closure. Residual wastes will remain in the landfill site for many years after degradation processes have ceased. Capital assets such as energy from waste plants and materials recovery facilities will also be operational for decades and so could be affected by climate change. Climate change is happening now and so could already be affecting waste management processes and operations that are subject to weather related impacts. Models suggest that the scale of climate change could increase during this century and sudden rapid large-scale changes with far reaching consequences although unlikely can not be entirely ruled out. There is therefore a need to consider potential changes over significant timescales and respond appropriately. Some of the generic climate change impacts discussed in this report could be relevant to radioactive waste management but the timescales and associated risks are significantly different. Therefore, radioactive waste management has not been considered in this report.

The Study

A literature review was carried out to inform the study. This revealed that much work has been done on GHG emissions from waste management processes, but very little research has been done on the potential impacts of climate change on waste management and the potential adaptation options.

Bringing together existing published information and the authors' experience of waste management planning and operations, the report describes the evidence for climate change and

how climate could change in the future. It examines the levels of confidence in the estimated changes and areas of uncertainty. Waste management processes and activities are then described, highlighting the changes that are likely to occur in the future due to changes in policy. Chapter 5 brings these two areas together by carrying out a qualitative assessment of the potential impacts of climate change on waste management. These are laid out in a series of tables.

Conclusions

Climate change has the potential to affect waste management processes and sites in a number of ways including:

- Increased disruption to supporting infrastructure e.g. road and rail, from increased flooding from surface water, groundwater and drainage systems. This could also affect some on site facilities e.g. weighbridges and gas and leachate collection systems
- Changes in site hydrology and temperature which in turn could affect waste management processes e.g. landfill degradation rates, leachate production and composition
- Increased damage to site buildings from storms
- Increased disruption to transport infrastructure due to flooding and hence delivery of waste
- Increased health risks to workers from increased sunshine and exposure to UV radiation and increased pathogen and vermin activity
- Reduced worker comfort, with negative impacts on productivity, from increased indoor and outdoor temperatures
- Increased site disamenity from odour, vermin, dust and litter
- Increased risk of subsidence and slope instability from drying out of soils followed by rapid wetting due to heavy rainfall
- Inundation and/or erosion of low lying coastal facilities
- Influencing the types and amount of flora and fauna on and around facilities and the choice of ecological communities used to restore landfill sites

The extent to which these potential impacts actually affect waste management sites and processes will often depend on site specific issues. Therefore, steps should be taken to assess the risk of climate change to individual sites and processes. This could start by examining waste management facilities and processes at the national scale and assessing which types of facilities and processes could be at most risk from climate change e.g. low lying coastal sites. This study has started that process but attempts should be made to quantify the risks and take appropriate action based on the risk assessment.

However, the understanding of the potential impacts of climate change on waste management is at a very early stage and more work needs to be done to understand the potential impacts and what can be done to address them by policy makers, regulators and site operators.

There is other work being carried out on climate change that may be useful in developing a better understanding of what climate change could mean for waste management. Climate change scenarios describe possible future climate conditions for the 2020s, 2050s and the 2080s.

Whilst this is useful for some planning horizons e.g. infrastructure development intended to last for 50 or more years, some processes e.g. spatial development planning, would benefit from shorter term indications of possible climate change impacts. According to a recent document outlining what climate change could mean for them, the Department for Environment, Food and Rural Affairs (Defra) are planning to produce guidance on shorter-term climate scenarios. The use of these scenarios for assessing the potential impacts of climate change on waste management should be examined. The Office of the Deputy Prime Minister (ODPM) are also carrying out a study into the potential impacts of climate change on the land use planning system. As many waste management processes and operations are subject to regulation under the land use planning system, this study could contribute to assessing the potential impacts of climate change on waste management and informing the appropriate responses.

As the understanding of the potential climate change impacts on waste management is at a very early stage, there is a lack of capacity within the sector in terms of knowledge, information exchange, learning, training, research and response. At present this covers waste management and climate change policy makers, regulators and site operators as well as academia, the professional institutions and other professionals associated with waste management.

Recommendations

The main recommendations from the study are:

- Waste management policy makers and regulators should continue the process of building a shared understanding of the potential impacts of climate change on waste management policy and practices
- Waste management policy makers and regulators should ensure that they have a firm and effective link to and dialogue with climate change policy makers in order to ensure that appropriate policies and regulatory activities are developed to respond to climate change issues that could affect waste management
- As climate change could significantly affect their business, waste management companies should ensure that they also have a good understanding of potential climate change impacts and how they could affect their operations. This will aid effective planning. An industry forum could be established to facilitate this process
- Waste collection and disposal authorities should be made aware of any issues arising from the potential impacts of climate change that could influence their service delivery responsibilities and contractual commitments

Up to the present time the majority of the focus for waste management and climate change has been on emissions and mitigation. The science of climate change and impacts has not, as yet, been a focus for waste management and hence is under-represented in the literature and in assessment studies. Action should be taken to ensure that waste management is a focus for climate change. A starting point for this process could be a more detailed sectoral study into the potential impacts of climate change on waste management drawing on regulators' and operators' experience of weather related impacts.

Other sectoral actions could include:

- Development of tools and techniques to assess site specific impacts e.g. use of climate downscaling techniques and other assessment tools including those for hydrology, leachate and gas yield. This will help to inform any changes that may be needed to site management practices
- Assessment of any site operational changes that may be needed in the short, medium and long term to address potential climate change impacts. This should cover the full range of issues affecting site operations e.g. site engineering, management, health and safety of workers, visitors and the community
- The development of a robust set of climate change indicators for waste management e.g. temperature, precipitation, wind speed, atmospheric pressure, flooding incidences, site damage and closure due to storms, disamenity complaints, species and habitat change and occupational health and safety related to climate change. This will help to monitor climate change at site level and to assess possible consequences
- Identification of adaptation options for waste management processes that could be affected by climate change. The engineering, operational, investment, timescale, costs, land use planning and other resource implications of these adaptation options for site managers, regulators and policy makers should be identified in order to assist effective planning of waste management activities

Specific actions for the regulators could include:

- Carrying out a high level risk assessment to identify those sites and processes that could be most affected by climate change and formulate appropriate action plans to address the potential impacts
- The UKCIP/EA study on risk, uncertainty and decision making should be adapted for use by waste management regulators, policy makers and site operators to inform decision making on waste management

Specific actions for policy makers could include:

- An assessment of how climate change could affect the health impacts and disamenity from waste management processes
- An assessment of how climate change could affect the choice of waste management options. For instance, could climate change extend or reduce periods of waste degradation? Could climate change mean that more waste management operations need to be performed under cover? Will additional investment be required for odour control measures as a result of climate change?

In order to address the areas of uncertainty, a research programme should be developed by the waste management industry, regulators and policy makers to cover the topics discussed above. In addition to this it is recommended that a robust set of waste management and climate change scenarios is developed and agreed between the main stakeholders that can be used to inform the strategy, policy making, regulation and management of waste.

The research should include assessment of possible adaptation responses for waste management under climate change scenarios and its potential cost. This should build on the work already done on adaptation and its cost. This would help policy makers, regulators and operators to plan for and implement appropriate adaptive actions to reduce the impact of climate change.

A range of actions should be taken to build capacity within the sector on climate change impacts on waste management e.g. research, information dissemination and training.

Most of the UK's regions have now produced climate change impacts studies. Most of the studies have identified a potential need for more frequent waste collection due to higher temperatures but waste management has not been considered in any depth in these studies. This is a gap and guidance should be produced on how waste management should be considered in regional studies in order to ensure that appropriate issues are identified e.g. modifications or restrictions on the location and type of waste management activities.

Contents

1. Introduction

1.1 Project Objectives

Waste management processes and climate change can operate at similar timescales i.e. over decades, so there is a need to understand what the potential climate change impacts may be on waste management in order to begin the process of identifying what changes may be needed in waste management operations, regulation, strategy, planning and policy.

The objectives of this study are:

- To make an initial assessment of the risk and impact of climate change variables to the siting, operations and security of a wide range of waste management facilities
- To make recommendations for further research and actions
- To feed into an internal briefing document for Agency staff
- To feed into a briefing document for the Agency Board

The scope of the waste management techniques and activities addressed within the report is focused on the management of municipal and household waste. The management of other waste streams will also be impacted by climate change and although these have not been specifically addressed many of the issues raised will also be of relevance when considering their future management.

1.2 Waste Management in the UK

1.2.1 Background

The waste management industry in the UK is undergoing a period of rapid change as the provisions of a number of European directives begin to take effect. It is anticipated that the UK's reliance on landfill, as the most common and cost effective waste disposal practice, will cease with a number of alternative management and disposal options coming to the fore. It is anticipated that even if the currently measured annual rates of municipal waste arisings growth (2.7%)[1] are tempered, without radical measures to control waste generation, the quantity of household waste requiring treatment or disposal in twenty years time could be double that at present.

A number of measures are being put in place that will impact on the rates of growth in waste arisings, its recovery, treatment and disposal in response to various European Directives concerning waste. It is clear that there will be a requirement for waste management facilities of radically differing characteristics to those developed historically. The planning and development of waste management facilities requires long term investment and the difficulties experienced in site selection, planning and development are likely to determine that, once approved, sites will retain a waste management use for many years to come. The site selection and planning process examines many of the environmental aspects of the proposed

[1] "Waste and Recycling Bulletin" May 2003 at www.defra.gov.uk/environment/statistics/wastats/bulletin/index

development. However, the potential impact of climate change has yet to be formally identified as an issue that should be considered in relation to the development of waste management infrastructure.

1.2.2 Waste Operations and Practices

The decomposition of waste in landfill sites relies on the interaction of putrescible waste, moisture and temperature in mostly anaerobic conditions. This gives rise to landfill gas (a combination of methane, carbon dioxide [CO_2] and trace components) and leachate and residual matter. Mechanical plant is used to extract, and hence control, landfill gas at many sites. The gas can be used to generate energy in an engine or burnt in a flare stack. Some landfill and landraise sites are in close proximity to ground and surface water with associated risks to water quality.

All waste management processes require some level of infrastructure and processing facilities. This can include fixed and mobile plant, buildings, vehicles and associated road, rail and water infrastructure.

Controlled wastes are subject to regulation, with waste management facilities and processes requiring, at present, a Waste Management Licence (waste management facilities such as landfill and incineration will be brought into regulation under the Pollution Prevention and Control [PPC] regime over the next 4 years). This specifies acceptable site engineering and management practices including the use of best available technology, site safety, operating hours and conditions (some sites can be closed due to high winds disrupting operations), amounts and types of waste allowed and operational practices e.g. method of fill, daily cover, control of litter, noise, odour, vermin, landfill gas migration and leachate. Although primarily the responsibility of the Waste Management Licence holder, waste management facilities are subject to routine inspection by EA staff to assess compliance. The application of Operator Pollution Risk Assessment (OPRA) to waste management processes results in a more risk-based approach to regulation.

Particular attention is paid by operators to the health and safety of personnel involved in waste management activities and surrounding communities. Outdoor and indoor waste management facilities give rise to different health and safety issues. For waste management personnel, outdoor facilities are directly affected by weather conditions and hazards associated with vehicle movements, the nature of the waste, potentially hazardous working environments caused by landfill gas (which can be explosive and an asphyxiant in certain concentrations) and mechanical plant e.g. weighbridges and gas extraction facilities. Surrounding communities can be affected by odours, landfill gas migration, litter, noise, vermin and vehicle movements. The Waste Management Licence, planning conditions and the operators working practices seek to manage these issues. Indoor waste management facilities can consist of processing plant including mechanical and high temperature plant. Health and safety issues relate to operating plant, indoor air quality and working conditions.

Dispersion of the emissions from incineration and other waste processing plant are of concern to surrounding communities and are affected by amongst other things, weather conditions including wind direction and ambient temperature. Both indoor and outdoor facilities are affected by noise to varying degrees, which can affect both workers and the surrounding community.

Waste management has seen many changes over recent years and this rate of change will continue e.g. due to implementation of the Landfill and PPC Directives. The Environment Agency predicts that between one and two thousand new waste management facilities will be required to effectively manage the waste diverted from landfill due to EC and national legislation and policies. This represents a significant level of capital investment by the industry in facilities that will be operational for decades. It is therefore pertinent to consider whether the potential impacts of climate change should be considered when developing waste management infrastructure.

1.3 Waste Management and Climate Change

An examination of the currently published literature has suggested that very little research has taken place into the issues that may impact on the development and operation of waste management infrastructure as a result of climate change.

This report seeks to provide an introduction to waste management and climate change. The intended audience is policy makers, professionals and decision makers within the Environment Agency who have an interest in waste management or climate change. The report is not intended to be comprehensive but should be read as an introduction to the subject. It is designed to provide a means of establishing the headline issues that will arise from the evolution in waste management practices over the medium to long term and allow some of the potential impacts of climate change to be superimposed upon them. The report seeks to identify the principal issues likely to arise as a result of climate change that may lead to the identification of further research requirements around specific facilities or sites.

Climate change could have an impact on the waste management industry and given the operational time frame for many waste management sites, there is a need to examine whether the issues that arise are of such significance that policy or operational changes are required. This report concentrates on the issues that are likely to arise from the management of municipal and household waste. However, many of the issues will also apply to the management, treatment and disposal of industrial, commercial, agricultural and construction and demolition wastes.

1.4 Report Structure

This report, in the six sections that follow, provides a general introduction to climate change and its potential impacts on waste management activity and an overview of waste management activities likely to be adopted in England and Wales. The principal areas of European legislation that are likely to influence waste management practices within the foreseeable future are described within Section 4. The fifth section examines the potential impacts of climate change on waste management activity and the final sections present some conclusions and recommendations for areas where further detailed examination may be required.

2. Climate Change

This chapter presents the evidence for past climate change and the output from models of future climate.

2.1 Our Climate is Already Changing

Global temperature has risen by about 0.6°C over the last 100 years and 1998 was the single warmest year in the 142-year global instrumental record[2]. 2002 was one of the warmest years in Britain since records began in 1659 and it is likely to have been the 4th warmest year on record[3]. An example of unseasonably high temperatures that may support these trends occurred on January 26th 2003 when Aboyne, Aberdeenshire saw temperatures rise to 18.3°C, equalling the warmest January day on record. Soon after this Scotland was hit by gale force winds and snow[4]. The storms across the country in October 2002 resulted in widespread damage to infrastructure leaving about two million homes without power. The electricity companies have recently agreed to pay compensation worth £1.8 million to their customers. Although these incidences are not in themselves proof of climate change, these types of observations serve to illustrate the type of climate that we may experience in the future. Hot summer days with temperatures exceeding 25°C, like the hot summer of 1995, have become more common. The hot spell during the summer of 2003 saw temperature records broken and August 10th 2003 was the hottest day ever recorded in the Britain. Figure 2.1 shows the observed temperature changes compared to a long term average.

UK winters have also been getting wetter, with more frequent heavy downpours. Again recent evidence seems to support these observations. For example, late 2002 and early 2003 saw a series of floods across the southern half of the country. The Thames Barrier was closed 14 times between 15th December 2002 and 15th January 2003. It is normally closed a handful of times during the year but this also increased substantially during the winter of 2000/01 due to prolonged high river flows. It is reported that the increased barrier use in 2002/03 was due in part to October, November and December 2002 being very wet months. For the Thames Region the period was the fourth wettest since 1882. This resulted in the need to deploy increased resources as it is estimated that over 1,000 EA staff were involved in responding to the floods. 1,200 properties were affected. Interestingly, the report reviewing the floods highlighted the issue of flooding from several sources including rising groundwater[5].

The average rate of sea level rise around the UK coastline during the last century, allowing for natural land movements, has been about 1mm per year.

