Increasing the climate resilience of waste infrastructure

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Executive summary

All economic activity in the UK is dependent on the infrastructure to supply energy and water, handle waste, move raw materials, finished goods and people around the country or internationally, and to provide the communications systems that knit the economy together. Climate change in the UK is predicted to bring increases in average temperatures and further sea-level rise, increasing frequency and intensity of extreme weather events with potential for droughts, increased flooding, heatwaves and greater pressure on resource availability. The national infrastructure, including waste infrastructure, is vulnerable to many of these changes.

This report presents the findings of a study which helps to fill the gap in knowledge relating to climate change and the waste sector, specifically by exploring the impacts of climate change on the waste sector and the potential for adaptation.

Weather already has the potential to interrupt waste services. Extreme weather leading to floods is a particular concern, as floods both create a large quantity of waste and can make transporting the waste very difficult if transportation networks are flooded. The changing climate is expected to bring increases in this kind of weather, in both frequency and severity.

There are a large number of climate impacts which could pose a risk to the waste sector. Although this is by no means a complete list, the following impacts were identified as some of the most critical for the sector:

- Increased rates of waste decomposition and degradation
- Increased impacts on neighbourhood from odour and dust
- Increased risk of flooding (fluvial and flash floods) affecting facilities, access and use of mobile plant
- Increased risk of flood-related disruption to critical infrastructure and suppliers (transport, energy, ICT, etc.)
- Reduced water availability for wet processes and site management (particularly during summer)
- Increased risk of flooding / inundation at low-lying coastal sites.

The presence of flooding in three of the impacts above is not surprising, especially given the strong interdependency between the waste sector and the transport sector. Climate impacts that affect the ability of waste to be transported are particularly critical due to the limited storage capacity at many sites.

Climate change may impact on the waste sector in a wide variety of ways; however, the consequences of these impacts fall into a smaller number of overall issues:

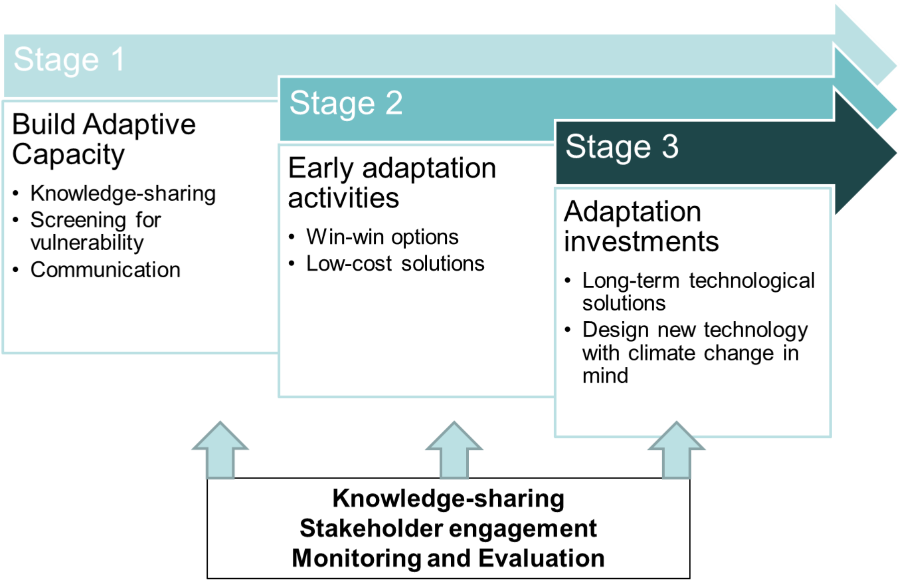
- Changes to operational business costs in response to environmental factors (for example, the need for additional odour or pest control, or additional fire risk management)
- Changes to working environments (indoor and outdoor) and associated health and safety of employees
- Implications for the surrounding environment and community as a result of changes in the amounts of leachate, odour, or dust
- Changes to the availability or reliability of waste services, from disruption caused directly or indirectly by weather events
- Environmental degradation of infrastructure, leading to changes to the expected lifetime of longer-lived structures (such as landfills), through changing frequency and intensity of a range of weather events

- Changes to the processes on site to compensate for changes in precipitation, water availability, or external temperatures.

While climate change looks to bring predominantly negative impacts and increasing costs, there are some positive opportunities. Many of these are linked to the projected increase in winter temperatures and reducing likelihood of snowfall, which reduces the risk of damage to infrastructure and the likelihood of disruption to the transport of waste. Additionally, this also means that on-site workers are less frequently exposed to the potential safety issues of trying to access the site and work in icy conditions.

There are a number of adaptation options that have been identified through the course of this study which could help build resilience to climate change in the waste sector. The options are varied, in terms of what they would actually require, the timing of implementation, and the cost of implementation. They include adaptation options which require technological change or development, activities which focus on awareness-raising and information sharing of best-practice, options which require change to or development of regulations in the waste sector, options which relate to spatial planning or the procurement process, research activities, and options which relate to risk management or disclosure.

One issue that became apparent during the course of this study is that the potential cost of adapting to climate change is a serious concern for stakeholders in the waste sector. Whilst this is a common concern for many sectors, it is particularly important for waste sector stakeholders. In response to these concerns, we have categorised adaptation options below in a series of three stages. This emphasises that a number of adaptation options can be implemented for little or no cost initially; more complex and potentially costly adaptation solutions could then be implemented at a later stage if a specific risk is identified.



We offer a number of recommendations to help the waste sector adapt to climate change, as summarised in the table below. These recommendations also include suggestions on which actors should be involved in each.

Recommendation	Policy (Central Government)	Environment Agency	Local authorities (procurers and advisers)	Infrastructure owners / operators	Research community & consultants
Research and data development					
Conduct an evidence review of the impact of past weather events on waste infrastructure.	✓		✓		✓
Conduct further research on the potential outcome of climate impacts (e.g. fire risk, changes to waste composition).					✓
Undertake vulnerability mapping to provide more detail on the current and future vulnerability of (current and planned) regulated sites to physical climate impacts.		✓	✓		✓
Examine the business case for adaptation in the waste sector.	✓			✓	✓
Conduct further research on international impacts, integrating potential climate impacts into a broader study of future global markets for key waste products.	✓				✓
Policy development					
Conduct a policy study to review the key stakeholder relationships and procurement/service provision models.	✓		✓		✓
In the new waste strategy, include climate resilience alongside low carbon as two major drivers of future waste infrastructure.	✓	✓			
Explore the way in which the spatial planning process for major waste infrastructure already does, or could do more to, ensure appropriate consideration of future climate risks.	✓	✓			
Consider the waste sector more fully under the infrastructure theme of the National Adaptation Programme.	✓	✓			
Consider the benefits of applying the Adaptation Reporting Power within the waste sector.	✓	✓			
Awareness-raising and engagement within the waste sector					
Develop guidance for the waste sector, aimed at sites operators, and examples of adaptation opportunities.	✓	✓			✓
Undertake activities to engage with and raise awareness across waste sector of the potential impacts of climate change.		✓			✓
Establish what effort is needed to engage appropriately with SMEs.		✓		✓	✓
Use existing fora to engage with facilities managers on a couple of key topics such as water use in the sector, the challenges of retrofitting, etc. This is potentially an action for waste sector trade bodies.			✓	✓	
Enhancing resilience of waste infrastructure					
Extend facility level contingency and emergency recovery plans to cover a full range of weather events.			✓	✓	
Use the procurement process as an opportunity to require innovation in climate resilient solutions and flexible contingency arrangements.			✓	✓	✓

Recommendation	Policy (Central Government)	Environment Agency	Local authorities (procurers and advisers)	Infrastructure owners / operators	Research community & consultants
Integrate climate risks within enterprise risk management and corporate responsibility programmes.				✓	
Take advantage of immediate opportunities to introduce low-cost, win-win, or no-regret measures to enhance site level management of climate risks.				✓	
Consider how the waste sector may be drawn into the Critical Infrastructure Resilience Programme in the future.	✓				
Develop a simple screening tool for vulnerability assessment at site level.	✓	✓			✓
Engagement beyond the waste sector					
Include the waste sector within future cross-Government work exploring interdependencies and climate resilience.	✓				
Improve the coordination of emergency response and local authority resilience plans with waste infrastructure owners / operators.		✓	✓	✓	

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1 Introduction

All economic activity in the UK is dependent on the infrastructure to supply energy and water, handle waste, move raw materials, finished goods and people around the country or internationally, and to provide the communications systems that knit the economy together. While the cross-government project on *Infrastructure and Adaptation* undertook much work to identify the potential impacts of climate change on some of these sectors (energy, water, transport, ICT), and how they should adapt, there remains a gap for the waste sector: this study starts to address that gap.

Climate change in the UK is predicted to bring increases in average temperatures and further sea-level rise, increasing frequency and intensity of extreme weather events (e.g. intense rainfall, very hot temperatures) with potential for droughts, increased flooding, heatwaves and greater pressure on resource availability, particularly water. The national infrastructure, including waste infrastructure, is vulnerable to many of these changes.

1.1 Policy context

This study meets the specific commitment outlined in the Government Command Paper, Climate Resilient Infrastructure (May 2011) to undertake a study on the impacts of climate change on waste infrastructure. In the Ministerial foreword to the Government's command paper, the Secretary of State for Environment, Food and Rural Affairs provided a concise summary of the case for adapting infrastructure to climate change:

"Our infrastructure is an increasingly interconnected network of high-value assets with long operational lifetimes. Our existing stock of bridges, roads and power stations is already vulnerable to today's extreme weather. Climate change will increase these vulnerabilities."

There is a growing awareness within Government, through on-going research and work undertaken for the Climate Change Risk Assessment (CCRA), that perhaps the most urgent and important area for adaptation activity is where decisions are both sensitive to current climate variability and also have long-lasting consequences – infrastructure being a perfect example[1].

The findings from this study are directly relevant to the implementation of the Government's Waste Policy Review for England[2] and subsequent policy actions. For example, under 'infrastructure and planning' (commitment number 26 of the Waste Policy Review) the Government outlines its commitment to provide 'advice and support for local authorities on science and technology" in the area of waste management. This advice and support should also communicate the need to build resilience to climate change into planned new waste infrastructure.

In its Adaptation Reporting Power report[3], the Environment Agency identifies the regulation of business and waste as an area that does not face significant risks but one that will need to adapt to provide the same services and achieve the same results they do now. The report states *"climate change should not directly affect our regulatory, advisory and support roles for industry and waste management, however it will influence how we carry out these duties. We know that climate change is likely to affect the frequency and severity of extreme weather events, sea level rise, flooding and low river flows, as well as increasing temperatures. These impacts may increase the vulnerability of regulated sites and their emissions to the environment."*

[1] See the Adaptation Sub-Committee's First Progress report 2010 and a paper by Stafford-Smith et al (http://rsta.royalsocietypublishing.org/content/369/1934/196.full).
[2] Available from: http://www.defra.gov.uk/publications/2011/06/14/pb13540-waste-review/
[3] Environment Agency, Adaptation Reporting Power http://publications.environment-agency.gov.uk/PDF/GEHO0111BTJW-E-E.pdf

The same report confirms the Environment Agency's commitment to:

- Investigating risks to regulated sites and their increasing vulnerability;
- Assessing the implications of the adaptation reports submitted by other reporting bodies, including utilities and public service providers;
- Examining how compliance information is recorded and monitored to ensure that causal links between climate change and permit breaches or pollution incidents can be identified; and
- Investigating how improved site management can help to reduce vulnerability to climate change impacts[4].

1.2 Project context

This project helps to fill the gap in knowledge relating to climate change and the waste sector, specifically infrastructure post-collection. While the scope of this project is England-only, it sits within a broader UK government context for identifying and managing risks relevant to national infrastructure.

This project also considers the international dimensions of climate impacts on waste, the interdependencies with other sectors, and provides recommendations for action by Government and the different actors involved in managing our waste sector and its related infrastructure.

The geographic scope of this study is non-location specific but focuses on climate impacts and waste sites in England. It includes all types of waste infrastructure and technologies. The focus of the study is strictly post-collection and does not include nuclear or hazardous waste types.

1.2.1 Objectives

The main aims for this project are as follows:

- To examine the short, medium, and long-term **impacts** of climate change on waste infrastructure
- To examine the technical **implications** on waste infrastructure and what this means operationally to the sector
- To examine how waste infrastructure needs to **adapt** to climate change and identify any possible opportunities for the sector
- To examine the **barriers** to adapting waste infrastructure to climate change, and
- Identify what changes will be required to increase resilience to the impacts of climate change and provide **recommendations for action**.

1.2.2 Methodology

In order to achieve these objectives, the project's methodology has followed a logical progression, starting with an investigation of the direct impacts of climate change on infrastructure, then exploring the implications or consequences of these impacts within the sector, from these considering adaptation needs (including opportunities and barriers), and finally articulating recommendations for action, addressing particularly the roles and responsibilities of different organisations and actors. Interdependencies between the waste sector and other sectors and also the international dimension have been considered.

The main project tasks included:

Task 1: Inception and Evidence Review – This task included a review of existing knowledge on the long-term impacts of climate change and adaptation on the waste sector. It also identified a number of possible case studies to investigate during the project.

[4] Environment Agency, Adaptation Reporting Power http://publications.environment-agency.gov.uk/PDF/GEHO0111BTJW-E-E.pdf

Task 2: Analytical work – Building on the synthesis of evidence, this task explored further the potential impacts of climate change in the waste sector. This included an analysis of the vulnerability of waste infrastructure sites across England, a vulnerability screening of infrastructure types using an asset metrics (criteria-based) approach, and an assessment of the interdependencies with other sectors.

Task 3: Case studies – This task developed three case studies which provide more detail on the types of resilience-building activities which are already being undertaken by different waste companies in England.

Task 4: Industry Focus Group – In order to ensure that the project's work was peer-reviewed by those who will be at the cutting edge of impacts, a focus group was held in October 2011 to gain feedback from the attendees. The 18 attendees of the Industry Focus Group provided concrete insight into barriers for adaptation and recommendations for actions for different actors.

Task 5: Consolidation of findings – This task brought together all the material generated by the project and provided an opportunity to expand on the issues raised at the Industry Focus Group.

1.2.3 Report Structure

The report is structured as follows:

Chapter 1 provides an introduction to the report and an overview of the project context.

Chapter 2 provides a summary of the waste sector in England, including a description of key technologies and possible developments in the future.

Chapter 3 gives an overview of climate change in the UK, including a summary of key impacts on waste infrastructure and the implications of those impacts.

Chapter 4 reviews some of the main cross-sectoral interdependencies that could have an effect on the waste sector, and also summaries some of the main international interdependencies.

Chapter 5 discusses adaptation options for the sector which would help build resilience to climate change, and also summarises some of the key barriers and challenges.

Chapter 6 provides three case studies which take a more detailed look at three different types of waste sites and how they are building resilience to climate change – 1) Veolia's Energy Recovery Facility (ERF) in North Quay, Newhaven, 2) Landfills in the East of England and 3) water efficiency at Shanks' anaerobic digestion plants.

Chapter 7 provides the headline conclusions and recommendations from this study.

2 England's waste sector

The latest yearly statistical release from Defra[5] shows the following trends for household waste:

- The total amount of local authority collected waste generated has decreased by 1.3% to 26.2 million tonnes between the financial years 2009/10 and 2010/11. This continues the reduction seen since 2007/08;
- The proportion of local authority collected waste being recycled, composted or reused continued the long term trend by increasing to 40.1% between the years 2009/10 and 2010/11; and,
- The proportion of local authority collected waste disposed of into landfill in 2010/11 was 43.4%. Over the last 10 years, local authority collected waste sent to landfill has decreased from 78.0% of generation in 2001/02. In 2010/11 England sent just under half (49%) the tonnage of waste to landfill compared to 2001/02.

In the UK, in 2008, total waste generation was estimated at 288.6 million tonnes (mt). This is a decrease of 6.0% from 2006 (307.1mt) and 11.3% from 2004 (325.3mt). In 2008, the largest contributing sector was construction (101.0mt), followed by mining and quarrying (86.0mt), commercial and industrial (67.3mt), household sources (31.5mt) and the remaining generation combined (2.7mt) [6].

The waste industry has a total turnover of £11bn and directly employs 142,000 people. The top seven waste management companies account for over 50% of turnover while hundreds of small and medium enterprises (SMEs) provide localised or more specialised services. Approximately 6,500 GWh energy, 1.5% of the UK's total electricity supply and over 25% of our renewable electricity is generated from waste combustion and landfill gas each year. The industry has reduced its greenhouse gas emissions by 70 % since 1990[7].

2.1 Policy landscape

2.1.1 Waste legislation and regulation

Policy for the waste sector in England is set by Defra. The Waste Strategy for England 2007 and the recent Government Review of Waste Policy in England[8] set out various policies and principal commitments, including:

- Reduction in landfill through the landfill tax (£56/t in 2011/12, increasing by £8/t pa up to £80/t for standard rate on inert material);
- Infrastructure development supported by the Government (previously through the Waste Infrastructure Development Programme (WIDP) and private finance initiative (PFI) projects). The intention is to accelerate the building of the infrastructure needed to treat residual waste without compromising efforts to minimise waste and support increasing recycling levels;
- Work to overcome the barriers to increasing the energy from waste which Anaerobic Digestion provides,
- Planning decision-making powers have returned to local authorities;
- End-of-waste protocols to help recover materials and turn them into one or more alternative products. (Environment Agency/WRAP);

[5] http://www.defra.gov.uk/statistics/files/mwb201011_statsrelease.pdf
[6] http://www.defra.gov.uk/statistics/environment/waste/wrfg01-annsector/
[7] Environmental Services Association (2011) http://www.esauk.org/
[8] Defra (2011) Review of Waste Policy in England

- Product roadmaps produced to improve sustainability across the life cycles of a range of important products and wastes. These aim to establish the impacts that occur across the life cycle of each product; identify existing actions being taken to address those impacts; and, develop and implement an action plan to address any gaps;
- Site Waste Management Plans to increase waste reduction and recovery from industry and business and identify economic as well as environmental benefits;
- Develop voluntary approaches to cutting waste, increase recycling, and improving the overall quality of recyclate material, working closely with business sectors and the waste and material resources industry (e.g. Courtauld, Halving Waste to Landfill).

Appendix 2 provides further information on the key pieces of legislation affecting waste infrastructure in England.

As for any development project, new waste infrastructure is also subject to spatial planning policy and regulation in England.

The Environment Agency has the critical role of ensuring that all of these multiple statutes and regulations are correctly applied and complied with across the waste sector in England and Wales. This involves regulating waste management facilities under the Environmental Permitting Regulations to ensure they do not pollute the environment or harm human health; implementing other regulatory regimes aimed at recovering waste and ensuring its safe management (for example hazardous waste and international waste movements); and tackling illegal waste activity (e.g. fly-tipping). In addition, the Agency advises Governments, regional bodies and local authorities on waste, providing data and information on waste and waste management to help inform decision making. The Agency also has a statutory role in all spatial planning decisions, and has recently been given an enhanced role in the delivery of adaptation in England.

A study into the possible implications of climate change impacts and adaptation for waste regulation and permitting[9] found evidence of greater non-compliance during extreme weather events. Potential compliance issues for waste management facilities centred on impacts on leachate levels, blown litter, drainage of contaminated water, and dust control.