Climate changes occur naturally but the Inter-Governmental Panel on Climate Change (IPCC) feels that "*…most of the warming observed over the last 50 years is likely to have been due to increasing concentrations of greenhouse gases*." Confirmation of this is obtained when

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[2] Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report, Hulme et al April 2002. ISBN 0 902170 60 0

[3] UK Meteorological Office press release, December 2002, January 2003, August 2003

[4] Ofgem press release, September 2003

[5] Review of the New Year Floods 2003, 19th March 2003 Environment Agency Board paper. Available at: www.environment-agency.gov.uk/commondata/105385/ea_03_11_new_year_floods.pdf

observed trends are simulated using climate models. Only when human induced and natural change are combined does the model show close correlation with the climate record.

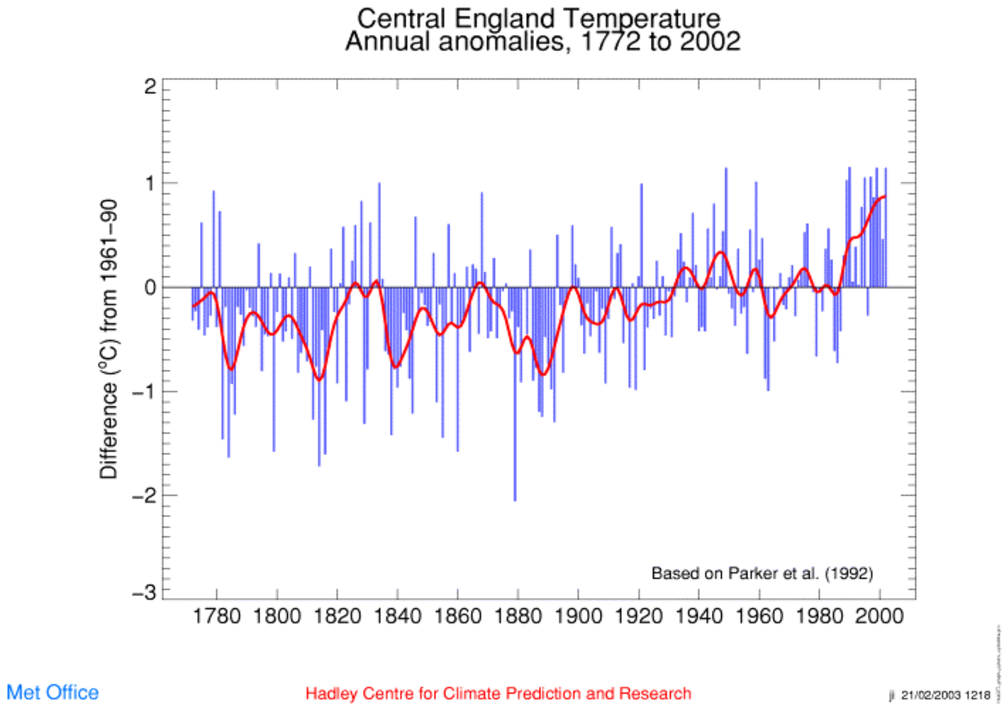


Figure 2.1 **Central England Temperature Anomalies 1772 to 2002. The figure shows a steady rise during the 20th century but with a marked increase at the end of the century. Central England Temperature (CET) is representative of a roughly triangular area of the United Kingdom enclosed by Bristol, Manchester and London. The monthly series began in 1659, and to date is the longest available instrumental record of temperature in the world. Since 1974 the data have been adjusted by 1-2 tenths °C to allow for urban warming.**

2.2 What Further Changes Could There Be?

In order to understand how our climate may change in the future, large scale computer models are run using different levels of greenhouse gas (GHG) emissions. The different levels of GHG emissions are based on a range of socio-economic scenarios including different rates of economic and population growth, consumption patterns, technological development and approaches to regulation of emissions. Table 2.1 illustrates the link between the different emissions scenarios, concentrations of carbon dioxide (CO_2 - the main greenhouse gas) in the atmosphere and potential temperature rise. In 2002, the UK Climate Impacts Programme (UKCIP) produced scenarios of climate change based on outputs from the Meteorological Office's Hadley Centre's climate models.

Table 2.1 **Increase in atmospheric CO_2 concentrations, temperature rise for the 2080s period (2071-2100 average) and their relationship to emissions scenarios**

UKCIP02 climate change scenario	Atmospheric concentration of CO_2	Increase in global temperature, ^oC
	Parts per million	
Low Emissions	525	2.0
Medium-Low Emissions	562	2.3
Medium-High Emissions	715	3.3
High Emissions	810	3.9

The UKCIP scenarios are related to the scenarios used by the Inter-Governmental Panel on Climate Change (IPCC). Pre-industrial CO_2 concentrations were about 280 ppm and were 370 ppm in 2001. The key results from the UKCIP02 scientific report[2] are given in Table 2.2 below.

Table 2.2 **Summary of results presented in the UKCIP02 scientific report**

The UK climate will become warmer by between 1 to 2ºC by the 2050's and by up to 3.5ºC by the 2080's, with parts of the south-east warming by as much as 5ºC in summer
Higher summer temperatures will become more frequent and very cold winters will become increasingly rare
Winters will become wetter and summers may become drier everywhere
Summer soil moisture may be reduced by 40% or more over large parts of England by the 2080s
Daily maximum temperatures of 33ºC, which occur about 1 day per summer in the south-east, could occur 10 days per summer by the 2080's
Snowfall amounts will decrease throughout the UK
The occurrence of heavy winter precipitation will increase
Relative sea level will continue to rise around most of the UK's shoreline
Extreme sea levels will be experienced more frequently
Winter depressions (low pressure systems or storms) could increase from 5 at present to about 8 by 2080s. The incidence of summer depressions could fall from 5 to 4 per season by 2080s
The Gulf Stream may weaken in the future, but it is unlikely that this weakening would lead to a cooling of UK climate within the next 100 years

The following figures[2] present the results of the models for the low and high emissions scenarios for the 2020s, 2050s and 2080s, on a map of the UK as represented by the 50km grid boxes used for modelling. Potential changes (precipitation and temperature) are presented for annual, summer (June, July and August) and winter (December, January and February) periods.

Figure 2.2 Modelled annual average precipitation changes for 2020s, 2050s and 2080s for low and high emissions scenarios

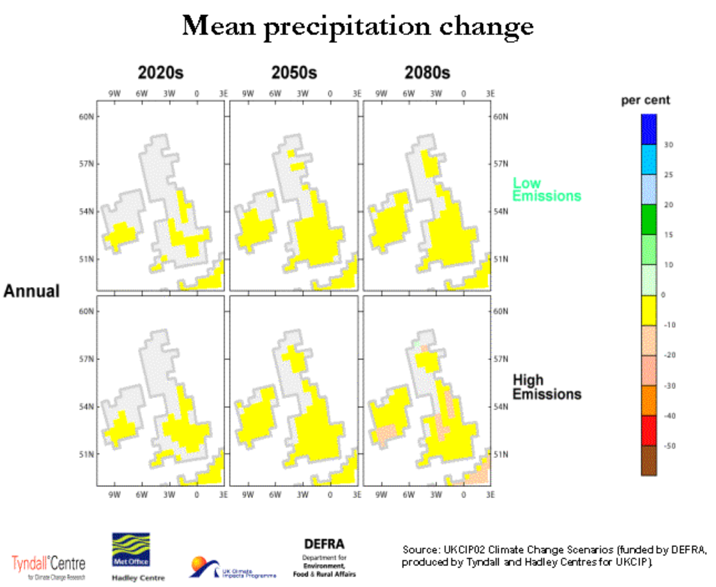


Figure 2.3 Modelled summer (June, July and August) average temperature changes for 2020s, 2050s and 2080s for low and high emissions scenarios

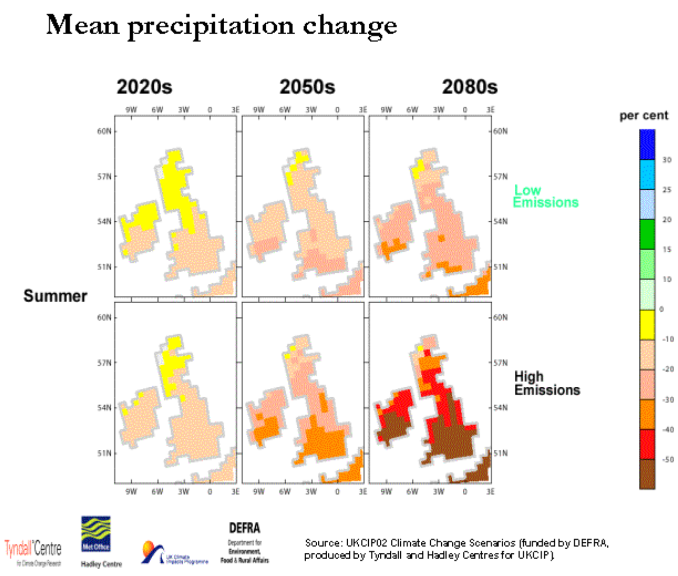
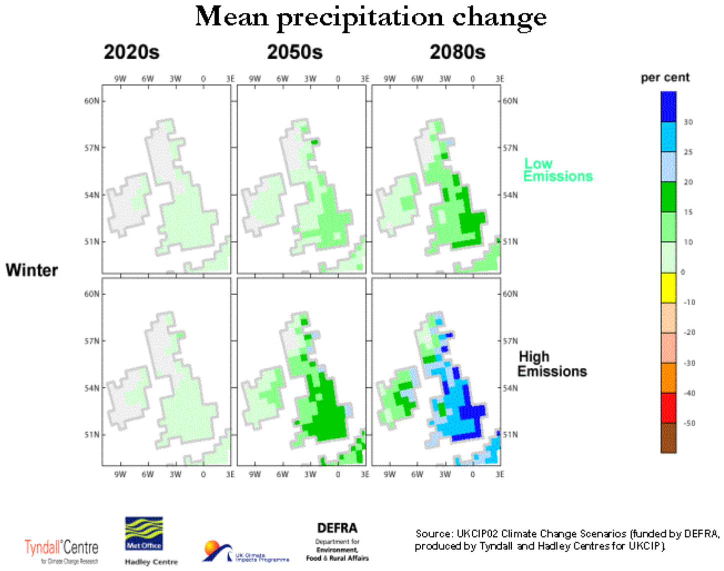


Figure 2.4 **Modelled winter (December, January and February) average temperature changes for 2020s, 2050s and 2080s for low and high emissions scenarios**



In summary, Figures 2.2 to 2.4 show:

- Wetter winters, by up to 30% by the 2080s for some regions and scenarios
- Drier summers, by up to 50% by the 2080s for some regions and scenarios
- Little change, or slight drying, in the annual total

Figure 2.5 **Modelled annual average temperature changes for 2020s, 2050s and 2080s for low and high emissions scenarios**

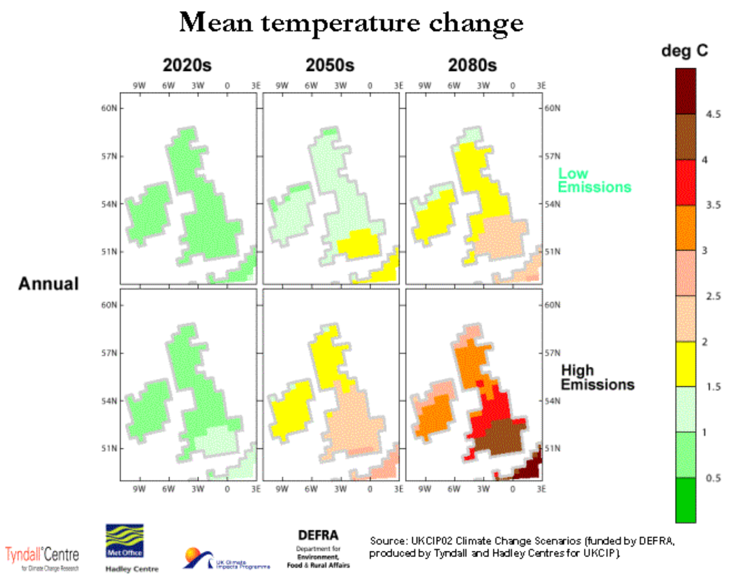


Figure 2.6 **Modelled summer (June, July and August) average temperature changes for 2020s, 2050s and 2080s for low and high emissions scenarios**

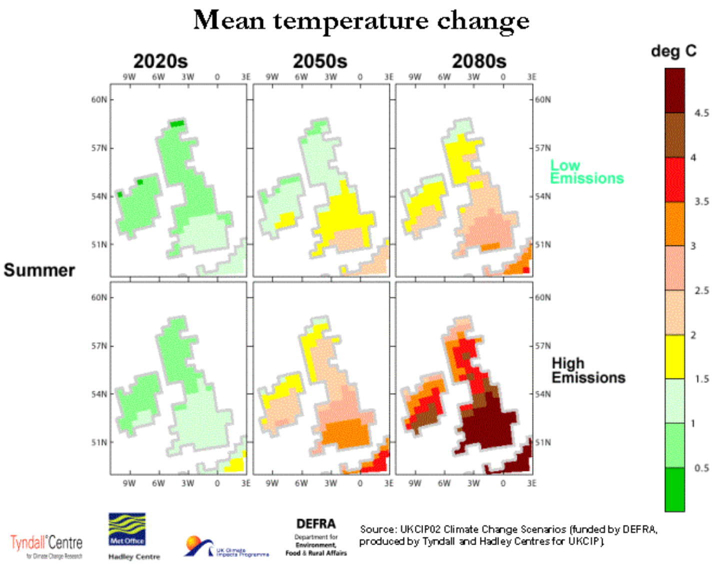
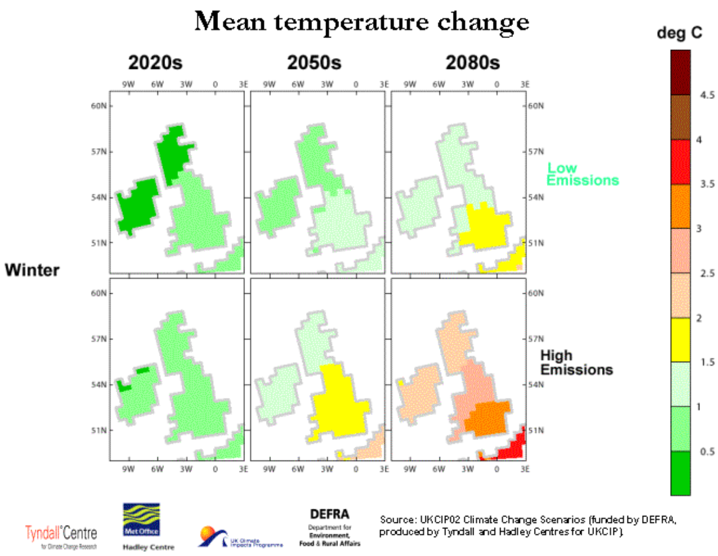


Figure 2.7 **Modelled winter (December, January and February) average temperature changes for 2020s, 2050s and 2080s for low and high emissions scenarios**



In summary, Figures 2.5 to 2.7 show:

- An annual warming by the 2080s of between 1° and 5°C depending on region and scenario
- Greater summer warming in the southeast than the northwest
- Greater warming in summer and autumn than winter and spring

2.3 What Does This Mean?

It is useful to use recent examples of extreme seasonal conditions to illustrate what the climate may be like in the future. Table 2.3 presents some climate analogues to illustrate the potential changes[2]. It shows that the occurrence of extremes could grow over the coming decades. For example, a dry 1995 type summer could be occurring once in every ten years by the 2020s, once every three years by the 2050s and once every other year by the 2080s.

Table 2.3 Percentage of years experiencing various extreme seasonal anomalies across central England and Wales for the Medium-High Emissions scenarios. The anomalies are shown relative to the average 1961-1990 climate

	Anomaly	2020	2050	2080
Mean Temperature				
A hot '1995 type' August	3.4°C warmer	1	20	63
A warm '1999 type' year	1.2°C warmer	28	73	100
Precipitation				
A dry '1995 type' summer	37% drier	10	29	50
A wet '1994/95 type' winter	66% wetter	1	3	7

2.4 How Confident are we about Future Changes?

There are various confidence levels attached to the outputs from the climate models[2]. Table 2.4 gives details of the confidence levels for seasonal changes. Table 2.5 gives details for daily changes. These could be used to inform the impact priorities and need for supporting work e.g. sensitivity analysis and use of approaches based on risk and uncertainty as laid out in UKCIP's recent publication developed with the Environment Agency[6].

[6] Climate Adaptation: Risk, uncertainty and decision making. UKCIP Technical Report, March 2003, Willows, R and Connell, R, (Eds)

Table 2.4 **Summary statements of the changes in average *seasonal* UK climate for the UKCIP02 climate change scenarios for which we can attach some confidence. Quantitative statements are deliberately avoided: see the relevant UKCIP02 scientific report chapter for detailed numbers. Relative confidence levels: H=high M=medium L=low**

Variable	UKCIP02 Scenarios	Relative Confidence Level
Temperature	Annual warming by the 2080s of between 1° and 5°C depending on region and scenario	H
	Greater summer warming in the southeast than in the northwest	H
	Greater night-time than day-time warming in winter	L
	Greater warming in summer and autumn than in winter and spring	L
	Greater day-time than night-time warming in summer	L
Precipitation	Generally wetter winters for the whole UK	H
	Substantially drier summers for the whole UK	M
Seasonality	Precipitation: greater contrast between summer (drier) and winter (wetter) seasons	H
	Temperature: summers warm more than in winters	L
Variability	Years as warm as 1999 become very common	H
	Summers as dry as 1995 become very common	M
	Winter and spring precipitation becomes variable	L
	Summer and autumn temperatures become more variable	L
Cloud Cover	Reduction in summer and autumn cloud, especially in the south, and an increase in radiation	L
	Small increase in winter cloud cover	L
Humidity	Specific humidity increases throughout the year	H
	Relative humidity decreases in summer	M
Snowfall	Totals decrease significantly everywhere	H
	Large parts of the country experience long runs of snowless winters	M
Soil Moisture	Decreases in summer and autumn in the southeast	H
	Increases in winter and spring in the northwest	M
Storm Tracks	Winter depressions become more frequent, including the deepest ones	L
North Atlantic Oscillation (NAO)	The NAO tends to become more positive in the future - more wet, windy, mild winters	L

Table 2.5 **Summary statements of the changes in *daily* weather extremes for the UK for the UKCIP02 scenarios. Quantitative statements are deliberately avoided: see the relevant UKCIP02 scientific report chapter for detailed numbers. Relative confidence levels: H=high M=medium L=low**

Variable	UKCIP02 Scenarios	Relative Confidence Level
Precipitation intensity	Increases in winter	H

Temperature extremes	Number of very hot days increases, especially in summer and autumn	H
	Number of cold days decreases, especially in winter	H
Thermal growing season length	Increases everywhere, with largest increases in the southeast	H
Heating "degree-days"	Decrease everywhere	H
Cooling "degree-days"	Increase everywhere	H

2.5 Uncertainties

Although our understanding of potential climate change is improving, along with the models used to support this, there are still a number of areas of uncertainty. The UKCIP scientific report[2] highlights the following uncertainties:

- Emissions levels. It is not known which of the emissions scenarios will be nearest to the actual future emissions. The actual emissions could lie outside the range of emissions modelled
- Feedbacks from the carbon cycle and atmospheric chemistry. The climate models include interactions between oceans, atmosphere and land. There is a version of the Hadley Centre model, which includes the interaction between the carbon cycle and climate. This model hasn't been used for the UKCIP02 scenarios as it is only a recent development. There are also reactions between atmospheric chemicals as climate changes. The net effect of these two feedbacks would likely be a larger warming of the UK climate
- Different approaches to modelling. The Hadley Centre global model has been developed over many years and has been extensively validated. However, other models have been used in the IPCC assessments and there is no easy way to attach higher or lower confidence to the results of the various models. A brief comparison is presented in the UKCIP02 scientific report[2]
- Natural variability. Although it is important to consider natural variability in impacts and adaptation studies, it cannot be predicted over long time scales. Consideration of the effect of natural variability is presented in the UKCIP02 scientific report[2]
- Possible changes to the Gulf Stream. This is a current of warm water that keeps northwest Europe warmer than locations on similar latitudes. It is part of larger ocean circulation and is driven by differences in water density caused by temperature and salinity. A shut down of the Gulf Stream in the future is not predicted by any climate model, although most show it weakening. A cooling of the UK climate due to changes in the Gulf Stream over the next 100 years is considered unlikely

These areas of uncertainty could be used to inform analysis of climate impacts and subsequent planning.

2.6 Model Resolution

Different levels of detail can be obtained from different types of climate models, from broad estimates of change at the global or regional level to more detailed information that can be used at a more local level for assessment and planning. The following section examines the different resolutions that can be obtained from climate models and how they are used.

There are a number of different spatial levels at which climate models operate:

- Global - coarse resolution e.g. HadCM3 (300 km)
- Global - intermediate resolution e.g. HadAM3H (120 km)
- Regional - high-resolution e.g. HadRM3 (50 km)

These all require different levels of computing power and produce outputs with various resolution. The coupled ocean-atmospheric model HadCM3 produces patterns of climate change across the whole surface of the earth at a relatively coarse level i.e. between 250-300 km grid boxes that cover the UK. As a consequence of its low resolution, whilst most descriptions are adequate for most purposes, some aspects of the climate are not described as well as they could be. In order to obtain a higher resolution for the UKCIP02 scenarios, the outputs from HadCM3 experiments provided the boundary conditions for a higher resolution (about 120 km grids) global atmosphere model (HadAM3H). The outputs from this model then provided the boundary conditions to drive the high resolution (about 50 km grids) regional model of the European climate (HadRM3). This approach improves the quality of the simulated European climate.

Further levels of detail can be obtained by using downscaling techniques either dynamical or statistical. Dynamical downscaling is how the 50km grid resolution was achieved for UKCIP02 scenarios i.e. using a low-resolution model to drive a higher resolution model - see above. Statistical downscaling (SDS) uses relationships calibrated from observations to infer relationships between global circulation model (GCM) outputs and local climate. Tools for this process have been developed for the Environment Agency[7]. Statistical downscaling is useful for higher resolution applications e.g. less than 50 km grids, that may be useful for site specific assessments. However, like other climate models they do not produce a single prediction and can produce results that vary from the lower resolution models. This could be useful for policy makers as it produces a range of scenarios to consider for strategy and planning purposes. An SDS website is available that gives data sources and contains an SDS manual[8]. There are uncertainties associated with SDS and more research needs to be undertaken to reduce such uncertainties.

SDS has been used in some of the regional climate change impacts studies e.g. East Midlands and London. More guidance is required on how SDS could help waste management site specific climate change assessments.

2.7 Conclusion

The following conclusions can be reached from the preceding analysis:

- There is evidence that climate change occurred in the last century. This was due, at least in part, to human activities
- A certain amount of climate change is inevitable because of past emissions of greenhouse gases
- We will have to learn to live with some level of climate change and adapt accordingly

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[7] Wilby, R.L., Dawson, C.W. and Barrow, E.M. 2002. SDSM - a decision support tool for the assessment of regional climate change impacts. Environmental and Modelling Software, 17, 145-157.

[8] http://www.sdsm.org.uk/

- Although climate change is likely to continue occur in the future, its scale and nature will depend on the choices we make today about how much greenhouse gases we emit

- There is growing scientific consensus on the causes and possible consequences of climate change but there are different levels of confidence in the outcomes that have been modelled and there are still many uncertainties surrounding climate change

- Climate change scenarios can help us to plan for future change

The following chapters describe the range of waste management activities undertaken in the UK and the changes facing waste management. These descriptions are then used to assess how climate change might affect waste management in Chapter 5.

3. Waste Management Activities

3.1 Introduction

The scope of the waste management techniques and activities addressed within the report is focused on the management of municipal and household waste. The management of other waste streams will also be impacted by climate change and although these have not been specifically addressed many of the issues raised will also be of relevance when considering their future management.

3.2 Waste Management Processes

Municipal waste management practices within the UK are currently going through a rapid period of evolution. The emphasis is being switched from disposal to reducing the volume of waste arising and seeking to recover value from the waste stream, either directly through re-use and recycling, or indirectly through energy recovery, in accordance with the waste hierarchy. The following illustration demonstrates the inter-relationships between the typical components of a modern integrated waste management service.

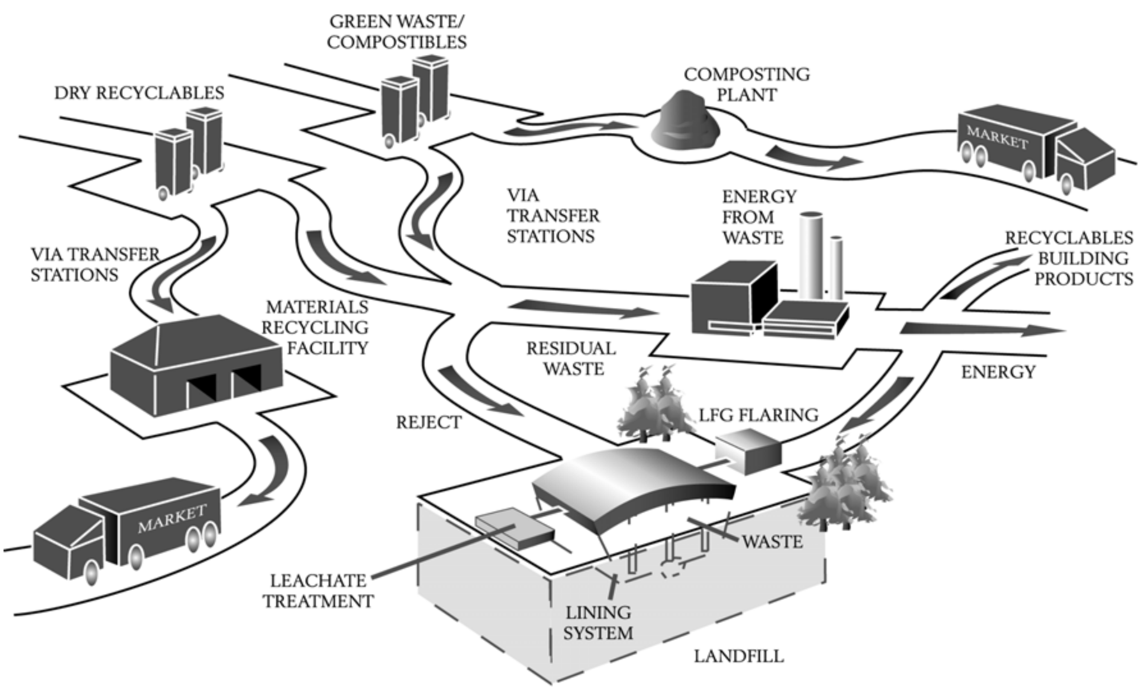

Figure 3.1 **Principal Components of an Integrated Waste Management Service**

In undertaking this review we have sought to identify the principal waste management activities that are likely to become common practice over the next 20 to 50 years. The activities set out in table below have been considered:

Disposal	Thermal Processing	Advanced Thermal Treatment	Biological Processing	Mechanical Processing	Collection and Transfer
Landfill	Energy from Waste/Incineration - Mass Burn Systems	Gasification Pyrolysis Gasification/ Pyrolysis (Sequential)	Composting - In Vessel	Material Recovery, Waste Segregation and Sorting Facility (MRF) Clean MRF's Dirty MRF's	Waste Transfer Stations
	Energy from Waste/Incineration - Fluidised Bed Systems		Composting - External Windrow (Traditional)	Bio-Mechanical Treatment	Civic Amenity and Bring Sites
			Anaerobic Digestion		Kerbside Waste Collection Systems - Mixed Waste
			Ethanol Production		

3.3 Disposal - Landfill

Landfill disposal of waste is the method of disposal that has historically formed the mainstay of the waste disposal industry in the UK. Historically, sites were generally identified for their reclamation potential and availability rather than their environmental suitability and many historic sites will continue to pose an environmental liability for many years to come.

In the past landfills were left unlined and any pollutants were ‘managed’ through ‘dilution and dispersion’. In recent years there has been a move towards building greater sustainability and engineered containment into the design of sites and there has been a move towards risk based assessment criteria in site selection, authorisation, operating and monitoring procedures and practices in response to a growing number of European Directives. Modern landfill sites are typically sited in areas where operational risks to the environment can be minimised, and engineered to a high standard in order to contain potential risks. The provisions of the European Landfill Directive sets out specific guidance regarding the engineering and operational standards for future landfill site operations.

A typical modern landfill site, engineered to the standards required by the Landfill Directive, will be underlain by an engineered lining system, incorporating leachate and landfill gas management infrastructure. Upon completion of the site an engineered cap will be constructed and measures put in place for the long term management and utilisation of landfill gas and the treatment of leachate. A long term monitoring and aftercare regime is also initiated. During its operational life the site is typically developed in phases (cells). As each cell is filled with waste the daily input is covered at the end of each working day in order to minimise the risk of windblown litter and discourage scavengers.

A typical landfill site will comprise the following principal operational elements:

Site security fence and gatehouse
Weigh-bridge and ticket office
Site roads and hard standing
Lined void for reception and deposition of waste
Stockpile of daily cover material
Plant and equipment (dozers, compactor plant etc.)
Workshops and offices
Leachate management and treatment facility
Surface water management system
Landfill gas management and utilisation system
Capped and restored cells

The generic environmental impacts are likely to be:

Landfill gas emissions
Leachate generation
Odour
Dust
Bioaerosols
Noise from site activity
Birds and carrion
Surface water runoff
Visual impact

Landfill capacity will always be required regardless of the other waste management options used, to dispose of the residual waste from other stages of the hierarchy. As landfill space is fast becoming filled, it has become increasingly difficult to obtain consent for new landfill capacity. Current and forthcoming EU Directives will inhibit future landfill development.

A typical landfill site may accept between 50,000-500,000 tonnes of waste per year. Legislation requires landfill pollutants including landfill gas and liquid/leachate emissions to be controlled.

Landfill Gas

The degradation of landfilled materials releases gases, predominantly methane and carbon dioxide. Landfill gas can be recovered and utilised as a fuel. As the biodegradable content of landfill wastes is reduced (as a result of the Landfill Directive), so the volumes of gas produced will also reduce. This may result in the recovery of landfill gas becoming more impractical and uneconomical. The rate of emission of landfill gas may be influenced by a range of climatic factors and considerable variations may be observed.

Bioaerosols

Bioaerosols are airborne micro-organisms that are generated during operations on waste management sites e.g. landfills, composting sites etc. They are often released when waste is agitated or disturbed and the released micro-organisms may be attached to dried residues, water droplets, particulate matter, soil, dust or fungal spores. Concerns have been raised that bioaerosols could affect the health of workers on waste management sites, and at composting sites in particular, as well as the health of nearby residents.

A recent report examined the evidence for a link between bioaerosols and worker and local residents' health[9]. Background levels and the dispersal of bioaerosols are affected by weather conditions, depending on the site's characteristics. However, most published studies indicate that bioaerosol levels in the atmosphere will return to background levels within the 250 metres of a composting process prescribed by the Environment Agency for risk assessment purposes. It seems likely that composting systems in the future may be enclosed or in-vessel, which could reduce emissions of bioaerosols - see section 3.5 below. There is currently no published evidence to demonstrate that bioaerosols from composting facilities cause respiratory ill health or that slightly elevated background levels represent a significant excess risk. However, the report recommends further research is carried out to examine the issue in more detail.

3.4 Thermal Processes

After recovering value through recycling and composting, obtaining 'energy' from the waste is the next step in the hierarchy. Many European countries integrate incineration with energy recovery plants with their composting and recycling programmes. There are several established methods for producing energy from waste.

3.4.1 Incineration with Energy Recovery

Incineration is the most commonly recognised form of energy recovery from waste in the UK and world-wide. There are currently 13 municipal waste incinerators operating in the UK, and in the order of 16 in various stages of planning and construction.