2.1.2 Future directions

In June 2011 Defra published its Review of Waste Policy in England, with an accompanying action plan. At the same time the Waste & Resources Action Programme (WRAP) published its business and delivery plan for England (2011 to 2015). These documents emphasise resource efficiency, realising the value of resources (not waste), communication with consumers, and improving levels of compliance to environmental regulation. European legislation to protect the environment and mitigate climate change also continues to act as a key driver for infrastructure investment in the waste sector. For the UK to meet the EU landfill diversion targets for 2020[10], it is estimated that an investment of around £10 billion in new infrastructure will be needed[11].

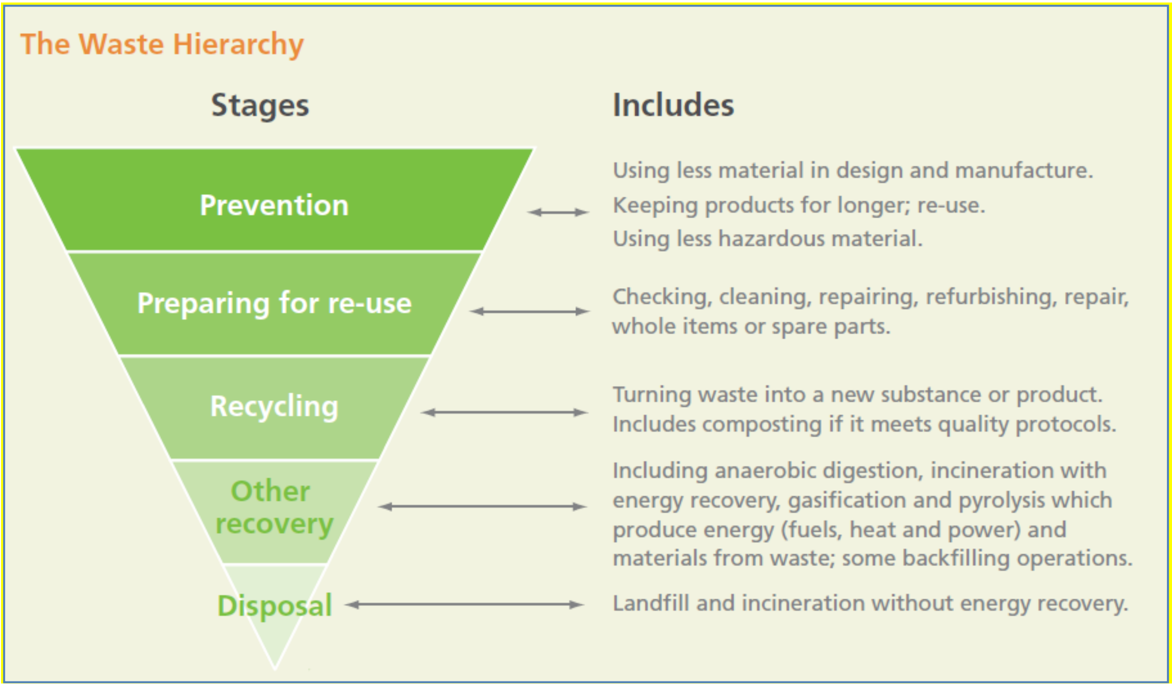
It is noteworthy that the Government's review of waste focused solely on the contribution of the waste sector to mitigation action (reduction of greenhouse gas emissions) with very little consideration of the need for waste infrastructure to adapt, and to be adaptable. Indeed almost all previous work on climate change in the waste sector has focused on mitigation rather than adaptation.

The National Infrastructure Plan[12] (2011) emphasised that the Government's vision for major waste infrastructure investment is to deal with waste in accordance with the waste hierarchy which focuses on waste prevention (Figure 1): reducing the amount of waste produced,

[9] Claire Barnett, Karen Phillipson, Suzanne Walsh (2008) Entec and Environment Agency. The impact of climate change on waste regulation, Science Report – SC030305.
[10] Landfill Directive (1999/31/EC). UK is obligated to reduce the amount of BMW sent to landfill based on the amount of this material landfilled in 1995 to 75% by 2010, to 50% by 2013 and to 35% by 2020.
[11] http://www.hm-treasury.gov.uk/iuk_environment_waste.htm
[12] Available from: http://www.hm-treasury.gov.uk/national_infrastructure_plan2011.htm

maximising reuse and recycling, and recovering energy from residual waste, with landfill used as a last resort. This demonstrates the desire to move towards 'a zero waste economy' as part of a transition to a green economy. Investment in sustainable waste management infrastructure is increasingly seen as investment in the low-carbon economy.

Figure 1: The Waste Hierarchy[13]



A major strand of investment in sustainable waste management infrastructure, emphasised in the National Infrastructure Plan (2011), is the expansion of anaerobic digestion as part of renewable energy supply. As part of the Anaerobic Digestion Action Plan, WRAP has set up a new loan fund of £10 million to provide debt finance to help stimulate investment in additional infrastructure to support this method of recovering energy from waste. There is also a recognition that enhanced investment across national infrastructure will be needed to adapt to the impacts of climate change, and build resilience against the increasing variety of hazards and threats (including climate hazards).

There are opportunities for growth in the waste and resource management sector, but in order to take advantage of these, the Government must ensure that the necessary infrastructure is built[14]. Following the 2011 Budget, local planning authorities are expected to prioritise growth when developing grant consents.

In summary, the key drivers likely to shape the evolution of England's waste infrastructure over coming decades are:

- Greater environmental sustainability driven by compliance to environmental regulation (including European legislation)
- Greater emphasis on resource efficiency including a continued drive towards a zero waste economy (waste hierarchy)
- Greater realisation of commercial value of recycled materials, in the UK, but also on international markets
- Continued move toward a low carbon economy, leading to expansion of technologies enabling energy recovery from residual waste
- Improved economic performance, through more efficient processes, new technologies and the greater use of ICT

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[13] Defra (2011) Review of Waste Policy in England
[14] Defra (2011) Review of Waste Policy in England

- Prioritisation of national investment into maintenance and more efficient use of existing facilities alongside large-scale capital projects
- Increasing engagement with consumers and communities, including communication through corporate reporting and monitoring

The box below outlines some of the possible future implications for the waste sector. It will be essential for enhanced climate resilience to be integrated into these trends in the design and operation of new infrastructure, and the maintenance of existing facilities.

Future trends for the waste sector

Expectations

- Smaller volumes of waste arising overall, with emphasis on waste minimisation and re-use
- Changes in the composition of waste streams
- Greater separation of materials (e.g., food waste separated from dry recyclables)
- Greater range of technologies for sorting and treating
- Increased recycling, composting and energy recovery from waste
- More local treatment of food waste
- Zero biodegradable waste to landfill, greatly decreased landfill overall
- Changes in transport: more journeys of lower tonnage, more waste moved by rail/water, less transport of waste overseas as UK infrastructure increases
- Greater use of onsite renewable energy and closed-loop power provision

Unknowns

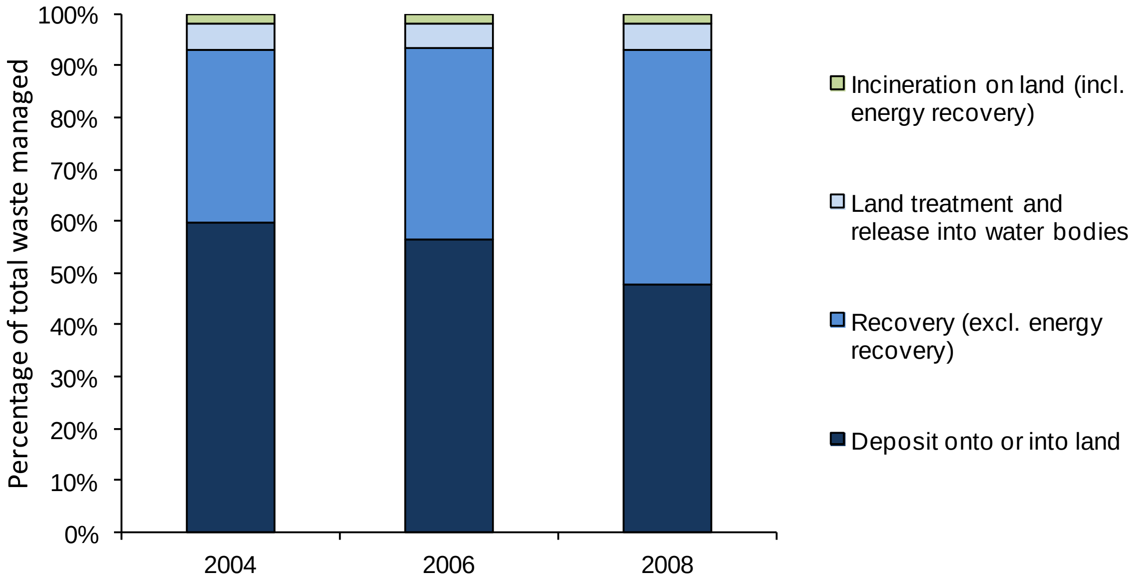
- Future markets for waste processing / products
- Implication of increasing competition for commodities
- Changes in water pricing

2.2 Waste infrastructure & interdependencies

Ten years ago, over three-quarters of Britain's waste went to landfill (compared to less than 50% today) and waste management was primarily focused on the logistics of collection and transport. While these still matter, the industry has developed a range of technologies to treat waste and extract value from it. Innovation is a constant feature of modern waste management[15].

[15] Environmental Services Association (2011) http://www.esauk.org/

Figure 2: Waste disposal by management method, UK, 2004–2008



Source: Defra - Waste Statistics Regulation return to Eurostat, 2004 to 2008

Appendix 2 provides a short summary of the main waste technologies currently in use. It is important to note that all are dependent on transport of waste on and off site, and almost all depend on energy for operations (though this may in some cases be generated on site).

Transport infrastructure is a critical component of the waste management process. The key stages of transportation are collection (predominantly from households and business), bulking and onward haulage to treatment facilities and transport of outputs from treatment facilities.

- Road: This is the main form of transport in the waste sector and almost always the primary method for collection from waste sources (household or businesses). Typical road vehicles are RCVs (refuse collection vehicles, used for residual, co-mingles dry recyclables, food and green waste), kerbside sorting vehicles (dry recyclables), hooklift vehicles (which transport large containers from civic amenity sites) and bulk haulage vehicles (large articulated trucks).
- Rail: ISO containers are often used in combination with the rail network to move waste and processed materials, such as solid recovered fuel/refuse-derived fuel (SRF/RDF) fuel. Rail is often used to move waste from conurbations (where there are high waste arisings and minimal treatment capacity) to more rural areas, where treatment facilities are situated.
- Water: Inland barges are used to move waste along rivers and canals (predominantly in London) to treatment facilities. Cargo ships are used for the transport of waste products (plastic film, SRF fuel, etc.) from treatment facilities to other countries worldwide.

Waste transport for the two stages of collection and treatment is usually managed under separate contracts. Under a collection contract, waste is collected and delivered to a set point for treatment or disposal. The treatment contractor is usually responsible for the transport of any products post treatment. While the collection of waste is unlikely to change significantly in the short to medium term, the transport options associated with the management and treatment of waste post-collection may. With increased separation of materials there may be a need for certain materials to travel longer distances to specialised processing plants until markets develop and local facilities become available.

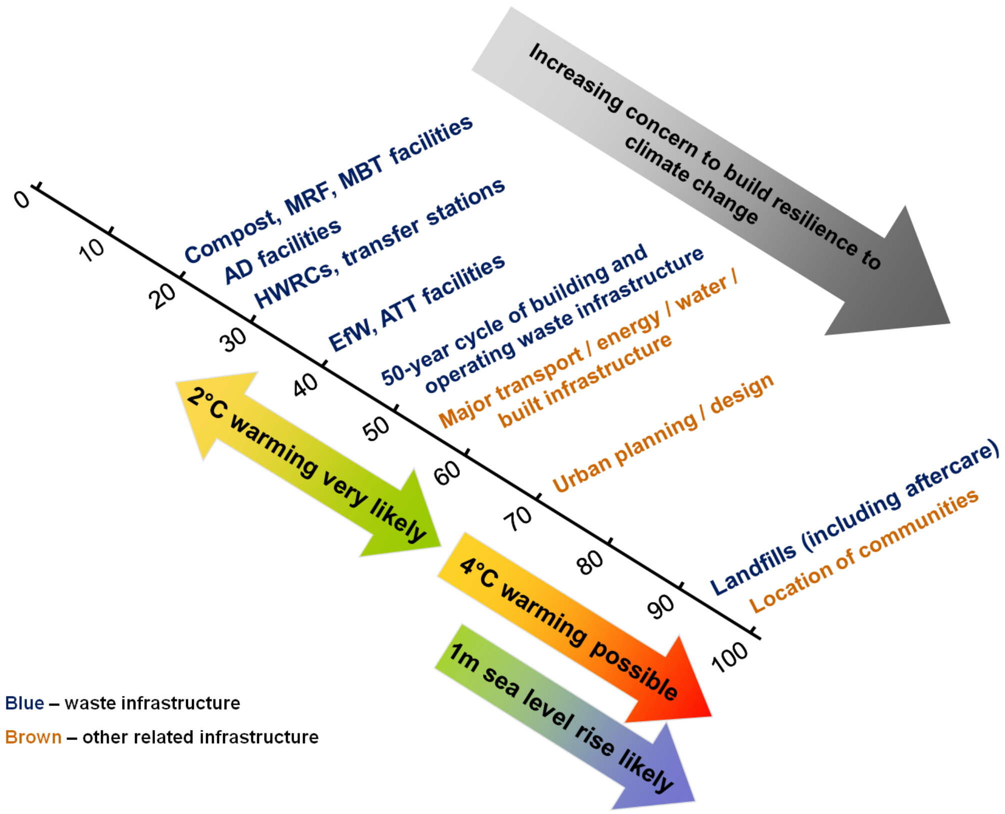
Road transport is likely to continue as the main transport method but rail will also be used, with a shift from untreated waste to SRF/RDF transported on the rail network. Water transport, predominantly inland barges in London, will continue, particularly given large new developments. For example, the Cory Riverside Energy from Waste (EfW) plant processes 585 ktpa, with over 85% of the waste arriving by barges along the River Thames. The Incinerator Bottom Ash (IBA) produced by this plant is also moved by river to a processing facility.

2.2.1 Infrastructure lifetimes

Figure 3 illustrates approximate operational lifetimes of major types of waste facilities and related infrastructure, compared with the timescales for projected climate impacts. Most waste facilities have a lifetime of between 20 and 40 years, with the exception of landfill which can remain operational (including the aftercare and restoration period) for 140 years or more.

However, the lead or planning time for new infrastructure is considerable, with commonly a decade from identification of site and contract procurement through the stages of commercial investment decision, design, planning permission, site permitting, construction and commissioning to fully operational status for large EfW facilities, for example. Following operations, there is a further decommissioning phase, so that typically a 50 year cycle of building, operating and decommissioning new waste infrastructure can be considered.

Figure 3 Approximate lifetimes (in years) of waste infrastructure facilities, compared with illustrative climate change timescales

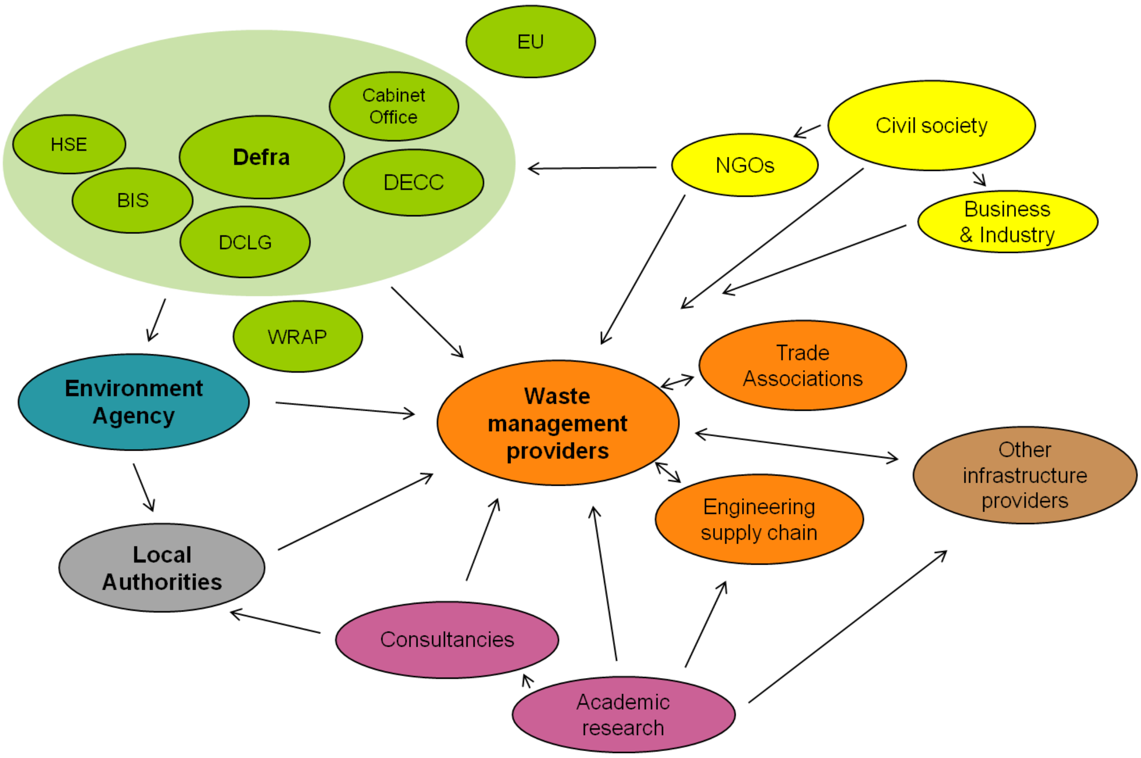


To a greater or lesser extent, many of these infrastructure types will potentially need to continue to operate under the changing climate conditions that will be experienced over the course of the 21st century, and beyond. Not only will climate change impacts need to be considered at the outset when designing new infrastructure, but there is likely a legacy (particularly of landfill sites) that may need enhanced resilience to deal with the future climate, and particularly extremes of weather.

2.3 Stakeholder landscape

Figure 4 illustrates the wide range of stakeholders which influence waste infrastructure planning, design, construction, operation and use in England. In most cases, large waste infrastructure is privately owned, with public contracting (primarily by local authorities) for service delivery.

Figure 4 Key stakeholders in the provision and operation of waste infrastructure



The figure shows how decisions to enhance the climate resilience of waste infrastructure are potentially influenced by the complex relationships between multiple stakeholders. The design of new infrastructure is strongly driven by the content of PFI (or similar large-scale public sector procurement) specifications, which in turn are influenced by regulatory requirements (defined by Environment Agency), which support national policy (coming from several different departments in central government). A trend that potentially complicates the picture further is that of greater partnership working among local authorities to achieve efficiencies in waste management.

For the purposes of this study, private sector infrastructure owners / operators have at times been considered as one amorphous group (the central hub in Figure 4), but owners of waste infrastructure vary tremendously in scale from SMEs to multinationals. Their awareness and capacity to address issues of climate resilience is extremely diverse.

Finally, it is important to recognise the wide range of stakeholders involved in opinion-forming and decision-making around waste infrastructure, in formal or informal capacities. Each group can increase demand for greater resilience, including climate resilience, through different stakeholder relationships.