In mass burn plants the waste is combusted without the need for sorting or pre-treatment and at high temperatures. Steam is produced, which is used to generate electricity. Some plants can also supply hot water to provide district heating for local buildings, so increasing the thermal and resource efficiency of the plant. Fluidised bed plants, of which there is currently only one operational plant in the UK, require pre-treatment of the waste stream.

Typical plants in the UK are likely to have capacities of between 55,000 tonnes to 400,000 tonnes of waste per year. The majority have been built in partnership with the private sector

[9] Occupational and environmental exposure to bioaerosols from composts and potential health effects – A critical review of published data. JRM Swan, A Kelsey and B Crook, Health and Safety Laboratory and EJ Gilbert, the Composting Association, 2003. ISBN 0 7176 2707 1

with contract commitments for a 20 to 30 year period. A modern incinerator facility can reduce the quantity of waste needing final disposal by up to 70%.

Common concerns raised with respect to incinerators relate to public health impacts and gaseous emissions. Of particular concern to some members of the public are dioxins and furans, because they are considered to be harmful to health. Modern plants are required to comply with strict emission and operating standards laid down within EC Directives.

The typical mass burn energy from waste installation will comprise:

Site security fence and gatehouse
Weighbridge and ticket office
Site roads and hardstandings
Waste reception hall and tipping pit
Waste charging system
Furnace
Boiler/economiser system
Gas cleaning system (addition of lime, carbon, ammonia etc.) and bag filters
Stack (approx. 75m in height)
Electricity generation turbine
Ash management facilities
Flue gas treatment residue management system

3.4.2 Gasification and Pyrolysis

Gasification and pyrolysis involve heating the waste in a low or zero oxygen environment, as opposed to burning it, producing gas, liquid and solid fuel. This can then be burnt in a gas turbine or gas engine to produce electrical power. In pyrolysis, waste is heated to a high temperature with no oxygen resulting in a gas or oil fuel, which can be burnt to produce electricity and/or heat. Many of the proposed technologies require pre-treatment of the waste stream. These technologies are being used outside the UK, with the first UK sites currently being planned or developed. It is anticipated that a number of these facilities may become operational in the near future. The gasification/pyrolysis plants currently being proposed can treat up to 50,000 tonnes of waste annually.

It is currently anticipated that a commercially viable gasification/pyrolysis plant, which will be enclosed within a building, will comprise:

Site security fence and gatehouse
Weighbridge and ticket office
Site roads and hardstandings
Waste reception hall and tipping pit
Waste sorting and conditioning system
Waste recovery facility (for removal of non combustibles and outsized fractions)
Waste charging system
Gasification/pyrolysis unit
Boiler/economiser system
Gas cleaning systems
Stack (approx. 15m in height)
Gas powered electricity generation turbine
Ash management facilities
Residue management system

3.4.3 Refuse Derived Fuel

The production of Refuse Derived Fuel (RDF) involves sorting and processing waste to produce a fuel with a consistent specification. This may be in the form of fuel pellets or floc. The pellets or floc may be burnt at a facility on the same site or in a different facility, to generate energy. This is an established technology in the UK where 5 plants are currently in operation or planned.

A RDF facility is similar to a Material Recovery Facility (MRF), in that it involves sorting municipal waste to remove the combustible material. The combustible material is either compressed and dried into fuel pellets if being transported, or sometimes shredded for immediate use. From municipal waste the process typically recovers 6% metal for recycling and 30-40% combustible material to be made into fuel pellets. The remainder is sent to landfill. The current facilities in the UK range in capacity from 50,000 to 100,000 tonnes of waste per year.

A typical RDF plant with burner, which will be enclosed within a building, will comprise:

Site security fence and gatehouse
Weighbridge and ticket office
Site roads and hardstandings
Waste reception hall and tipping pit
Waste sorting and conditioning system
Waste recovery facility (for removal of non combustibles and outsized fractions)
Waste fuel manufacturing process (creating either a floc or pelletised fuel)
Fuel storage silo or bunker
Combustion unit
Boiler/economiser system
Gas cleaning systems
Stack
Electricity generation turbine
Ash and residue management facilities

3.5 Biological Processing

3.5.1 Composting

Composting is a biological process that uses micro-organisms to degrade organic matter using atmospheric oxygen. The stabilised end product occupies a reduced volume compared with the starting materials. The principal emissions are CO_2 and water vapour, bioaerosols and odour. It is estimated that nearly a quarter of all household waste is organic and can be composted. Composting may be undertaken in the open, as it needs oxygen but more sophisticated enclosed plants with air injection are also available.

Home Composting

This simple process has been encouraged by many Local Authorities through the sale and distribution of subsidised composting units. The householder places garden waste and certain kitchen scraps into the compost bin and after an extended period of time (up to one year) the material has stabilised and may be used as a soil conditioner. This option is only suited to household that have gardens suitable for the placement of the container and is not an option for those living in flats and apartments or with very small gardens.

Centralised and On Farm Composting

This is a variant on the home composting concept except that a centralised facility serving a small community is developed. The sites are often located on farms and the methods deployed include the regular turning of the material in order to increase the availability of oxygen within the process. The product may be bagged for sale or utilised within the farmer’s business. The facilities and process are simple and typically comprise an open windrow turned using standard agricultural machinery over a period of weeks or months.

External Windrow (Traditional)

The process has found favour in the treatment of source-separated green waste and waste that do not include material subject to the provisions of the Animal By-Products Order. Small operations may simply include an area of hard standing with mobile plant such as a shredder, conveyor and classifiers with the turning being undertaken by front end loader or specialist pieces of plant. Waste is placed in rows several metres long and 2 to 3 metres in height, which are periodically turned. Temperature and moisture content is monitored and at the conclusion of the composting process the material is graded and classified prior to storage, packaging and use. Larger units may have weighbridge and office facilities on site.

A typical municipal open air windrow system would comprise:

Site security fence
Hardstanding (concreted)
Surface water drainage system
Windrow piles
Mobile plant and equipment and garaging
Finished product storage area

In-Vessel Systems

The provisions of the Animal By-Products Order are forcing composting operations along a more process orientated direction. Modern in-vessel systems provide levels of control that are not available with more simple open systems and allow wider sources of waste arisings to be considered and may include a number of defined process stages. The systems are also devised in a way that excludes carrion, vermin and scavengers. The process is controlled by adjusting air flows, moisture content and waste input composition mixture in response to measured data covering temperature and moisture content. A typical system may comprise:

Site security fence and gatehouse
Weighbridge and ticket office
Site roads and hardstanding
Waste reception and conditioning area (enclosed)
Primary composting stage
Secondary composting stage
Product classification and conditioning plant
Storage and packing facility

Anaerobic Digestion

Anaerobic digestion also uses micro-organisms to break down organic waste. However, the digestion process is undertaken in an oxygen free (anaerobic) environment within an enclosed unit. The products are a flammable gas comprising mainly methane and carbon dioxide and a stabilised sludge residue, which after further treatment may be used in a similar manner to compost. The enclosed unit allows emissions to be controlled and the gases to be collected. The gas can then be utilised to produce electricity. Odour can be a problem due to the anaerobic nature of the process.

Anaerobic digestion has been used for some time in the UK for treating sewage sludge. Although there are no commercial plants treating solid municipal waste in the UK, there are over 50 plants operating in the rest of Europe. An anaerobic digestion plant with a capacity of approximately 50,000 tonnes of waste per year will take up an area of approximately 8,000 m^2, the highest structure being the digester reactor vessel, in which the bacteria treats the waste, which may measure 25 m in height. Gas generated within the process may be used for the generation of electrical energy.

A typical anaerobic digestion plant may comprise:

Site security fence and gatehouse
Weighbridge and ticket office
Site roads and hardstanding
Waste reception and conditioning area (enclosed)
Primary digestion stage
Secondary digestion stage
Product classification and conditioning plant
Odour control system
Wastewater treatment system
Gas engine
Storage and packing facility

3.5.2 Ethanol Production

There has recently been a recognition that it may be both commercially viable and practical to produce ethanol from the decomposition of biodegradable and organic waste. Commercial scale development has yet to be initiated within the UK and the characteristics of a typical system have yet to be defined. However, it is anticipated that the characteristics of a typical plant will be similar to those of an industrial or chemical manufacturing facility.

3.6 Mechanical Processing

3.6.1 Material Recovery, Waste Segregation and Sorting Facility (MRF)

A large amount of the waste stream can be recycled i.e. reprocessed, to produce a material for use within society, e.g. the recycling of paper to produce newsprint. The UK municipal waste recycling rate for 2001/02 was 13.5%[10] and lags behind that achieved in many other European countries.

The householder has an important role in separating household waste. It is easy to separate paper, glass, plastics, textiles and green wastes for recycling. The household can either deliver the separate items to centrally located facilities, called “bring sites”, or to make it more convenient for the householder, recyclables can be collected from the home by Local Authorities in kerbside collections. Local Authorities are tasked with introducing both kerbside collection schemes and providing bring sites.

[10] Defra Statistical Release 182/03, 22 May 2003

The collected material is taken to a Materials Recovery Facility (MRF) where it is sorted by material type (plastic, glass, aluminium, garden waste etc.) and baled together ready for distribution to reprocessing facilities for reuse or recycling. There are two types of MRF, a ‘pre-sorted’ MRF and a ‘dirty’ MRF.

A ‘pre-sorted’ or ‘clean’ MRF deals with recyclable materials, which have been separated from the main waste stream – usually by the householder. The quality of pre-sorted recyclable material is generally higher because it is less likely to be contaminated.

A ‘dirty’ MRF deals with unsorted waste from the ‘black bag’ or ‘wheelie bin’ collection. The recyclable material in a dirty MRF is often contaminated, making the quality poor for reprocessing facilities. Sorting may be mechanical, manual or a combination of the two.

A typical modern, clean MRF would probably receive segregated waste from kerbside collection schemes. The waste may be sent to a number of locations throughout the UK or overseas for processing. Recent initiatives by Waste Resource Action Programme (WRAP) are attempting to encourage the development of additional reprocessing facilities and markets across the UK in order to limit the movement of recyclables. For recycling to be successful, there must be a market for recycled products.

A typical MRF will be fully enclosed within a building and may comprise:

Site security fencing and gatehouse
Weighbridge and ticket office
Site roads and hardstanding
Building
Waste reception pit
Waste processing equipment (trommel mills, classifiers, shredders, etc.)
Conveyor belts and hand sorting lines
Recovered material storage bays
Odour control and dust suppression systems RDF manufacturing and pelletisation unit (on some MRFs)
Waste water collection and management system

3.6.2 Bio-Mechanical Treatment

Bio-mechanical treatment is a relatively new concept within the UK and in essence combines the facilities found within a MRF, composting plant and RDF production facility. The characteristics of such plant are likely to be similar to those listed above. Current project proposals are suggesting that a compost/soil conditioner suitable for re-use in agriculture and a waste derived fuel pellet will be the principal products after the removal of recyclables. It is conceivable that these products will be unsuitable for their intended markets and landfill disposal may be required.

3.7 Collection and Transfer

3.7.1 Waste Transfer Stations

Waste transfer stations are used by waste collection authorities and waste management companies as a means of increasing the efficiency of their waste collection service through the bulking up of waste into larger consignments prior to transfer to processing and disposal facilities. A typical facility will receive waste delivered by standard kerbside refuse collection vehicles where it is discharged onto a tipping floor (smaller facilities) or into a bunker (larger facilities). At the smaller facilities it is then either loaded directly into large bulk container vehicles or compacted into specialist compactor containers prior to transfer out of the facility, often by road. Larger facilities may be linked to rail or waterborne transport infrastructure and waste is typically loaded into compactor containers prior to dispatch.

A typical small facility comprises:

Site fencing and gatehouse
Weighbridge
Covered tipping hall within a building
Waste loading facility
Roads, hard standings and surface water management system

A typical large facility comprises:

Site fencing and gatehouse
Weighbridge
Covered tipping hall within a building
Waste loading facility
Railway sidings or wharfage
Workshop and offices
Roads, hard standings and surface water management system

Environmental impacts commonly cited are:

Odour
Dust
Bioaerosols
Noise from site activity
Birds and carrion
Surface water pollution and surface water runoff management

Waste transfer stations are often located either within or on the fringes of the urban area in close proximity to the sources of waste arisings.

3.7.2 Civic Amenity and Bring Sites

Civic amenity and bring sites are provided by Local Authorities to allow members of the public to deposit household waste free of charge. Their size is principally determined by the population size of the catchment served and the availability of land in the area. Traditionally they were provided with a number of skips or compactor containers accepting mixed waste.

However, many Local Authorities have recently redesigned their sites to include a number of skips and containers each dedicated to specific waste streams with the members of the public being expected to segregate and deposit their waste as directed by signs or a site operative. A typical site may include skips and containers dedicated to the collection of the following waste streams:

General waste	Hazardous household waste (paint, chemicals, solvents etc.
Green garden waste	Asbestos
Paper	Construction and demolition waste
Wood	Glass
Metal	Cardboard
Oil	Plastic bottles
Batteries	Clothing

Modern sites are being designed in order to facilitate recycling and reclamation activity rather than merely to accept general waste for disposal. The most basic sites are developed around the placement of the skips on a flat slab with associated signage and roadways. However, the best modern sites are often developed around the segregation of the public and operational areas and may incorporate a split level design concept in order to facilitate public access. Bring recycling sites are often located in supermarket car parks or adjacent to council offices.

A typical civic amenity and bring site facility will comprise:

Site fencing and entrance gate security system
Site office
Skips and containers for reception of waste
Roads and hard-standing
Surface water management
Storage areas for recovered material awaiting dispatch from the site

These facilities are often sited within urban areas and in close proximity to residential accommodation. Consequently facility design has to consider the minimisation of nuisance arising from noise, odour, traffic (particularly at weekends), surface water runoff, litter, vermin and scavengers.

3.7.3 Kerbside Collection Systems - Mixed Waste

Three methods of collection for the kerbside of municipal and general waste are typically used within the UK:

- Traditional dustbins
- Wheeled bins
- Plastic sacks

The following table presents the operational characteristics of different collection systems:

Traditional Bin System	**Wheeled Bins**	**Plastic Sacks**
High crewing levels and labour inefficient	Low crew levels and labour efficient	Low crew levels and labour efficient
Slow collection rate	Fast collection rate	Fast collection rate
Residual waste remains in bin unless cleaned	Residual waste remains in bin unless cleaned	Low odour potential
High odour potential	Low odour potential	High risk of waste spillage
Flies and vermin attraction	Increase in collected waste arising	Bags prone to attack by scavengers (rats, mice, birds, cats etc.)
Elevated risk of crew injury	Low risk of crew injury	Elevated risk of crew injury

In all systems waste is collected from individual properties from a point that is determined by the Local Authority. Very few Authorities currently retain a traditional bin collection and in many of those that do, it is anticipated that alternative collection methods will be introduced as the requirement to meet specific recycling targets is integrated into the service. Wheeled bin systems have been progressively introduced in many authorities over the last twenty years. There are many recorded instances of considerable gains in service efficiency being realised after their introduction. However, the size of the container traditionally deployed (240 litres) has in many instances led to a rise in the quantity of waste being collected by the collection authority. In order to prevent this upward trend a number of collection authorities have piloted the introduction of smaller bins (110 litres). The collection of general waste presented for collection in plastic sacks remains popular, in part due to the sack providing a volume inhibitor on the quantity of waste presented. Sacks may either be provided by the householder or the collection authority.

3.7.4 Kerbside Collection Systems - Segregated Waste

The introduction of mandatory performance targets for waste recycling have led to the introduction of a number of alternate schemes for the kerbside collection of recyclable materials being piloted. These fall into two main categories: those that collect segregated materials at the kerbside for subsequent sorting at a MRF and those that aim to undertake the sorting at the kerbside using specialised compartmentalised vehicles. To date, there have been no firm conclusions drawn as to which approach or variant provides the most efficient system and many systems are currently being piloted.