3 Vulnerability and impacts

3.1 Climate change in the UK

Climate change is an international phenomenon. Across the globe, the evidence for climate change is undeniable, with observed impacts on a wide range of natural and human systems. In their Fourth Assessment Report (2007), the IPCC set out a range of projections for global climate change and sea level rise. Since then, climate research has continued to develop, with climate models improving in skill and accuracy; most recent projections indicate that without drastic cuts in emissions, global warming of 4 °C above pre-industrial levels could be possible by the 2070s.[16]

There is evidence of climate change in the UK as well. The past few decades have seen such changes as:

- An increase in the Central England Temperature by about 1 °C since the 1970s, with 2006 being the warmest year on record;
- An increase in the frequency of severe windstorms around the UK;
- An increase in the contribution to winter rainfall from heavy precipitation events;
- In all regions except North East England and Northern Scotland, a decrease in the contribution to summer rainfall from heavy precipitation events.

Average temperature across all regions of the UK has risen since the mid-20th century, as have average sea level and sea surface temperature around the UK coast. Over the same time period, trends in precipitation and storminess are harder to identify. Appendix 3 provides further information on these changes.

There are extremely clear trends in UK annual average temperatures, indicating the scale and rate of climate change that we are now facing. Recent observations of rainfall show smaller changes, with only a slight trend for increased rainfall in winter and decreased rainfall in summer detected over the last 250 years. However, one clear trend is that all regions of the UK have experienced an increase in the amount of winter rain that falls in heavy downpours.

3.1.1 Future projections of climate change in the UK

The UK Climate Projections provide probabilistic information about climate change in the UK over the 21st century (Murphy, et al., 2009). The projections over land are provided for three emissions scenarios based on the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios (SRES): low (B1), medium (A1B) and high (A1F1), at 25 km resolution and for administrative regions and river basins. These land projections are also reported for seven overlapping 30-year time periods from the 2020s (2010-2039), to the 2080s (2070-2099), where each future time period is named after the decade upon which it is centred.

In Table 1 **Headline messages from the UK Climate Projections (medium emissions scenario)** we summarise expected changes under the medium emissions scenario by the 2080s (relative to the 1961–1990 baseline). The figures provided are the central estimates of change (those at the 50% probability level) followed, in brackets, by changes which are very likely to be exceeded, and very likely not to be exceeded (10% and 90% probability levels, respectively). For sea level rise, only the central estimate is quoted.

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[16] Betts, et al. 2009

Table 1 *Headline messages from the UK Climate Projections (medium emissions scenario)*

Climate projections for the 2080s under the medium emissions scenario (UKCP09)	
Climate variable	Projection
Temperature	• Average temperature increases in all areas of the UK, more so in summer than in winter. Changes in summer mean temperatures are greatest in parts of southern England (up to 4.2ºC (2.2 to 6.8ºC)). • Mean daily maximum temperatures increase everywhere. Increases in the summer average are up to 5.4ºC (2.2 to 9.5ºC) in parts of southern England and 2.8ºC (1 to 5ºC) in parts of northern Britain. Increases in winter are 1.5ºC (0.7 to 2.7ºC) to 2.5ºC (1.3 to 4.4ºC) across the country. • Changes in the warmest day of summer range from +2.4ºC (–2.4 to +6.8ºC) to +4.8ºC (+0.2 to +12.3ºC), depending on location, but with no simple geographical pattern. • Mean daily minimum temperature increases on average in winter by about 2.1ºC (0.6 to 3.7ºC) to 3.5ºC (1.5 to 5.9ºC) depending on location.
Precipitation	• Central estimates of annual precipitation amounts show very little change everywhere at the 50% probability level. Changes range from –16% in some places at the 10% probability level, to +14% in some places at the 90% probability level, with no simple pattern. • The biggest changes in precipitation in winter, increases up to +33% (+9 to +70%), are seen along the western side of the UK. • The biggest changes in precipitation in summer, down to about –40% (–65 to –6%), are seen in parts of the far south of England. Changes close to zero (–8 to +10%) are seen over parts of northern Scotland. • Changes in the wettest day of the winter range from zero (–12 to +13%) in parts of Scotland to +25% (+7 to +56%) in parts of England.
Storms and wind	• The UK Climate Projections do not include projections of wind speed. The Met Office Hadley Centre regional climate model projects changes in winter mean wind speed of a few percent over the UK. • Projected changes in storms are different in different climate models. Future changes in anticyclonic weather are equally unclear.
Humidity	• Relative humidity decreases by around –9% (–20 to 0%) in summer in parts of southern England, but by less elsewhere. In winter, changes are a few percent or less everywhere.
Sea level rise	• Relative sea level rise, with respect to 1990 levels, shows an increase of 36.3cm for London, 36.2cm for Cardiff, 24.4cm for Edinburgh and 25.3cm for Belfast under the central estimate.

In summary, by the 2080s, under the medium emissions scenario, average temperatures across all areas of the UK are expected to rise, more so in summer than in winter, and more so in southern England than in the Scottish Islands. The largest increases in precipitation are in winter on the western side of the UK. The greatest reductions in precipitation are in summer in the far south of England. The wettest days in winter become wetter in England.

Southern England sees the largest decline in summer wettest day rainfall. Relative humidity and cloudiness during the summer decrease in parts of southern England with minimal changes in winter and everywhere else. The UK Climate Projections do not include projections for changes in snow. However the Met Office Hadley Centre regional climate model projects reductions in winter mean snowfall of typically 65 to 80% over mountain areas and 80 to 95 % elsewhere (by the 2080s, relative to baseline climate).

Projections of future climate are different for other time periods and other emissions scenarios. For sea level rise a high++ scenario was developed to test vulnerability beyond the standard range of uncertainty included in UKCP09. The high++ scenario range indicates that time-mean sea-level rise around the UK could be 93 cm to approximately 190 cm in 2095 (relative to the present day mean of 1980–1999).

Environment Agency advice[17] to organisations responsible for national infrastructure located at or near the coast is to plan for roughly 1 m of sea level rise by the end of the century, depending on location. However, they also indicate that caution is needed because sea level rise could be as much as 1.9 m over this time period.

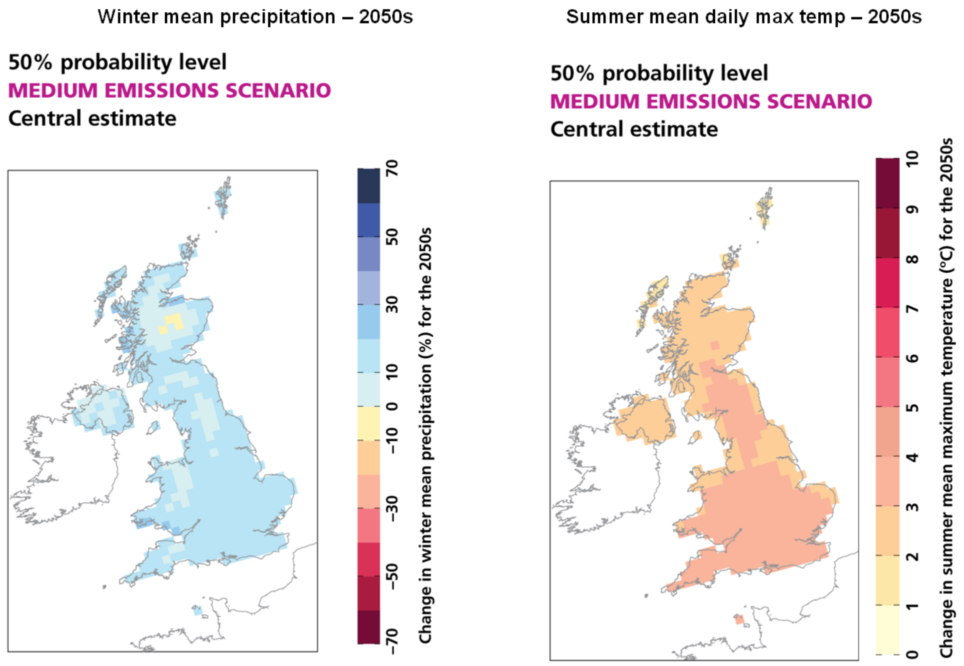
3.2 Climate projections and waste infrastructure

Clearly there are noticeable and predicted changes in climate in the UK. In order to determine the extent to which climate change will affect waste infrastructure, we have compared the latest UK climate projections (UKCP09) to the location of different waste sites in England. This provides an indication of how many sites are located in areas of England which are likely to be affected by two important climate variables – an increase in the average maximum daily summer temperature or an increase in average winter precipitation.

For this analysis, we have used the latest UK climate projections for two relevant land based climate variables, and have considered the wider range of outcomes; that is, from the lowest to highest value for all emissions scenarios and three (10, 50, and 90%) probability levels for each 30-year time period. The maps (Figure 5) below display the 50% probability level for the Medium emissions scenario for the two variables.[18]

[17] Presentation to transport authorities in the south east in the context of planning responses to the Adaptation Reporting Power, 5 March 2010. More detailed information, with reference to Defra's flood and coastal defence appraisal guidance available online at http://www.environment-agency.gov.uk/research/planning/116769.aspx.
[18] The full set of UKCP09 maps for the 10% - 90% probability range is included in Appendix 2.

Figure 5: UK climate projected changes for two climate variables



Comparing these future climate projections to the location of different waste technology types taken from AEA's database of major waste treatment facilities[19], we see the following for the two temperature and precipitation variables:

Temperature change

- 68% of all[20] the major waste sites in England are located in areas (in southern and mid England[21]) expected to see an increase in summer mean maximum temperature between 1 and 4 °C by the 2020s.
- 65% of the major planned waste sites are also located in this area of greatest temperature increase in England, as well as 50% of the closed sites.
- 39 out of the 58 (67%) major planned combustion waste facilities are also due to be built in this area which could see a 4 °C increase in summer maximum temperature by the 2020s, right at the start of the plant's operation time.
- 78% of operational composting sites and 89% of operational Anaerobic Digestion sites in England could also be subjected to this summer maximum temperature increase during their operational lifetime, by the 2020s.
- By the 2050s all 392 major English waste sites could be exposed to an increase of between 6 and 8 °C during the summer, and by the 2080s this could be as much as 10 °C for all sites.

Precipitation change

- All[21] 392 larger English waste facilities are expected to see a change in winter mean precipitation of between a decline of 10% and an increase of 20% by the 2020s; highlighting the large variability in the model projections for winter rainfall and snow in England.
- For the 286 southern and mid England waste sites, this variability increases at the upper end of the range to an increase of 40% by the 2050s, reaching up to 50%

[19] excluding landfill, and windrow composting, with not all waste transfer stations recorded - summary available in the Appendix
[20] All includes operational, planned and closed site as classified as of September 2011 in AEA's waste facilities database
[21] Which includes totals for the South West, South East, London, East of England, East Midland and West Midlands

along the southern coast by this time period. By the 2080s this increase in winter mean rainfall and snow could be as high as 60% (70% in Southern England).

3.2.1 Flood risk and waste sites

In addition to being subject to changes in summer temperature and winter precipitation, waste sites are also located in areas at risk of flooding. Current flood risk is assessed by the Environment Agency for river, coastal and tidal flood risk at regulated waste sites in England and Wales. In England results show that 16% of waste sites (from small combustion boilers to large waste facilities) are located in areas with the highest probability of flooding (Environment Agency flood zone 3), with 21% located in areas with a chance of flooding (Environment Agency flood zone 2).

Unsurprisingly, the most effected Environment Agency region is the Thames, where 19% of waste sites are situated in high probability flood zones, are larger proportion (29%) are in zone 2 and 11% have been flooded in the past. Conversely, the North West of England has the lowest number of sites located in flood zone 3 (highest risk) at 10% and only 2% have experienced historic flooding (Table 2).

Table 2: Summary of Environment Agency Flood Risk at regulated waste sites (England and English regions only) (Environment Agency, 2011)

River, Coastal and Tidal flood risk at waste sites in England		Select Environment Agency regions										Total	
		North East		North West		South West		Southern		Thames		England	
Flood risk	**Effected**	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Highest probability of flooding (flood zone 3)	**Yes**	533	**16%**	230	**10%**	249	**15%**	197	**18%**	346	**19%**	2428	**16%**
	No	2878	**84%**	2061	**90%**	1467	**85%**	908	**82%**	1438	**81%**	13204	**84%**
Chance of flooding (flood zone 3)	**Yes**	698	**20%**	331	**14%**	315	**18%**	244	**22%**	509	**29%**	3220	**21%**
	No	2713	**80%**	1960	**86%**	1401	**82%**	861	**78%**	1275	**71%**	12412	**79%**
Surface Water Risk	**Yes**	748	**22%**	540	**24%**	311	**18%**	230	**21%**	486	**27%**	3493	**22%**
	No	2663	**78%**	1751	**76%**	1405	**82%**	875	**79%**	1298	**73%**	12139	**78%**
Historic flooding	**Yes**	220	**6%**	38	**2%**	92	**5%**	84	**8%**	205	**11%**	1015	**6%**
	No	3191	**94%**	2253	**98%**	1624	**95%**	1021	**92%**	1579	**89%**	14617	**94%**
Benefit from defences	**Yes**	116	**3%**	27	**1%**	10	**1%**	50	**5%**	173	**10%**	516	**3%**
	No	3295	**97%**	2264	**99%**	1706	**99%**	1055	**95%**	1611	**90%**	15116	**97%**
Nafra probability	**Unlikely**	2759	**81%**	1979	**86%**	1438	**84%**	855	**77%**	1306	**73%**	12638	**81%**
	Low	161	**5%**	87	**4%**	64	**4%**	86	**8%**	244	**14%**	1049	**7%**
	Moderate	208	**6%**	147	**6%**	91	**5%**	85	**8%**	110	**6%**	1014	**6%**
	Significant	283	**8%**	78	**3%**	123	**7%**	79	**7%**	124	**7%**	931	**6%**
Total waste		3411	**22%**	2291	**15%**	1716	**11%**	1105	**7%**	1784	**11%**	15632	

Least effected/lowest
Most effected/highest

This centrally collated data on flood risk at regulated sites prepared by the Environment Agency does not include climate change, and accounts for the current flood risk year on year. Future flood risk in England is currently being assessed by the latest round of Catchment Flood Management Plans for fluvial flood risk and in Shoreline Management Plans for coastal and tidal flood risk at a local and catchment level. Local Strategic Flood Risk Assessments (SFRAs) are also being carried out by Local Authorities in response to Planning Policy Statement 25 (DCLG, 2010) and also capture future flooding risk under climate change. However, this concentrates on providing information to aid planning location decisions because the PPS25 requires Local Authorities to review flood risk across their district, steering all development towards areas of lowest risk (Scott Wilson, 2009).

To get an England-wide picture of future flooding under climate change, waste operators are advised by the Environment Agency that if there is no such climate change assessment, operators can simulate climate change by adding 20% to the maximum on-site depth of river or surface water flooding. For coastal flooding, operators use the allowances (which include vertical land movement and are taken from the IPCC Third Assessment report) recommended by the Environment Agency (Environment Agency, 2011) and are also given in Planning Policy Statement 25 (PPS25) (DCLG, 2010). These allowances and sensitivity ranges were developed before the UK's latest climate projections were produced. The Environment Agency believes that in the light of UKCP09 they remain very reasonable estimates of change. However, they advise that if operator's sites are particularly vulnerable they should consider testing their vulnerability to higher allowances (Environment Agency, 2011).

UKCP09 results show that rainfall and snow is expected to increase over winter under climate change, by the 2050s when some waste technologies with 30-40 year lifetimes such as Energy from Waste and Anaerobic Digestion plants could still be operational, winter mean precipitation is projected to increase, being very unlikely to be greater than a 40% increase under the high emissions scenario in the Thames region, which today is the region with the highest percentage of waste sites situated in high risk flooding zones. By the 2080s, when today's landfills will still be reaching stability, under the high scenario this precipitation could reach as much as a 70% increase.

Coastal areas of the North West of England are also expected to receive the same increases in winter mean precipitation by the 2050s and 2080s as the Thames under the high scenario. However significantly less (1%) currently benefit from flooding defences compared to the Thames (10%). Sea level rise around England is also expected to rise between 0.5 and 1 m, depending on the coastal location and the rate of vertical land movement, with the South East expected to experience higher relative sea level rise than the North West.

Environment Agency advice[22] to organisations responsible for national infrastructure located at or near the coast is to plan for roughly 1 m of sea level rise by the end of the century, depending on location. However, they also indicate that caution is needed because sea level rise could be as much as 1.9 m over this time period.

3.3 Climate impacts on waste infrastructure

Clearly waste sites will not be immune to the effects of climate change – they are already affected by weather events. Flood events create large quantities of household waste which puts pressure on nearby waste sites; winter storms make accessing sites and transporting waste difficult; heat waves increase odour and dust from sites. As discussed in Section 3.2, the majority of existing waste sites in England are likely to be located in areas where summer temperatures are higher, the risk of flooding is greater, and winter precipitation is more variable than it is now. But what are the impacts of these climatic factors on the waste sector and what are the consequences of those impacts? Previous work commissioned by the Environment Agency has examined the potential impacts of climate change on the waste sector[23] and on waste regulation[24] and identified a number of significant impacts to the sector. This project has further developed the list of possible impacts and assessed possible consequences of the impacts, as summarised in Table 3.

[22] Presentation to transport authorities in the south east in the context of planning responses to the Adaptation Reporting Power, 5 March 2010. More detailed information, with reference to Defra's flood and coastal defence appraisal guidance available online at http://www.environment-agency.gov.uk/research/planning/116769.aspx.
[23] Jonathan Bebb, Jim Kersey (2003) Entec and Environment Agency. Potential impacts of climate change on waste management
[24] Claire Barnett, Karen Phillipson, Suzanne Walsh (2008) Entec and Environment Agency. The impact of climate change on waste regulation, Science Report – SC030305.

Table 3: Potential climate impacts on waste infrastructure and their consequences (Red crosses indicate a potential negative effect, green ticks a potential positive effect, and black bi-directional arrows where the direction of the effect is uncertain.)

		Consequences				
Climatic change	**Potential impact**	Business Cost	Health & Safety	Quality & reliability of service	Corporate responsibility & reputation	Opportunities for innovation
Increase in average, and minimum, temperatures (including fewer frost days)	Increased rates of waste decomposition and degradation (also dependent on moisture)	✘	✘	✘	✘	✓
	Increased production possible from EfW and AD facilities	⇔				
	Reduced winter damage (e.g. requiring winter maintenance) and disruption (e.g. to transport)	✓	✓	✓	✓	
	Reduced need for space heating in buildings and facilities	✓				
	Reduced requirement for domestic (district) heating supplied from EfW facilities	⇔			⇔	✓
	Reduced health and safety risks to employees from wintry weather	✓	✓	✓		
	Increased health risks, e.g. disease transmission from putrescible waste	✘	✘		✘	
Increase in daily maximum temperatures (and higher frequency of "very hot" days and heatwaves in summer)	Increased health risks to employees from high temperatures and worse air quality	⇔	✘	✘	✘	
	Increased need for space cooling in buildings and facilities	✘				
	Increased fire risk from combustibles (also dependent on moisture)	✘	✘	✘	✘	✓
	Increased impacts on neighbourhood from odour and dust	✘	✘		✘	✓
Increase in extreme daily precipitation, mainly in winter (and higher frequency of "very wet days")	Increased risk of flooding (fluvial and flash floods) affecting facilities, access and use of mobile plant	✘	✘	✘		
	Increased risk of flood-related disruption to critical infrastructure and suppliers (transport, energy, ICT, etc.)	✘	✘	✘		✓
	Increased risk that site drainage systems will be overwhelmed during heavy rainfall	✘	✘	✘		✓
	Increased potential for waterlogging of open containers, with impacts on processing of materials	✘		✘		