A typical example of the collection of recyclables for subsequent sorting at a MRF may include the provision of a container (bin, bag, box etc) for the collection of dry recyclables e.g. paper, card, plastic, metal cans etc. and a second container for general mixed waste. Examples of separate collections include a box or bag for paper, a “brown bin” for green waste and a “blue” bin for paper and card. The collection vehicles are generally non-specialised bulk collection units and may be operated with similar crews to those used for general refuse collections.

The sorting of waste directly at the kerbside necessitates the deployment of trained staff who are able to identify and sort materials directly into the correct compartments on a specialised collection vehicle. Recyclable material is generally presented by the householder within a box housing a number of dry recyclables. These are then sorted into their fractions and placed in the requisite compartment on the vehicle by an operative.

3.8 Other Waste Streams

The waste management practices set out above are those generally adopted for the management of municipal solid waste. However, the management of other waste streams often requires that similar methods be deployed.

3.8.1 Construction and Demolition Waste (C&D Waste)

The management of C&D waste is influenced by both the landfill tax and the levy on virgin aggregates. In recent years there has been a rapid expansion in the reprocessing of C&D waste into secondary and reclaimed aggregates to specified qualities. This trend is likely to continue. There have also been developments in the reclamation of timber for conversion into chipboard or a fuel. Problematic wastes still remain, most notably plastic and uPVC, chemicals and asbestos, which will require disposal in specialised incineration plant or high integrity hazardous waste landfill as required under the Landfill Regulations.

3.8.2 Agricultural Wastes, Waste Water and Sewage Sludge

This report does not address waste management practices directed specifically towards agricultural waste, waste water and sewage sludge. However, it is likely that many of the identified issues and impacts arising from climate change will also exert influence on waste management processes deployed for these wastes. It is anticipated that biological processes such as anaerobic digestion and composting will commonly be used in the treatment of these waste streams.

Organic wastes from agriculture are often re-incorporated into the soil e.g. through landspreading, injection or ploughing. Climate change may impact on the sustainability of these high volume, low technology processes.

3.8.3 Commercial and Industrial Waste Streams

Waste disposal practices for commercial and industrial waste streams are dictated by the nature of the waste streams generated by the waste producer. The treatment and disposal practices most commonly used are similar to those for municipal waste.

3.8.4 Radioactive Wastes

Issues relating to the potential impacts of climate change on the management of radioactive wastes falls outside the scope of this study, and as such their management is not discussed. However it should be recognised that climate change may impact on their management in the future.

4. Policy Drivers

4.1 Introduction

This chapter provides an overview of the policy framework and key statutory requirements that will impact on the development of future waste management provisions. The legislative framework has been developed without direct reference to the evolving body of knowledge on the potential impacts of climate change. It is therefore conceivable that the waste management practices that are being developed in response to changes in legislation will not adequately address climate change consequences.

The main drivers that are encouraging industry and Local Authorities to review their waste management systems can be grouped into three categories:

- European legislation and policy
- National legislation and policy
- Financial instruments

These will have a profound impact on the available waste disposal routes, waste management capacity, waste collection methods and overall economics of waste management.

4.2 European Legislation

4.2.1 The Landfill Directive

One of the most notable drivers at present is the Landfill Directive (Council Directive 1999/31/EC on the Landfilling of Waste) which was agreed in Europe in 1999 and has now been transposed in Great Britain e.g. through the Landfill Regulations. This seeks to prevent or reduce the negative environmental effects from the landfilling of waste by introducing uniform standards throughout the EU. The Directive sets ambitious targets for the reduction of biodegradable municipal waste (BMW) that is disposed of to landfill (Table 4.1).

Table 4.1 National Diversion Targets for Biodegradable Municipal Waste

By 2010 biodegradable municipal waste (BMW) must be reduced to 75% of the total BMW (by weight) produced in 1995
By 2013 BMW must be reduced to 50% of the total BMW (by weight) produced in 1995
By 2020 BMW must be reduced to 35% of the total BMW (by weight) produced in 1995

The Landfill Directive also imposes tighter controls on the way all wastes are managed when disposed to landfill. All wastes will require pre-treatment prior to landfilling. Exceptions are for inert wastes or any other waste for which treatment does not contribute to the protection of the environment or human health by reducing the quantity or hazardousness of the waste.

In addition, co-disposal of hazardous and non-hazardous wastes (a widespread practice in the UK) is banned under the Directive, as is the disposal of liquid wastes, infectious clinical wastes and specified hazardous wastes. Landfilling of tyres is also banned (2003 for whole tyres and 2006 for shredded tyres).

In addition the Landfill Directive requires the classification of landfills into:

- Inert waste landfill
- Non inert, non hazardous landfill
- Hazardous waste landfills

The Directive also sets out minimum standards for the design, construction, operation and monitoring of landfills. It is widely accepted that the introduction of such measures will result in fundamental changes in waste management practices in the UK.

4.2.2 Directive on Packaging and Packaging Waste

The Directive on Packaging and Packaging Waste (94/62/EEC) was implemented in England by two pieces of legislation: the Producer Responsibility Obligations (Packaging Waste) Regulations 1997 and the Packaging (Essential Requirements) Regulations 1998.

The first of these sets targets for the recycling of packaging waste, placing the responsibility upon those in the packaging chain. Packaging also includes the boxes and pallets used in the delivery systems. All obligated companies have to arrange for the recycling or recovery of a proportion of the packaging they handle. The EU has set 2006 targets of 60-75% overall recovery and 55-70% overall recycling, with material-specific recycling targets for glass of 60%, paper and board 55%, metals 50% and plastics 20%. This may have the effect of encouraging producers to fund the enhanced recycling of post-consumer packaging in household waste, and could have an effect on prices for recyclates and the provision of recycling infrastructure. In England and Wales, recovery and recycling targets for obligated business are set by the Government and for 2002 were 59% recovery and material-specific recycling target of 19%. These targets will remain the same for 2003.

The responsibility for proof of recovery falls on those businesses handling packaging and as such into the commercial and industrial sector. Proof of compliance is achieved and proved by the issue of the Packaging Recovery Note (PRN). PRN’s can only be issued by an accredited reprocessor. Accredited reprocessors are approved by the Environment Agency and include energy from waste facilities, which accept domestic waste. PRN's from these facilities can be issued for 19% of the household waste throughput of the plant. PRN’s can be a source of income having an intrinsic and tradable value.

4.2.3 EC Regulation No 2037/2000 on Substances that Deplete the Ozone Layer

Otherwise known as the Ozone Depleting Substances Regulation, it requires Member States to remove ozone depleting substances (ODS) (including CFCs and HCFCs) from refrigeration equipment before such appliances are scrapped. In the UK this applied to domestic appliances from 1 January 2002.

Facilities for delivering the requirements of the Regulation are currently being introduced in the UK. However, there is a legacy of redundant appliances in temporary storage and some suggestions that there has been an increase in the fly tipping of or illegal dumping of appliances in some areas.

4.2.4 Waste Incineration Directive (2000/67/EC)

In 1989 two Council Directives (89/369/EEC and 89/429/EEC) were adopted to control emissions of certain pollutants from municipal waste incinerators (MWIs). These have made a considerable contribution to the reduction of emissions, however, their scope was limited to municipal waste. To supplement these Directives and the Hazardous Waste Incineration Directive (Council Directive 94/67/EC), a new Waste Incineration Directive (2000/76/EEC) has been adopted.

The new Waste Incineration Directive addresses municipal and hazardous wastes excluded from the scope of 94/67/EC, such as waste oil, solvents and clinical waste, as well as other non-hazardous wastes. It also addresses the co-incineration of wastes excluded from the scope of 94/67/EC. The requirements of the new Waste Incineration Directive have been developed to reflect the ability of incineration plants to more cost effectively achieve high standards of emission control in comparison to the 1980s.

The Directive seeks to integrate the technical progress made in recent years in the control of incineration emissions and extend the scope of existing measures to combat the pollution of air, water and land caused by the incineration of wastes not covered by the Hazardous Waste Incineration Directive (HWID). It will contribute to the protection of human health and the environment by achieving its key objectives that include:

- To reduce substantially emissions of several key pollutants to air and control releases to water and land
- To provide a major contribution to the achievement of the target set in the Fifth Environment Action Programme to reduce emissions of dioxins and furans from known sources by 90% between 1985 and 2005
- To contribute to a reduction in releases in heavy metals in accordance with the Fifth Environment Action Programme objective of eliminating exceedances of critical loads and levels
- To provide a coherent methodology for the regulation and operation of non-hazardous waste incineration and co-incineration

4.2.5 The End of Life Vehicles Directive 2000/53/EC

This EU Directive was adopted by the EU in September 2000. The Directive:

- Requires that end of life vehicles can only be treated by authorised dismantlers or shredders who must meet tightened environmental standards
- Requires vehicle producers, dismantlers, and shredders ("economic operators") to establish adequate systems for the collection of end of life vehicles
- States that owners must be able to return their vehicles into these systems free of charge from 2007
- Requires producers to pay all or a significant part of the costs of takeback and treatment from January 2007
- Sets rising re-use, recycling, and recovery targets which must be met by economic operators by January 2006 and 2015
- Restricts the use of heavy metals in new vehicles from July 2003

4.2.6 Other European Initiatives

Other key European initiatives which specifically affect waste management, either at present or in the future include:

EU Directive on Waste 75/442/EEC (amended 91/156/EEC and 91/692/EEC), Articles 3, 4 & 5

This places a requirement on Member Sates to have a regard to the need to minimise waste, encourage recycling and waste recovery. There must also be a regard given to the need to protect the environment and human health in the context of potentially polluting developments.

EU Directive on Waste Electrical and Electronic Equipment (WEEE)

WEEE was adopted by the EU in April 2002 and is due to be fully transposed into national law by December 2005.

The EC estimates that this waste stream is increasing by 16-28% every five years[11], and is one of the fastest growing waste streams, principally due to the increasing frequency of new versions of consumer products and a growth in the number of households. A target recovery level of 4kg per inhabitant per year is to be achieved by the end of 2006. The Directive will affect manufacturers, sellers and recyclers of electrical and electronic equipment, including household appliances, IT and telecoms equipment, audio-visual equipment, lighting, electrical and electronic tools, toys, leisure and sports equipment.

[11] ENDS Report No 334 - Waste Management Report No. 155 The WEEE Directive: A new era for electrical good producers (pgs. 27-30)

The WEEE Directive will place the following key obligations on producers:

- Lead, mercury, cadmium, hexavalent chromium and the brominated flame retardants PBDEs and PBBs must not be used in products, with limited exemptions, by July 2006

- Either directly or through third parties, producers must establish "systems" to treat and recover waste appliances using the best available treatment, recycling and recovery techniques. This may be done either collectively or individually and will need to be in place within 30 months of the Directive's entry into force

From the same deadline, producers must finance the collection, treatment, recovery and disposal of household WEEE from the point at which it has been taken to collection facilities, such as civic amenity sites. They must also finance the collection and recovery of commercial WEEE for "historic waste". All producers will share the treatment and recovery costs through collective schemes, each contributing "proportionately", for example by market share for different types of equipment.

Government guidance is that Local Authorities should consider working with producers (i.e. manufacturers and importers for electrical and electronic equipment), who will be responsible for treatment, recovery and meeting recycling targets. The community sector may also have a role to play.

Proposed Batteries Directive

A proposed producer responsibility Batteries Directive will require the separate collection and recycling of all types of batteries in the EU. Current national collection and recycling rates vary significantly across Europe, although it is fair to say that collection infrastructure in the UK is significantly behind other EU countries (e.g. Germany and France who currently collect all battery types). The Directive aims to harmonise the very different situations in Member States and sets high recovery targets. In doing so, the Directive aims to reduce the quantities of post consumer batteries entering the waste stream. Under the current proposal (March 2001), targets have been set to separately collect 75% by weight of all spent consumer batteries and 95% of spent industrial and automotive batteries, with a 55% recycling target. Batteries containing mercury will be banned immediately and those containing more than 5ppm of cadmium by weight will be banned from 2008. The Batteries Directive poses a significant challenge to the UK as there are no operational collections for mixed domestic batteries at present.

European Directive 96/59/EC on the Disposal of Polychlorinated Biphenyls (PCBs) and Polychlorinated Terphenyls (PCTs)

This requires that where reasonably practicable, PCB containing equipment (which is less than 5 litres in volume) and which is contained within another piece of equipment, shall be removed and collected separately when the latter equipment is taken out of use, recycled or disposed of. The PCB containing equipment will need to be treated as hazardous waste. The components involved consist of small capacitors in electrical equipment such as refrigerators, washing machines, cookers, and fluorescent light fittings, which were manufactured between the 1950s and 1986.

Hazardous or Special Waste Legislation
The Hazardous Waste List (94/904/EC) has been refined, increased in length and incorporated within the European Waste Catalogue, which is the new standard by which all waste in the EU must be defined. This means that many items, which were formerly not considered hazardous, will in future be considered as such (e.g. much electrical equipment, and fluorescent tubes). Implementation of this in the UK is expected to be through new regulations.

Working Document on The Treatment of Biodegradable Wastes (2nd Draft)
In February 2002, the European Commission issued the 2nd draft of a working group document on the treatment of biodegradable wastes. This discussion document sets out proposals that could represent the embryonic development of a potential future EU Directive on biodegradable waste designed to compliment the requirements of the Landfill Directive.

The Landfill Directive does not specify the way in which the required reductions in the landfilling of biodegradable wastes are reached. However, it gives a clear indication that biodegradable waste should preferably be treated via biological treatment processes such as composting and anaerobic digestion. Both the EU Council and Parliament therefore invited the European Commission to evaluate whether there was a need for an EU initiative to promote and harmonise the regulation of biological treatment systems.

The working document sets out a series of measures designed to enhance home composting, community composting and other forms of biological waste treatment. These include the mandatory introduction of separate collection systems for biological waste for all urban areas with a population of more than 2000 inhabitants within 5 years. The document also proposes minimum technical requirements for biological treatment processes (e.g. windrow composting) and limitations on the use of compost/stabilised biowastes based upon specific quality standards.

4.3 National Pressures

4.3.1 National Waste Policy

The National Waste Strategy for England and Wales [12] was published in May 2000 and sets out the Government's policy and vision for the promotion of sustainable waste management over the next twenty years. The document expands on information previously published in the Government White Paper "Away with Waste" [13], by providing additional detail on the Government's aspirations over the short, medium, and long term and the contributions that local authorities will be required to provide in meeting the national objectives. Local Authorities are required to consider four broad policy objectives when making strategic waste management decisions:

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[12] Department of the Environment, Transport and the Regions (2000). Waste Strategy 2000. ISBN 0 10 146932 2 May 2000.

[13] Away with Waste: A draft waste strategy for England and Wales Parts 1 and 2. Department of the Environment, Transport and the Regions, June 1999.

- BPEO (Best Practicable Environmental Option)
- Waste hierarchy
- The proximity principle
- Regional self-sufficiency

The BPEO methodology establishes, for a given set of objectives, the waste management option that provides the most benefit or least damage to the environment. Other considerations such as affordability are also considered.

The waste hierarchy is founded on the principle that waste arisings should be avoided, and unavoidable wastes are to be treated and managed in a way that first maximises reuse, then recycling and recovery (composting, digestion, energy from waste etc). At the bottom of the hierarchy is landfilling.

The proximity principal requires that waste should be managed as close as possible to its place of production, thus minimising the adverse impacts of transportation. In a similar vein the principle of regional self-sufficiency requires that waste arisings should be treated and disposed of within the region in which it is produced.

The national waste strategy sets a series of targets for recycling and composting and recovery for 2005, 2010, and 2015. The key national targets set out in Waste Strategy 2000 are presented in Table 4.2 and 4.3.

Table 4.2 National Targets for the Recycling and Composting of Household Waste

To recycle or compost at least 25% of household waste by 2005
To recycle or compost at least 30% of household waste by 2010
To recycle or compost at least 33% of household waste by 2015

Table 4.3 National Targets for the Recovery of Municipal Waste

To recover value from 40% of municipal waste by 2005
To recover value from 45% of municipal waste by 2010
To recover value from 67% of municipal waste by 2015

Recovery means to obtain value from waste through recycling, composting, other forms of material recovery, or recovery of energy.