Climatic change	Potential impact	Consequences				
		Business Cost	Health & Safety	Quality & reliability of service	Corporate responsibility & reputation	Opportunities for innovation
	Increased risks to gas and leachate collection / control during heavy rainfall or floods	✘		✘		
	Increased risk of erosion and instability of bunds and capping layers	✘	✘	✘	✘	
Changes in seasonal precipitation patterns - generally wetter winters (and less precipitation as snow) - generally drier summers (and greater likelihood of drought)	Changes to site hydrology	⇔		⇔		
	Increased risk of subsidence in clay substrate areas, with impacts on buildings and facilities	✘	✘	✘		
	Increased volume of leachate during winter	✘	✘		✘	
	Reduced volume but higher concentrations in organic waste streams in summer	⇔	⇔			
	More frequent low flows in rivers and canals during summer, affecting riverine and canal transport	✘	✘	✘		
	Reduced water availability for wet processes and site management (particularly during summer)	✘		✘		✓
	Increased stress on vegetation used in landscaping, screening, site restoration, etc. during summer		✘		✘	✓
Potentially, more frequent winter storms (including more frequent high winds)	Increased storm damage to buildings and facilities, as well as affecting transport by road, rail and sea	✘	✘	✘	✘	
	Increased storm-related disruption to critical transport (road, rail, sea, etc.)	✘	✘	✘	✘	
	Increased risk of windblown litter and debris, and wind damage to uncontained materials	✘		✘	✘	✓
	Increased health and safety risks to employees exposed to extreme weather conditions	✘	✘	✘	✘	
Rising sea levels (particularly in south-east and eastern England) and increase in storm surges	Increased risk of flooding / inundation at low-lying coastal sites	✘	✘	✘	✘	
	Increased risk of erosion in coastal sites (e.g., erosion of bunds)	✘	✘	✘	✘	
	Increased risk of seawater intrusion to coastal landfill	✘	✘	✘	✘	
	Potential disruption to marine transport	✘		✘	✘	

The impacts listed in Table 3 are categorised according to related climate factor; they could also have been categorised according to whether they affect infrastructure, waste processes, society and economy, or the environment, as in the reports commissioned by the Environment Agency.[25]

Through project activities, in particular discussions at the Industry Focus Group, a number of the impacts identified in Table 3 were identified as the most critical impacts for the waste sector. Although this is by no means a complete list, the following impacts were identified as some of the most important for the sector:

- Increased rates of waste decomposition and degradation
- Increased impacts on neighbourhood from odour and dust
- Increased risk of flooding (fluvial and flash floods) affecting facilities, access and use of mobile plant
- Increased risk of flood-related disruption to critical infrastructure and suppliers (transport, energy, ICT, etc.)
- Reduced water availability for wet processes and site management (particularly during summer)
- Increased risk of flooding / inundation at low-lying coastal sites.

The presence of flooding in three of impacts above is not surprising, especially given the strong interdependency between the waste sector and the transport sector. Climate impacts that affect the ability of waste to be transported are particularly critical due to the limited storage capacity at many sites. The consequences of such climate impacts are discussed further in the following section.

3.3.1 Consequences of climate impacts

Climate change may impact on the waste sector in a wide variety of ways, as indicated in Table 3. However the consequences of these impacts fall into a smaller number of overall issues:

- Changes to operational business costs in response to environmental factors (for example, the need for additional odour or pest control, or additional fire risk management)
- Changes to working environments (indoor and outdoor) and associated health and safety of employees
- Implications for the surrounding environment and community as a result of changes in the amounts of leachate, odour, or dust
- Changes to the availability or reliability of waste services, from disruption caused directly or indirectly by weather events
- Environmental degradation of infrastructure, leading to changes to the expected lifetime of longer-lived structures (such as landfills), through changing frequency and intensity of a range of weather events
- Changes to the processes on site to compensate for changes in precipitation, water availability, or external temperatures.

While climate change looks to bring predominantly negative impacts and increasing costs, there are some positive opportunities. Many of these are linked to the projected increase in winter temperatures and reducing likelihood of snowfall, which reduces the risk of damage to infrastructure and the likelihood of disruption to the transport of waste. Additionally, this also means that on-site workers are less frequently exposed to the potential safety issues of trying to access the site and work in icy conditions.

Climate impacts and consequences for waste infrastructure occur at a local or sub-regional level. For example, a flood could generate a large amount of household and commercial

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[25] Jonathan Bebb, Jim Kersey (2003) Entec and Environment Agency. Potential impacts of climate change on waste management

waste in the area flooded, as occurred in Cumbria during the November 2009 flood[26]. While the disruption caused by any one event may be restricted to local areas, such incidents could have considerable social, environmental and economic impacts locally.

[26] http://www.cumbria.gov.uk/floods/damageanalysis/environmentalimpact.asp

4 Interdependencies

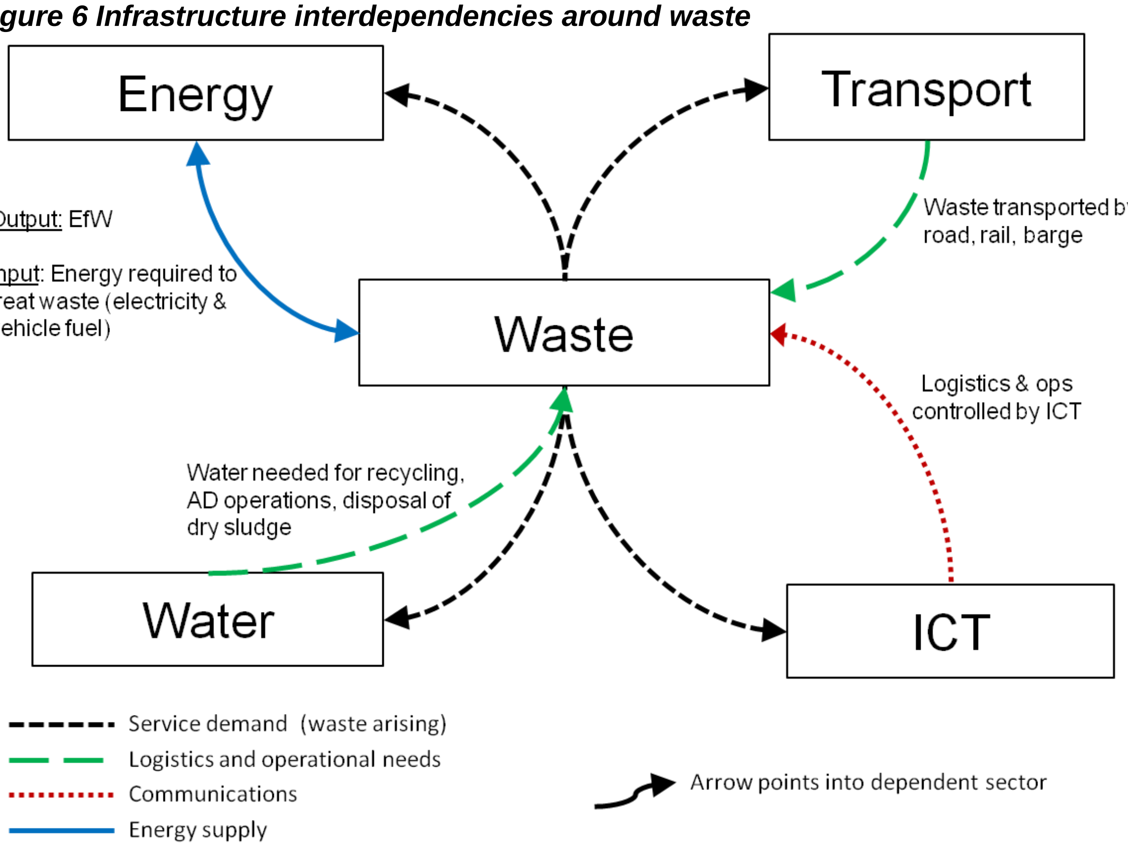
This section reviews two areas of critical interdependencies for England's waste sector, and their implications for enhancing climate resilience. First, it examines the relationship of waste infrastructure to other elements of national infrastructure (predominantly transport, energy, ICT and water). Second, it highlights links between waste infrastructure in England and international supply chains or markets, with vulnerabilities to climate impacts globally.

4.1 Infrastructure interdependencies

National infrastructure is a highly interconnected "system of systems". Climate impacts in any one infrastructure sector can have knock on implications for others. To explore interdependencies of waste infrastructure with other sectors, we used a system mapping approach. The systematic linkages of waste infrastructure with energy, transport, water and ICT, were considered in the context of wider drivers of change, including policy and socio-economic landscapes, and then explored under possible future seasonal climates, concentrating on "hotter drier summers" and "wetter winters".

Infrastructure interdependencies have been identified in a number of recent studies, including work by Defra under the *Infrastructure and Adaptation* project (HMG, 2011), and work is continuing on this topic in both policy (e.g. by Infrastructure UK) and academic (e.g. the Infrastructure Transitions Research Consortium) contexts. Figure 6 shows the key relationships of direct relevance to waste infrastructure (links between other sectors have been omitted for clarity).

Figure 6 Infrastructure interdependencies around waste



Interdependencies between infrastructure sectors are growing. Systematic dependencies are seen in increasing integration (such as increasing reliance on technology and digital networks to control operations), co-location of major infrastructure to reduce costs, and ultimately co-optimisation to exploit efficiencies by aligned management of plants and processes in related sectors.

Previous studies have identified two categories of interdependency risk: cascade failure and regional convergences (e.g. URS, 2010). The risk of cascade failure exists where damage to one network can produce a series of linked impacts or failures in others. Regional convergences refer to the effect of hazards on regional concentrations of infrastructure, with potential for much further-reaching consequences on infrastructure functionality. In some publications, these two categories are known as physical and geographical[27] dependencies.