To ensure that all Local Authorities contribute to achieving these targets, the Government has set statutory performance standards for recycling and composting for each Local Authority for 2003 and 2005. The Government will also set statutory performance standards for Local Authorities for 2010 and 2015 following future consultation.

4.3.2 Landfill Permits Trading

The Landfill Directive sets out requirements to reduce the amount of BMW sent to landfill as detailed in Table 4.1. A Wastes and Emissions Trading Bill was introduced in the House of Lords in November 2002. When passed it will allow the Government to impose allowances or annual limits on the amount of BMW that Local Authorities can send to landfill and permit Local Authorities to trade in their landfill allowances. If the new Bill progresses smoothly the scheme could be operational within the next year.

4.3.3 Animal By-Products Order

As a result of the 2000/01 foot and mouth crisis in the UK, the Government amended the Animal By-Products Order (ABPO) in May 2001. Under the ABPO 2001 amendments it became an offence to allow livestock (including birds) access to catering waste containing meat or products of animal origin, or catering waste which has originated from premises where meat or products of animal origin are handled. This applied equally to all catering wastes regardless of any treatment. Thus the 2001 amendments to the ABPO banned the application to land of catering wastes which had been composted ("processed"). However, this position is set to change as a draft EU Regulation on Animal By-Products will allow the use of properly composted mixed waste on all land except pasture land.

Proposed Animal By-Products (Amendment) (England) Order 2002

The ABPO 2002 amendments are to allow for the composting of catering wastes with the resulting compost able to be applied to farmland providing certain restrictions and controls are adhered to (those identified in the risk assessment).

In October 2001, Defra commissioned a risk assessment to determine the risks to cattle, sheep, pigs and chickens of infection from pathogens potentially present in that meat after the catering waste has been composted and applied to land. The results were published in May 2002. The ABPO 2002 amendments are based on this risk assessment.

Under the proposed amendments, the feeding of catering wastes to any livestock is to remain illegal, as is allowing any livestock to have access to any catering wastes. However, under the new proposals, livestock will be allowed onto land onto which compost (derived from catering waste) or digestion residues have been applied once a two month period has elapsed.

The Order details strict requirements for the operation of composting plants receiving catering wastes, including the requirement for in-vessel, or enclosed treatment and requirements on keeping "contaminated untreated" material separate from composted materials.

4.4 Summary

As detailed above there are a number of European Directives, Regulations and Proposals to regulate the manner in which wastes are managed. These initiatives are founded on the policy objective to manage resources in a more sustainable manner. From EU level, such policies have cascaded down through national, regional and local waste management strategies. Local Authorities are recognising the need to establish waste awareness and education programmes to achieve waste minimisation and increased recycling and recovery of the waste stream.

Business is not excluded. The growing number of producer responsibility Directives and proposed Directives requires industry to develop take-back schemes and to ensure products are more readily disassembled to aid with recycling.

Implementation of these policies may require the separate collection of dry recyclables and certain consumer goods. Traditionally the UK has managed its waste arisings predominantly through disposal to land. As legislative and economic drivers force waste arisings away from landfill, alternative processing capacity will be required throughout the UK.

The legislative framework has been developed without direct reference to the impacts of climate change. There may therefore be a need to review their practical implementation as the impacts of climate change become clearer. Examples of where such a review may be beneficial are in the siting of landfill facilities (a landuse planning matter) and their operation.

5. Potential Climate Change Impacts on Waste Management Processes

Climate change could have an impact on the future development and operation of waste management facilities and infrastructure as it could result in changes to a number of factors that affect waste management processes including changes in temperatures, cloud cover, rainfall patterns, wind speeds and storms. The timescales for climate change and waste management are similar. For instance, landfill sites can be operational for decades and still active for decades following their closure. Capital assets such as energy from waste plants and materials recovery facilities will be also be operational for decades and so could be affected by climate change. There is therefore a need to consider potential changes over significant timescales and respond appropriately. The following sections describe both general and specific potential climate change impacts on waste management.

5.1 General Climate Change Impacts on Waste Management

In order to give some indication of how climate change and waste management could interact, Table 5.1 presents a general assessment of what climate change could mean for waste management. The potential climate changes are derived from the UKCIP02 scientific report[2]. As there is minimal literature on the potential impacts of climate change on waste management, the examples of potential impacts on waste management are the authors' assessment, inferred from climate change studies. It is also important to note that waste management practicalities are evolving due to social, economic and environmental change. Therefore potential climate change impacts need to be considered alongside other changes that could affect waste management in order to obtain a fuller understanding of potential change.

Table 5.1 Summary of Potential Climate Changes and their Impacts

Climate Variable	Potential Climate Change	Examples of Potential Impacts on Waste Management
Temperature	Annual warming by the 2080s of between 1^{o} and $5^{o}C$ depending on region and scenario	Increased water demand for both workers and site operations
	Greater summer warming in the southeast than the northwest	Exacerbation of heat island effect in urban areas
	Years as warm as 1999 become more common. Number of very hot days increases, especially in summer and autumn	Decline in air quality and subsequent negative impacts on health of vulnerable groups
	Number of cold days decreases, especially in winter	Impacts on biological processes e.g. composting, anaerobic digestion etc
	Thermal growing season increases everywhere, with largest increases in the southeast	Increased risk of subsidence due to drying out of soils
	Soil moisture decreases in summer and autumn in the southeast but increases in winter and spring in the northwest	Reduced need for space heating in buildings. This could reduce operational costs
	More frequent stagnant summer anticyclones in southeast	Increased need for cooling. If not addressed this could result in a deterioration of indoor working conditions and loss of productivity. Mechanical based air conditioning would further increase emissions if not supplied from renewables
		Lack of water could adversely affect some flora and fauna but longer growing season and increased CO_2 concentrations could benefit some species
		Increased risk of fires
		Changes in distribution of vermin and pests
Precipitation	Generally wetter winters for the whole of the UK	Increased risk of flooding in winter from groundwater, surface water, tidal and sea sources
	Precipitation intensity increases in the winter	Disruption to infrastructure e.g. road, rail, and underground cables
	Total snowfalls decrease significantly everywhere	Increased leachate production in the winter months
	Greater contrast between summer (drier) and winter (wetter) precipitation	Increased precipitation intensity could lead to inundation of drainage systems

Climate Variable	Potential Climate Change	Examples of Potential Impacts on Waste Management
Precipitation (continued)		Increased precipitation intensity could affect slope stability on waste management sites[14]
		Less disruption due to transport infrastructure due to reduced snowfalls.
		Less need for winter maintenance e.g. road gritting
		Reduced water availability in summer
		Changes in ground and surface water flows e.g. more frequent low river flows
		Impacts on biological processes e.g. composting, anaerobic digestion etc
Cloud cover	Reduction in summer and autumn cloud, especially in the south, and an increase in radiation	Risk to workers of skin conditions associated with increased exposure to sunshine during outdoor working
	Small increase in winter cloud cover	Number of days when outdoor working conditions outside of acceptable levels, on hot days, in summer increases, reducing productivity
		Outdoor working conditions outside of acceptable levels on cold days in winter reduces, improving productivity
Storm tracks	Winter depressions become more frequent, including the deepest ones	Stronger winds in the south affecting outdoor operations
		Storm damage to buildings and infrastructure
		Changes to insurance costs and availability
Humidity	Specific humidity increases throughout year	20% fewer fog days in winter across UK by 2080s reducing disruption to transport systems and outdoor operations
	Relative humidity decreases in summer	Impact on outdoor biological treatment processes
Thunderstorms	Lightening rate expected to more than double over southwest by 2080s but thunderstorms reduced by half	Together these mean that overall lightening strikes each year will remain the same
Sea level	By the 2080s, mean sea level will be up to 86cm above its current level due to thermal expansion and natural land movements	Inundation of coastal facilities
	In addition to the above sea level rise, additional extreme sea levels could occur due to storm surges between 10 and 20 times more frequently by the 2080s, for some coastal locations	Increased erosion of coastal areas
		Disruption to water based transport

[14] For example: Jones, D.K.C. 1993. Slope stability in a warmer Britain. Geographical Journal, 159, 184-195

5.2 Specific Climate Change Impacts on Waste Management Processes

The following tables apply these potential impacts to various waste management processes in more detail. Tables 5.2 to 5.7 present potential impacts for waste management processes as follows:

- Table 5.2: Disposal/landfill
- Table 5.3: Thermal processing including mass burn, fluidised bed, gasification, pyrolysis and RDF
- Table 5.4: Biological processing including in vessel composting, windrow composting, anaerobic digestion and ethanol production
- Table 5.5: Mechanical processing including clean materials recovery facility (MRF), dirty MRF and bio-mechanical treatment
- Table 5.6: Collection including kerbside collection of mixed waste and kerbside collection of recyclables
- Table 5.7: Transfer including transfer stations, civic amenity sites and recycling bring sites

Table 5.2 Disposal/Landfill

Waste management option Disposal/Landfill	Higher temperatures could: • alter waste decomposition rate. This would have implications for the amount of landfill gas generated, length of active gassing phase, site settlement, closure and completion etc. However, decomposition processes are complex and decomposition rate depends on other factors e.g. waste composition (putrescible fraction, moisture content etc), site management practices e.g. fill method, daily cover, leachate extraction rate etc. Higher temperatures and less moisture could reduce decomposition rate. Higher temperatures and adequate moisture could increase decomposition rate • lead to reduced water availability, alter site hydrology and hence leachate production • lead to reduced water availability and hence increased strength of leachate due to reduction in dilution • reduce outdoor workers' productivity. In some cases extreme temperatures could adversely affect outdoors workers at risk from heat stress • give rise to situations where there is a greater risk of disease being transmitted e.g. water borne and food poisoning types ailments due to increased pathogen activity, bioaerosol releases • reduce disruption to transport infrastructure from snow and ice in winter • give rise to increased vermin e.g. flies • give rise to increased risk of odour nuisance • increased stress to vegetation and planting in landscaping and screening areas Reduced precipitation in summer could: • alter the waste decomposition rate (see above) • alter site hydrology (see above) • increase leachate strength • reduce water availability for site management e.g. dust suppression • increase the risk of shrinkage in clay lining and capping layers Increased precipitation in winter could: • increase flooding occurrences on site due to saturated waste and rising groundwater. This could result in increased risk of offsite pollution from leachate and gas migration (depending on nature of site) and inundation of site facilities e.g. weighbridge, roads, offices, leachate treatment equipment, gas extraction equipment, offices etc depending on site location. This could have periodic implications for environmental protection • alter waste decomposition rate • increase leachate production in winter months (increased treatment and disposal costs) • lead to disruption to transport infrastructure (road and rail) due to flooding and hence delivery of waste • increase slope stability risks • increase risk of erosion of bunds and capping layers • saturation of ground restricts use of some mobile plant, alternative equipment or seasonal tyre changes may be required

Table 5.2 Disposal/Landfill (continued)

Waste management option Disposal/Landfill	Reduced cloud cover and increased UV radiation could: • increase the risk to outdoor workers from sunburn and other skin conditions associated with over exposure. Although these issues are generally addressed through Health and Safety requirements there could be a need for additional protection measures • have an adverse impact on the life of exposed materials e.g. High Density Polyethelyne (HDPE) liner, plastic pipework and drainage ducts etc. • increase the risk of damage to the HDPE liner due to solar gain requiring additional protection measures during installation Any increased storminess could: • lead to disruption of water based waste transport • lead to increased incidences of windblown litter and debris. In severe cases this could increase risk of injury from flying objects, mainly for site workers • lead to damage to buildings and site closure. Procedures exist for addressing these problems but they may become more frequent • lead to change in the cost and availability of insurance cover Any increase in stagnant, anti-cyclonic conditions could: • reduce dispersal of emissions e.g. flared gas, odour etc. Rising sea level could: • lead to inundation of sites near to the coast • lead to increased damage from storm surges for sites near to the coast

Table 5.3 Thermal Processing

Waste management option	
Thermal Processing Mass Burn Fluidised Bed Gasification Pyrolysis RDF	Higher temperatures could: • reduce workers' productivity due to temperatures in buildings being outside acceptable working conditions. In some cases extreme temperatures could adversely affect workers at risk from heat stress • reduce disruption to transport infrastructure from snow and ice in winter • increase the rate of waste decomposition within waste reception and storage bunkers leading to higher levels of odour, dust, insect infestation and bioaerosols Reduced precipitation in summer could: • reduce water availability for site management e.g. dust suppression Increased precipitation in winter could: • increase flooding occurrences on site due to inundation of site facilities e.g. weighbridge, roads and offices depending on site location • lead to disruption to transport infrastructure due to flooding and hence delivery of waste • impact on the combustion process if waste is of higher moisture content than anticipated. This may result in variations to chemical and reagent usage in the flue gas treatment system Any increased storminess could: • lead to increased incidences of windblown litter and debris • lead to increased damage to buildings. This could result in site closure. Procedures exist for addressing these problems but they may become more frequent • lead to change in the cost and availability of insurance cover Any increase in stagnant, anti-cyclonic conditions could: • reduce dispersal of stack emissions Rising sea level could: • lead to inundation of sites near to the coast • lead to increased damage from storm surges, for sites near to the coast

Table 5.4 Biological Processing

Waste management option Biological Processing In Vessel Composting Windrow Composting Anaerobic Digestion Ethanol Production	Higher temperatures could: • alter waste decomposition rate for windrow composting. Higher temperatures and adequate moisture could increase decomposition rate • reduce outdoor and indoor workers' productivity. In some cases extreme temperatures could adversely affect outdoors workers at risk from heat stress • reduce disruption to transport infrastructure from snow and ice in winter • give rise to increased vermin e.g. flies (windrow composting) • increase in temperature could lead to increased combustion risk as outer layers of windrows dry out • increase the risk of odour nuisance and bioaerosols • increase dust potential Reduced precipitation in summer could : • alter the waste decomposition rate (see above) • reduce water availability for site management e.g. dust suppression • lead to increased combustion risk (see above) • increase dust potential Increased precipitation in winter could: • increase flooding occurrences on site due to inundation of site facilities e.g. weighbridge, roads and offices depending on site location • alter waste decomposition rate. Too much moisture could reduce waste decomposition rate • lead to disruption to transport infrastructure due to flooding and hence delivery of waste Reduced cloud cover and increased UV radiation could: • increase risk to outdoor workers from sunburn and other skin conditions associated with over exposure. Although these issues are generally addressed through H&S requirements there could be need for additional protection Increased storminess could: • lead to increased incidences of windblown litter and debris (windrow composting). Procedures exist for addressing these problems but they may become more frequent • lead to damage to site buildings • lead to change in the cost and availability of insurance cover Rising sea level could: • lead to inundation of sites near to the coast • lead to increased damage from storm surges for sites near to the coast

Table 5.5 Mechanical Processing

Waste management option	Higher temperatures could: • reduce workers' productivity due to temperatures in buildings being outside

Mechanical Processing Clean Materials Recovery Facility Dirty Materials Recovery Facility Bio-mechanical Treatment	acceptable working conditions. In some cases extreme temperatures could adversely affect workers at risk from heat stress • give rise to situations where there is a greater risk of diseases being transmitted where putrescible waste is being processed • reduce disruption to transport infrastructure from snow and ice in winter • require changes to equipment due to increased potential of dust, odour, bioaerosol release and combustion risk in both waste receptors and processing areas Reduced precipitation in summer could: • reduce water availability for site management e.g. dust suppression Increased precipitation in winter could: • increase flooding occurrences on site due to inundation of site facilities e.g. weighbridge, roads and offices depending on site location • lead to disruption to transport infrastructure and hence delivery of waste • require changes to equipment due to higher moisture content of waste Any increased storminess could: • lead to damage to site buildings • lead to change in the cost and availability of insurance cover Rising sea level could: • lead to inundation of sites near to the coast • lead to increased damage from storm surges for sites near to the coast

Table 5.6 Collection

Waste management activity	Higher temperatures could:
Collection and Transfer Kerbside Collection – Mixed Waste Kerbside Collection – Recyclables	• result in the need for increased level of collections for mixed waste containing putresibles and segregated biodegradable waste collections due to increased rate of decomposition with resultant odour and insect infestation potential and bioaerosol releases • reduce outdoor workers' productivity. In some cases extreme temperatures could adversely affect outdoors workers at risk from heat stress • give rise to situations where there is a greater risk of diseases being transmitted where putrescible waste is handled • reduce disruption to transport infrastructure from snow and ice in winter • impact on the selection of waste collection containers if adverse impacts are to be avoided Increased precipitation in winter could: • lead to disruption to transport infrastructure from increased flooding and hence collection and delivery of waste • require provision of containers designed to keep waste dry. Any increased storminess could: • lead to increased incidences of windblown litter and debris. In severe cases this could increase risk of injury from flying objects for collection workers Rising sea level could: • lead to disruption of collection rounds on the coast

Table 5.7 Transfer

Waste management activity	Higher temperatures could:
Transfer Transfer Station Civic Amenity Recycling Bring Sites	• reduce outdoor and indoor workers' productivity. In some cases extreme temperatures could adversely affect outdoors workers at risk from heat stress • give rise to situations where there is a greater risk of diseases being transmitted where putrescible waste is handled • reduce disruption to transport infrastructure from snow and ice in winter • lead to odour impacts due to increased rate of decomposition requiring sophisticated odour and bioaerosol control measures at the transfer station and a reduction in the volume of waste that may be stored on site for a reduced time • require greater frequency of material removal to reduce nuisance potential Reduced precipitation in summer could: • reduce water availability for site management e.g. dust suppression Increased precipitation in winter could: • increase flooding occurrences on site due to inundation of site facilities e.g. weighbridge, roads and offices depending on site location • lead to disruption to transport infrastructure due to floods and hence delivery of waste to site and transport off site Reduced cloud cover and UV radiation could: • require the provision of shaded areas over skips and waste reception containers Any increased storminess could: • lead to increased incidences of windblown litter and debris. In severe cases this could increase risk of injury from flying objects, mainly for site workers • lead to damage to buildings and site closure. Procedures exist for addressing these problems but they may become more frequent • lead to change in the cost and availability of insurance cover • require more sophisticated buildings than currently provided Rising sea level could: • lead to inundation of sites near to the coast • lead to increased damage from storm surges for sites near to the coast

As can be seen from the tables, climate change could have a range of impacts on various waste management options. The extent to which these potential impacts actually affect waste management sites and processes will often depend on site-specific issues. Therefore, steps should be taken to assess the risk of climate change to individual sites and processes. This could start by examining waste management facilities and processes at the national scale and assessing which types of facilities and processes could be at most risk from climate change e.g. low lying coastal sites. This study has started that process but further attempts should be made to quantify the risks and take appropriate action based on the risk assessment. This is discussed in more detail in the following chapters covering conclusions and recommendations.

The remaining sections in this chapter discuss related climate change impact areas in more detail based on recent literature and their implications for waste management.

5.3 Health and Disamenity

The impacts of waste management processes and operations on human health, the environment and disamenity are key foci for policy makers, regulators, operators and the public. The following sections are a preliminary examination of how climate change could interact with these issues. Preliminary work has been carried out into the potential impacts of climate change on some of these areas e.g. health but more work needs to be done to assess the nature and scale of the relationship between climate change, waste management, health, the environment and disamenity.

5.3.1 Climate Change and Health

The Department of Health (DoH) study into climate change and health[15] reached the following conclusions:

- Mortality and morbidity in vulnerable groups within the general population are affected by temperature – both extremes of hot and cold
- 10,000 extra cases of food poisoning associated with higher temperatures could occur
- More work needs to be done on water borne diseases and climate change
- An increase in the frequency of severe storms is likely to be associated with significant damage to buildings and personal injury from flying debris. Analysis of a worst case scenario – a windstorm in the late afternoon in London and south east England – suggest that such an event might be associated with several hundred deaths, several hundred hospital admissions as well as minor injuries. It is likely that the National Health Service (NHS) would cope adequately with this scale of impacts
- A detailed risk assessment of the likely effects of a major flood of low lying areas is required

[15] Department of Health (2001), Health effects of Climate Change in the UK. Institute of Environment and Health, Leicester. 290pp. Copies available from: http://www.doh.gov.uk/airpollution/climatechange02

- There is likely to be a reduction in episodes of cold still weather associated with winter air pollution episodes but an increase in summer pollution associated with hot sunny days, such as an increase in background concentrations of ozone

- Reduced cloud cover is likely to lead to increased exposure to UV radiation. Reductions in emissions of substances that deplete the ozone layer should reduce this increased exposure. However, by 2050, 5,000 extra cases of skin cancer and 2,000 more cases of cataract may be reported each year

Health Implications of Climate Change for Waste Management

Although the DoH report did not specifically consider the interaction between health, climate change and waste management, the following impacts could be inferred:

- Although the conclusions for temperature changes and mortality/morbidity were not specifically explored for waste management workers, they could affect those workers already susceptible to temperature related ailments. However, it is expected that adaptive action would be taken to address these conditions

- Again, although increases in food poisoning ailments are not directly applicable to waste management workers, higher temperatures could give rise to conditions that could foster food poisoning type ailments. However, the health and safety (including hygiene) issues on waste management sites handling material that may give rise to pathogens and bioaerosol releases are well understood and again it is expected that adaptive action would be taken

- Increased storms could result in damage to buildings and risk of personal injury from flying debris. Risk of damage and injury during storms is well known on waste management sites and they are usually closed during the most severe weather when risk is greatest

- Depending on the nature of the site and its location, more frequent or severe flooding of a landfill site or transfer station containing putrescible waste could increase the risk to public health. The DoH report pointed to the need for a detailed risk assessment of the likely effects of a major flood in low lying areas (see above) this should include consideration of waste management sites

- Measures to reduce exposure to increased sunshine are effective such as use of sun block and appropriate clothing. These could be used by waste management workers if it was considered that they were at increased risk

These potential health impacts have been used to inform the potential impacts tables. However, more work needs to be done on the risk associated with these potential health impacts in order to inform decision making by policy makers, regulators and site operators.

There are specific concerns about the health effects of emissions from landfill on local communities. Several studies have been carried out[16]. Given that the research in this area is at an early stage, any connection between changing climate conditions and the health impacts of emissions from landfill would only be speculative.

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[16] Birth outcomes and selected cancers in populations living near to landfill sites. Report to the Department of Health, Aug 2001. Paul Elliott et al, The Small Area Health Statistics Unit (SAHSU), Dept of Epidemiology and Public Health, imperial college St Mary's Campus, Norfolk Place, London W2 1PG. Available at www.doh.gov.uk/landh.htm

5.3.2 Disamenity

A recent report[17] attempted to estimate the disamenity costs and externalities of landfill. Disamenity encapsulates the nuisance caused locally by the landfill and includes noise, dust, litter, odour and vermin. The report adds visual intrusion and enhanced perceptions of risk. Externalities convey external costs and benefits carried by others that are not reflected in the price of an activity. They are a form of market failure as the full cost to society of an activity is not reflected in the direct cost. Externalities can be adjusted through a number of mechanisms including economic instruments. Externalities are broader than disamenity and could include greenhouse gas (GHG) emissions contributing to climate change and air pollution contributing to health effects and soil and land contamination.

The report concluded that there was a reduction in house prices near to landfill sites. Some of this was explained by physical and socio-economic factors but taking these into consideration, there was still a statistically significant stock disamenity effect for houses closer than 0.5 miles from a landfill. As the report was largely an analysis of the statistical evidence for the impact of landfill disamenity it did not cover the potential impacts of climate change on these disamenity costs.

Disamenity Implications for Climate Change and Waste Management

It could be inferred from the above that certain aspects of climate change could exacerbate disamenity e.g. increased summer dry weather and winter storms could lead to increased dust and litter, whilst higher temperatures could lead to increased odour and vermin. Alongside increased risk of disamenity, perception of risk could also change e.g. changes in attitude to potential health impacts. However, the above analysis is inferred and more work needs to be done on the potential impacts of climate change on the disamenity of waste management.

Marginal Damage Cost of Methane Emissions from Landfill

It has been estimated[18] that each tonne of carbon emitted could give rise to a marginal cost (the difference in future damage levels caused by a marginal change from the current level of emissions) of £70 (2000 prices) for carbon emissions in 2000. This could increase by £1 per year for each tonne of carbon to account for the increasing cost of damage over time. These costs include damage from sea level rise, increased flooding, effects of higher temperatures on people, buildings and infrastructure and changes in storm patterns. It includes a social equity weighting to account for difference in income levels and damage costs across different regions. More work would need to be done to assess whether it would be possible to convert these figures into a meaningful damage cost figure for GHG emissions from UK waste management and the implications this may have for policy makers, regulators and operators.

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[17] A study to estimate the disamenity costs of landfill in Great Britain. Cambridge Econometrics in association with EFTEC and WRc, Feb 2003. ISBN 0-85521-011-7

[18] Government Economic Service Working Paper 140: Estimating the social costs of carbon emissions, Jan 2002. Richard Clarkson and Kathryn Deyes, Environment Protection Economics Division, Defra

5.4 Biodiversity

Climate change could have implications for the distribution and occurrence of climate sensitive flora and fauna[19].

Landfill sites present numerous opportunities for the creation of a wide variety of habitats. These have an intrinsic value in their own right, as well as providing links to adjacent areas, thus helping to maintain habitat connectivity. The restoration of landfill sites has in recent years seen a change in orientation away from agricultural after-uses towards those focused on a mixture of amenity, forestry and nature conservation. It should be noted however, that successful habitat restoration can only occur if solutions are sought to the complex range of engineering problems that landfill sites present. Table 5.8 gives an illustration of sites previously used for landfill that have been restored to areas of nature conservation interest[20].

Table 5.8 Landfill sites of nature conservation interest

Site History	Nature Conservation Interest
One of a series of old Pulverised Fuel Ash (PFA) lagoons. Planning permission for landfill was granted in 1983. Landfill operations ceased in the early 1990s and habitat creation works were completed in 1995	Species rich hay meadow, woodland and a number of ponds
4 ha site located within an old limestone quarry. Landfill operations ceased in 1996 and the completion of the limestone grassland was completed in 1998	Calcareous grassland containing a similar species composition to the site's neighbouring SSSIs
Landfill ceased in 1981 and restoration commenced in 1983. A small area to the north east of the site has yet to be restored	Woodland containing native tree species and species rich grassland
Small site closed several years ago. At times of high annual rainfall up to 600 m^3 of leachate can be produced a day. Remedial works commenced in 1996 involving engineering, design and construction. More than 5 ha of various wetland habitats were created at this time	Species rich wetland and a 1 ha pond with aquatic vegetation

Climate change could influence the choice of ecological communities used to restore landfill sites[21]. Although the literature has not extensively covered this aspect of biodiversity, this role should be monitored and enhanced, where possible.

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[19] Defra: Climate change and UK nature conservation: A review of the impact of climate change on UK species and habitat conservation policy. Available at www.defra.gov.uk/wildlife-countryside/climatechange/nature

[20] Ecoscope (2000). Wildlife Management and Habitat Creation on Landfill Sites: A Manual of Best Practice. Ecoscope Applied Ecologists, Muker. ISBN 0-9539189-0-4

[21] Carver, S.M. 2003. The protection of ecology on landfill sites. In: Moore, H.M., Fox, H.R and Elliott, S. (eds). Land Reclamation: Extending the Boundaries. Swets and Zeitlinger, Lisse. ISBN 90 5809 562 2

6. Conclusions

This study has been compiled from the climate change and impacts literature related to waste management. The authors have also used their judgement to interpret the information and apply it to waste management in order to reach conclusions and put forward recommendations. This study has begun the process of understanding what climate change could mean for waste management. However, much more work needs to be done in order to develop a robust understanding of the potential impacts of climate change on waste management. This chapter presents a range of conclusions derived from the preceding analysis. These cover:

- Climate change science and impacts
- Climate change and waste management
- Climate change uncertainties
- Capacity building
- Related studies and resources

6.1 Climate Change Science and Impacts

Climate change is happening and it could lead to the following changes to the UK climate in this century:

- Increased winter and summer temperatures
- Increased winter precipitation
- Reduced summer precipitation
- Increased intensity of rainfall events
- Increased sunshine
- Increased frequency of winter storms
- Rising sea levels and increased sea storm surges

These changes could have implications for economic, social and environmental systems including the availability and quality of water, risk of flooding, damage to buildings, exposure of people to UV radiation and coastal erosion and inundation. However, there is still much work to do on understanding potential climate changes and their specific impacts on these systems.

6.2 Climate Change and Waste Management

Climate change has the potential to affect waste management processes in a number of ways including:

- Increased disruption to supporting infrastructure e.g. road and rail, from increased flooding from surface water, groundwater and drainage systems. This could also affect some on site facilities e.g. weighbridges and gas and leachate collection systems
- Changes in site hydrology and temperature which in turn could affect waste management processes e.g. landfill degradation rates, leachate production and composition
- Increased damage to site buildings from storms
- Increased disruption to transport infrastructure due to flooding and hence delivery of waste
- Increased health risks to workers from increased sunshine and exposure to UV radiation and increased pathogen and vermin activity
- Reduced worker comfort, with impacts on productivity, from increased indoor and outdoor temperatures
- Increased site disamenity from odour, vermin, dust and litter
- Increased risk of subsidence and slope instability from drying out of soils followed by rapid wetting due to heavy rainfall
- Inundation and/or erosion of low lying coastal facilities
- Influencing the types and amount of flora and fauna on and around facilities and the choice of ecological communities used to restore landfill sites
- Influencing lifestyle changes that may lead to variations in the quantities and characteristics of the waste to be managed

However, the understanding of the potential impacts of climate change on waste management is at a very early stage and more work needs to be done to understand the potential impacts and what can be done to address them by policy makers, regulators and site operators.

6.3 Climate Change Uncertainties

There are still many areas of uncertainty associated with climate change and its potential impact on waste management including:

- Uncertainties surrounding climate modelling e.g. climate model resolution and other scientific uncertainties such as feedbacks from the carbon cycle and natural variability
- The exact nature and scale of potential climate change impacts on waste management processes

- How waste management itself might change due to changes in legislation and regulatory and management practices and market conditions. Waste management could also change due to changes in consumer preferences and attitudes to consumption, resource use and environmental impacts

Risk, Uncertainty and Decision Making

Chapter 2 described the levels of confidence and nature of risk associated with climate change. A recent technical report from UIKCIP[22] sets out a framework for risk based climate related decision-making. It describes a range of tools and techniques that can be used to assess risk and help to plan appropriate action. More work will need to be done to translate this framework for use where there could be climate change impacts on waste management such as choice of site, choice of waste management option and site management practices. Although focussed on longer term planning, this risk-based approach could help to inform site management practices that may need to be adapted for climate impacts.

The UKCIP02 scenarios describe possible future climate conditions for the 2020s, 2050s and the 2080s. Whilst this is useful for some planning horizons e.g. infrastructure development intended to last for 50 or more years, some processes e.g. spatial development planning, would benefit from shorter term indications of possible climate change impacts. According to a recent document outlining what climate change could mean for them[23], Defra are planning to produce guidance on shorter term climate scenarios. These scenarios could be useful for developing approaches to assessing the potential impacts of climate change on waste management.

6.4 Capacity Building

As the understanding of the potential climate change impacts on waste management is at a very early stage; there is a lack of capacity within the sector in terms of knowledge, information exchange, learning, training, research and response. At present this covers waste management and climate change policy makers, regulators and site operators as well as academia, the professional institutions and other professionals associated with waste management. There are a range of actions that can be taken to address this capacity issue including research, information dissemination and training.

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[22] Willows, R. and Connell, R. (Eds.). (2003) Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report, UKCIP, Oxford

[23] The impacts of climate change: implications for Defra, Department for Environment, Food and Rural Affairs, Jan 2003. Available at:

www.defra.gov.uk/environment/climatechange/impacts2/pdf/ccimpacts_defra.pdf

6.5 Related Studies and Resources

6.5.1 Adaptation

Work has been undertaken in the UK to begin to quantify the potential costs of adaptation to climate change[24]. The areas assessed were water resources, flooding, buildings and nature conservation. The possible ranges of costs were large but give an indication of the scale of potential costs and the adaptation options e.g. water demand management or development of new water supply infrastructure. Waste management was not addressed in the study.

6.5.2 Landuse Planning

The Office of the Deputy Prime Minister (ODPM) is currently undertaking a study into the potential impacts of climate change on the land use planning system. This may have implications for planning issues for waste management facilities e.g. site location and disamenity.

6.5.3 Regional Climate Change Impact Studies

Most UK regions have undertaken some form of scoping study to begin the process of assessing the potential impacts of climate change. These are available on the UKCIP website.

Most have focused on the potential environmental impacts but later ones have begun to consider potential socio-economic impacts using a combination of socio-economic scenarios and economic evaluation techniques. The socio-economic and economic evaluation approaches used were those developed for UKCIP. The socio-economic scenarios[25] are available on the UKCIP website and the economic evaluation methodology will be available shortly. Most of the regional studies have pointed to the potential need for more frequent waste collection. This could occur because of higher temperatures and hence increased waste decomposition and associated odour and potential adverse health impacts. These related studies and resources can be used to inform further development of the understanding of potential climate change impacts on waste management.

The following chapter on recommendations puts forward a range of actions to address climate change, climate change and waste management, uncertainty and capacity building issues.

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[24] Department of Environment, Transport and the Regions: Potential UK adaptation strategies for climate change. ERM, May 2000

[25] UK Climate Impacts Programme, (2001), Socio-economic scenarios for climate change impacts assessment: a guide to their use in the UK Climate Impacts Programme. UKCIP, Oxford

7. Recommendations

This scoping study has begun the process of understanding what climate change could mean for waste management. As it is a new area, it is recommended that more research is carried out into specific impacts. The following are suggestions for how the gaps in knowledge could be addressed and how capacity building on climate change can take place in the sector. They follow the format of the preceding section on conclusions and cover:

- Climate change science and impacts
- Climate change and waste management
- Climate change uncertainties
- Capacity building
- Related studies and resources

7.1 Climate Change Science and Impacts

It is recommended that the following actions are taken on climate change:

1. Waste management policy makers and regulators should continue the process of building a shared understanding of the potential for climate change to have an impact on waste management policy and practices. This could involve researching the literature - an initial engagement through the UKCIP website is an excellent introduction to the subject
2. Waste management policy makers and regulators should ensure that they have a firm and effective link to and dialogue with climate change policy makers in order to ensure that appropriate policies and regulatory activities are developed to respond to climate change issues that could affect waste management
3. As climate change could significantly affect their business, waste management companies should ensure that they also have a good understanding of potential climate change impacts and how they could affect their operations. This will aid effective planning. An industry forum could be established to facilitate this process
4. Waste collection and disposal authorities are made aware of any issues arising from the potential impacts of climate change that could influence their service delivery responsibilities and contractual commitments

Recommendations 1 and 2 could be carried out through a climate change forum for policy makers and regulators. Appropriate links with the industry forum discussed in recommendation 3 should also be considered.

7.2 Climate Change and Waste Management

Waste management is a key public health and resource management activity with significant environmental impacts and implications across the public and private sectors.

Up to the present time the majority of the focus for waste management and climate change has been on emissions and mitigation. The science of climate change and impacts has not, as yet, been a focus for waste management and hence is under-represented in the literature and in assessment studies. Action should be taken to ensure that waste management is a focus for climate change. A starting point for this process could be a more detailed sectoral study into the potential impacts of climate change on waste management drawing on regulators' and operators' experience of climate impacts. This study could seek to apply the UKCIP tools and techniques e.g. socio-economic scenarios and economic evaluation, to the sector. It could also include a survey of site operators and regulators on recent climate related events e.g. closure due to storms, flood events, changes in biodiversity, changes to operating practices because of higher temperatures, increased odour problems, more pests, rise in complaints etc. This survey could indicate the scale and understanding of weather related risks on waste management.

Other cross-sectoral actions could include:

- Development of tools and techniques to assess site specific impacts e.g. use of climate downscaling techniques and other assessment tools including those for hydrology, leachate and gas yield. This will help to inform any changes that may be needed to site management practices

- Assessment of any site operational changes that may be needed in the short, medium and long term to address potential climate change impacts. This should cover the full range of issues affecting site operations e.g. site engineering, management, health and safety of workers, biodiversity, visitors and the community

- The development of a robust set of climate change indicators for waste management e.g. temperature, precipitation, wind speed, atmospheric pressure, flooding incidences, site damage and closure due to storms, disamenity complaints, species and habitat change and occupational health and safety related to climate change. This will help to monitor climate change at site level and to assess possible consequences

- Identification of adaptation options for waste management processes that could be affected by climate change. The engineering, operational, investment, timescale, costs, land use planning and other resource implications of these adaptation options for site managers, regulators and policy makers should be identified in order to assist effective planning of waste management activities

Actions for regulators could include:

- Carrying out a high level risk assessment to identify those sites and processes that could be most affected by climate change and formulate appropriate action plans to address the potential impacts

- The UKCIP/EA study on risk, uncertainty and decision making should be adapted for use by waste management regulators, policy makers and site operators to inform decision making on waste management

Actions for policy makers could include:

- An assessment of how climate change could affect the health impacts and disamenity from waste management processes
- An assessment of how climate change could affect the choice of waste management options. For instance, could climate change extend or reduce periods of waste degradation? Could climate change mean that more waste management operations need to be performed under cover? Will additional investment be required for odour control measures as a result of climate change?

7.3 Climate Change Uncertainties

In order to address the areas of uncertainty, a research programme should be developed by the waste management industry, regulators and policy makers to cover the topics discussed above. In addition to this it is recommended that a robust set of waste management and climate change scenarios is developed and agreed between the main stakeholders that can be used to inform the strategy, policy making, regulation and management of waste.

7.4 Capacity Building

It is recommended that a range of actions are taken to build capacity within the sector on climate change impacts on waste management. These include:

- The production and distribution, by email if possible, of a regular waste management and climate change impacts publication e.g. bulletin. This would serve as a focus for information exchange and inform the main stakeholders on key developments
- Engagement of academia in climate change impacts and waste management research in order to build a more robust understanding of the issues. This could be through commissioning individual studies or influencing funding mechanisms to address the topic e.g. NERC and EPSRC research funding
- Articles in trade and technical journals to raise awareness of the topic
- Conference and seminar presentations on the topic to facilitate discussion. In the next year or so there could be an opportunity to organise a specific seminar or conference on waste management and climate change impacts in order to take stock of current understanding and precipitate action
- In time, the development of training courses for professional to develop their understanding of the topic

Cross-sectoral action will need to be taken to move forward in these areas, emphasising the importance of the establishment of cross-sectoral fora.

7.5 Related Studies and Resources

A range of activities should be considered covering adaptation, landuse planning and regional climate change impacts studies including monitoring developments in climate change that could help to build a better understanding of how climate change could affect waste management e.g. Defra's forthcoming shorter range scenarios (see section 6.3).

7.5.1 Adaptation

Research should be carried out into the possible adaptation responses for waste management under climate change scenarios and its potential cost. This should build on the work already done on adaptation and its cost. This would help policy makers, regulators and operators to plan for and implement appropriate adaptive actions to reduce the impact of climate change.

7.5.2 Landuse Planning

The forthcoming work of the ODPM on climate change and landuse planning should be examined for its implications for waste management e.g. site location and disamenity. This could help regulators in their role as consultees in the planning process to assess the potential impacts of climate change on waste management and put forward appropriate responses.

7.5.3 Regional Climate Change Impacts Studies

Most of the UK's regions have now produced impacts studies. Most of the studies have identified a potential need for more frequent waste collection but waste management has not been considered in any depth in these studies. This is a gap and guidance should be produced on how waste management should be considered in regional studies in order to ensure that appropriate issues are identified e.g. modifications or restrictions on the location and type of waste management activities.

Appendix A
Climate Change Glossary

Terms in *italics* are found elsewhere in this Glossary.

Anthropogenic	Resulting from, or produced by, human beings.
Aquifer	Layer of permeable rock, sand or gravel which allows water to pass through it and which if underlain by impermeable material, holds water to form a saturated layer or water table.
Atmosphere	The gaseous envelope surrounding the Earth, comprising almost entirely of nitrogen (78.1%) and oxygen (20.9%), together with several trace gases, such as argon (0.93%) and *greenhouse gases* such as carbon dioxide and water vapour.
Climate	The 'average weather' described in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organisation (WMO).
Climate change	Statistically significant variation in either the mean state of the *climate*, or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to *external forcings*, or to persistent *anthropogenic* changes in the composition of the atmosphere or in land use.
Climate model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.
Climate prediction	An attempt to produce a plausible descriptions or estimates of the actual evolution of the climate in the future, e.g. at seasonal, inter-annual or long-term time scales.
Climate projection	A projection of the response of the climate system to emission or concentration scenarios of *greenhouse gases* and *aerosols*, or *radiative forcing* scenarios, often based on simulations by *climate models*. As such climate projections are based on assumptions concerning future socio-economic and technological developments.
Climate scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic *climate change*.
Climate variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.
Downscaling	The development of climate data for a point or small area from regional climate information. The regional climate data may originate either from a *climate model* or from observations. Downscaling models may relate processes operating across different time and/or space scales.
Emission scenario	A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. *greenhouse gases*, *aerosols*), based on a coherent and internally consistent set of assumptions about driving forces and their key relationships.
Extreme weather event	An event that is rare within it's statistical reference distribution at a particular place. Definitions of 'rare' vary from place to place (and from time to time), but an extreme event would normally be as rare or rarer than the 10th or 90th percentile.
General Circulation Model (GCM)	A three-dimensional representation of the Earth's atmosphere using four primary equations describing the flow of energy (first law of thermodynamics) and momentum (Newton's second law of motion), along with the conservation of mass (continuity equation) and water vapour (ideal gas law). Each equation is solved at discrete points on the Earth's surface at fixed time intervals (typically 10-30 minutes), for multiple layers in the atmosphere defined by a regular *grid* (of about 200 km resolution). Couple ocean-atmosphere general circulation models (O/AGCMs) also include ocean, land-surface and

	sea-ice components. See *climate model*.
Greenhouse gas	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. The primary greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3).
Grid	The co-ordinate system employed by *GCM* or *RCM* to compute three-dimensional fields of atmospheric mass, energy flux, momentum and water vapour. The grid spacing determines the smallest features that can be realistically resolved by the model. Typical resolutions for GCMs are 200 km, and for RCMs 20-50 km.
Regional Climate Model (RCM)	A three-dimensional, mathematical model that simulates regional scale climate features (of 20-50 km resolution) given time-varying, atmospheric properties modelled by a General Circulation Model. The RCM *domain* is typically 'nested' within the three-dimensional *grid* used by a GCM to simulate large-scale fields (e.g. surface pressure, wind, temperature and vapour).
Relative humidity	A relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature expressed as a percentage.
Resolution	The *grid* separation of a climate model determining the smallest physical feature that can be realistically simulated.
Scenario	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative story-line'.
Specific humidity	The ratio of the mass of water vapour (in grams) to the mass of moist air (in kilograms) in a given volume of air.
Uncertainty	An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from a lack of information or from disagreement about what is known or knowable. It can also arise from poorly resolved climate model parameters or boundary conditions.

Appendix B
Waste Management Glossary

Centralised composting	Large-scale composting schemes that can process the organic fraction of municipal wastes, including kitchen and garden waste from household sources and suitable waste from parks and gardens.
Civic Amenity Sites	Sites provided by local authorities for the disposal of excess household and garden waste free of charge, as required by the Refuse Disposal (Amenity) Act 1978. Although these sites were originally established to provide householders with a means of disposing of bulky household wastes and garden waste, in recent years CA sites have received significant quantities of recyclables. In non-unitary areas, it is usually the Waste Disposal Authority that is responsible for ensuring that CA sites are provided.
Co-mingled materials	Waste collected in a mixed form that is destined for recycling after further sorting, usually in a materials reclamation facility (MRF).
Commercial waste	Waste arising from premises which are used wholly or mainly for trade, business, sport, recreation or entertainment.
Composting	An aerobic, biological process in which organic wastes, such as household garden and kitchen wastes, are converted into a stable granular material which can be applied to land to improve soil structure and enrich the nutrient content of the soil.
Home composting	Compost can be made at home from garden, kitchen and other wastes (e.g. 'bulking' agents such as shredded paper) using a traditional compost heap, a purpose-designed container, or a wormery.
Household Waste	This includes waste from household collection rounds (waste within Schedule 1 of the Controlled Waste Regulations 1992), waste from services such as street sweeping, bulky waste collection, hazardous household waste collection, litter collections, household clinical waste collection and separate garden waste collection (waste within Schedule 2 of the Controlled Waste Regulations 1992), waste from civic amenity sites and wastes separately collected for recycling or composting through bring/drop off schemes, kerbside schemes and at CA sites. Beach cleansing waste, rubble, abandoned vehicles and waste resulting from the clearance of fly-tipped materials are not included.
Household recycling (includes composting)	Includes household waste (see above) materials collected and sent for recycling by local authorities as well as wastes collected from household sources by private and voluntary organisations. Incinerator residues are not included and are counted under incinerated waste, regardless of the final destination. Home composting estimates are also not included.
Incineration with Energy from Waste (EfW)	Schemes in which waste is combusted under controlled conditions and energy is recovered from the process in the form of electricity and/or heat recovery.
Integrated co-collection	Kerbside schemes in which materials for recycling are co-collected with the ordinary household waste using a special compartmentalised vehicle.
Kerbside collection	Any regular collections of recyclables from premises, including collections from commercial or industrial premises as well as from households. Excludes services delivered on demand.
Landraise	A landfill site that extends above the level of the surrounding area.
Mechanised metal extraction (MME)	The mechanical extraction of ferrous and non-ferrous metals from waste. This includes magnetic extraction and eddy current separation, but does not include hand-sorting.
Materials Reclamation Facility (MRF)	Facility used to sort waste and separate out recyclable fractions for subsequent processing. Recyclables are segregated by means of manual sorting on conveyor belts and mechanical processes (such as MME).
Municipal waste	This includes household waste and any other wastes collected by a Waste Collection Authority, or its agents, such as municipal parks and gardens waste, beach cleansing

	waste, commercial or industrial waste and waste resulting from the clearance of fly-tipped materials
Non household sources	Includes wastes collected by a local authority from non-household sources (i.e. not covered by Schedules 1 and 2 of the Controlled Waste Regulations 1992).
Non household recycling (includes composting):	Municipally collected materials for recycling from commercial sources.
Other Household Sources	Schedule 2 wastes under the Controlled Waste Regulations 1992 - those from household sources not collected as part of the ordinary waste collection round service.
Private waste disposal contractor	As defined in the Environmental Protection Act 1990. It includes those providing a recycling service and private managing agents
RCV	Refuse collection vehicle
Refuse Derived Fuel (RDF)	A process whereby municipal waste is compressed into pellets which are then used as a solid fuel supplement in a power station. The pellets typically have a calorific value of about half that of coal.
Regular household collection	Wastes within Schedule 1 of the Controlled Waste Regulations 1992. It is acknowledged that small amounts of commercial and industrial wastes may also be included where collection rounds include mixed domestic and commercial premises
Separate collection	In distinction to co-collection schemes, these are kerbside collections where materials for recycling are collected either by a different vehicle or at a different time to the ordinary household waste collection.