In the context of climate change, interdependencies can result in distinct or unexpected risks to infrastructure, in addition to any direct climate impacts and their consequences (such as summarised in Section 3). For example, power failures resulting from flooding or storms may delay or halt operations at waste processing sites. Road networks face increased risks of flooding, landslides and high temperature impacts on road surfaces: any of these could severely disrupt the movement of waste streams for treatment, or of recyclate. Increasing storm intensity could have negative impacts on shipping of waste products to global markets. In some cases, it is possible that the indirect impacts arising via interdependencies are more significant than the direct impacts.

In this study, we have concentrated on interdependencies with other infrastructure sectors. In addition to the relationships summarised in Figure 6, it is important to recognise the significance of the interdependence of business and industry more widely with waste infrastructure: the waste treatment processes (and infrastructure) that are required today and in future have to respond to the nature of the waste streams anticipated from consumers, both domestic and commercial. Equally, many areas of business and industry in England depend upon efficient and timely disposal of waste materials, for safe and effective functioning, sometimes on a daily basis. This relationship is articulated in the increasing development of on-site waste management plans for large commercial and industrial facilities (e.g. recycling of paper, cardboard, scrap metal and waste oils, and ash can be used in construction rather than going to landfill).

4.1.1 Transport

Waste materials are transported to large waste infrastructure for treatment by road, rail, inland water and sea. Residues or waste products are transported away for use in industry, agriculture, or for export.

Most waste is currently transported by road and currently there are few alternatives to this, making the sector highly vulnerable to any weather-related disruption to road infrastructure. Going forward, the carbon agenda is likely to drive a move towards other transport modes (rail, sea and inland waterways). Increasing the available transport options provides some inherent flexibility to cope with impacts.

Previous studies have examined climate risks to transport infrastructure (e.g. URS, 2010). Major risks that could result in disruption to the transport networks upon which waste infrastructure depends include increases in extreme rainfall and increased flooding, potential for increased subsidence and embankment instability. Strong winds and more frequent and intense storms may result in damage to transport infrastructure. Rail networks in regions with

[27] In recent (Oct 2011) Cabinet Office publication: Infrastructure dependencies are defined as the reliance by one piece of infrastructure on a service provided by another. There are two types of dependencies; physical and geographical. Physical dependencies are those resulting from a connection between installations, sites and with other networks. For example, the physical dependency on electricity supply for the operation of water treatment works, or the dependency upon communications for the control of remote plant and equipment. Geographical dependencies are where key infrastructure sites or installations are co-located in one close geographical area and hence are both dependent upon local infrastructure e.g. local roads, energy supplies and emergency services. In addition, infrastructure can have interdependencies where assets are dependent upon each other. For example, electricity needs telemetry to run its operations whilst communications needs electricity to run its networks. Unknown dependencies and interdependencies often lead to emergencies escalating in unexpected directions through cascading failures.

significant increases in extreme temperatures or heat waves may experience buckling of railway lines where design specifications are exceeded.

In London, some waste sites have canal access and use barges to transport waste. Water retention in canals could be a major problem as summer rainfall decreases.

Increased storminess at sea could lead to disruption of supply chains through longer transit times and the need for re-routing during stormy weather, which would slow the delivery of waste and increase cost. Strong winds could also mean that increased containment is required for any materials during transit. Increased storminess could also have an impact on ports, although port infrastructure is generally considered resilient to all but the most severe storms. Storm surges around ports could become more damaging, as the current infrastructure would not be adequate to cope with the consequences of the expected rise in sea levels in the 2040s[28].

4.1.2 Energy

Approximately 6,500 GWh energy, 1.5% of the UK's total electricity supply and over 25% of UK renewable electricity, is generated from waste combustion and landfill gas each year. However the waste management sector is still an energy intensive sector, particularly due to its transport requirements. Waste infrastructure requires energy to power systems and services. There is a gradual shift in the emphasis from an over-reliance on a single energy source towards renewable energy or closed looped scenarios. The waste sector is already making moves to become more sustainable using biofuels derived from wastes to power vehicles and energy from waste to power facilities.

The UK is highly reliant on international infrastructure for energy transportation. Since 2004 the UK has been a net importer of fuels and in 2009 had an energy trade deficit of £8.2 billion. The supply of natural gas has long been determined by the availability of pipeline infrastructure, which is expensive to construct and must be planned well in advance. In 2008, 72% of the UK's gross gas imports were by pipeline from Norway. Natural gas is essential to power the UK's industrial processes and to enable electricity generation and provide heating. Thawing permafrost and rising sea levels have a negative impact on infrastructure for energy transportation, affecting the prices and security of UK energy and fuel imports. This will lead to growing demand for renewable energy development in the UK.

New combined heat and power (CHP) enabled EfW facilities will help to mitigate climate change impacts through the delivery of low carbon energy. They will also improve the UK's energy security and this has already been recognised by government. Yet at present, waste derived fuels from EfW tend to be sent overseas due to difficulties in establishing new EfW infrastructure in the UK. This is the result of planning complexities, funding confidence and policy preference for particular technologies (e.g. anaerobic digestion and unproven thermals such as pyrolysis and gasification). As more waste fuels are sent overseas because of conflicting drivers in the UK market, along with attractive gate fees in continental Europe (a function of overcapacity) it will become more important to consider climate change impacts on energy and transport infrastructure outside of the UK.

Increasing summer temperatures may compromise the comfort and safety of workers at waste management facilities, thus reducing productivity. The use of air conditioning will need to be considered as a potential adaptation; however this could increase demand for energy supply and counteract the UK's greenhouse gas mitigation efforts.

4.1.3 Water

Water is a significant input to the waste industry and is used across most technologies to a varying degree. Water can be sprayed at bulking or landfill sites to suppress dust; it is required for other aspects environmental control (such as leachate treatment); water can be

[28] The Government Office for Science (2011) Foresight International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change.pdf

a major input to waste treatment processes, such as in AD or autoclaving, or be integral to energy generation and cooling for EfW facilities. Currently many waste facilities are vulnerable if there is a failure in the water sector.

Increasing seasonality in rainfall and the potential for more frequent or longer periods of drought present risks to water supply, and major infrastructure in the water sector is vulnerable to flood-related damage, which is expected to increase with climate change (URS, 2010). Co-location of waste and water facilities and a more sustainable approach to water management on site could reduce the vulnerability of waste infrastructure to climate impacts on water.

During the extreme freezing temperatures experienced in the UK in 2010-2011, water supply problems in Northern Ireland resulted in millions of bottles of water being supplied to residents. This led to a temporary change in the nature of the waste stream[29]. Incidences such as this may become more common in future, placing new pressures on waste management infrastructure as a consequence of climate-related impacts on water supply.

4.1.4 ICT

ICT is used, to a greater or lesser extent, for waste facilities, vehicles, navigation, logistics, and data management, as well as communications and information provision. As dependency on ICT increases and traditional (pre ICT skills) diminish, the waste sector will become more vulnerable to any ICT failures. There are strong ICT systems in place at waste facilities for operations and emission controls, and this use of ICT will continue to improve and develop due to the controversial nature of these site and the emissions from them. There is a growing demand for ICT support for the waste sector with the drive for better quantification of waste flows and management of more sophisticated plant. Any future shortage of trained staff able to operate and manage new plant will increase vulnerability to weather disruption.

4.1.5 Examples

The impacts of flooding on waste infrastructure and related sectors provide an example of how risks to both physical and geographical interdependencies can converge. At times of major flooding, waste infrastructure may face direct impacts (at sites or on staff). In addition, operations at major waste facilities could be affected by secondary impacts from flood-related failures of other infrastructure (transport initially, but potentially also power and water). In this situation, waste treatment options may be limited, and the sector may be unable to maintain services required by local business and other industry during the immediate flood crisis.

During, and after, flood episodes, there is also an increase in the volume of waste arising from flood damage to homes and businesses. Because both the treatment facilities and the transport required may be operating below capacity, much of this spike in waste may ultimately be diverted to landfill (following potentially longer than usual periods between collections). Commonly, the convergence of systemic failures such as this can have a multiplier effect in terms of social impacts on the most vulnerable groups and communities.

Energy from Waste facilities (such as the Newhaven case study in Section 5) provide a demonstration of interdependencies in action. The case study provides more detail, but in short, the critical relationships involve transport to bring waste to the site, energy input for some aspects of waste treatment, and the provision of energy output in the form of power and heat (to national grid and/or local communities). Onward transport of any residual waste is also needed. This technology inherently straddles the infrastructure sector divide of waste and energy, and there seems to be an increasing trend in this direction as the potential for renewable energy from waste is unlocked. The close integration of multiple infrastructure

[29] Ward, Phillip. Crunch time on climate. MRW, 27 January 2011.

sectors in and around one facility means that optimised systemic planning of operations, and of contingency arrangements in the event of major climate-related disruption, is desirable.

4.1.6 Key messages

Table 4 provides a summary of some of the potential impacts on other infrastructure arising from extreme weather impacts, and the consequences that these may have for waste infrastructure.

Table 4 Weather-related interdependency impacts on waste infrastructure

Potential impacts on infrastructure	Consequences for waste infrastructure	Opportunities
Loss of primary transport routes	Delays to inward delivery of waste streams; operations delayed or halted. Delays to onward transport of waste products or residue; reduced income.	Increase flexibility through multiple transport options
Loss of power supplies	May require switch off of operations, loss of critical ICT.	Provision of local source of heat and power (if resilient), closed loop power.
Loss or contamination or significant reduction of water supplies	Wet processes cease to function. Water supply unavailable for site management	Waste processes maximise use of recycled water / onsite supplies Development of more dry treatment options
Increased demand for emergency power	Waste sector may have reduced access to power if it is diverted to emergency uses	Greater provision of energy from waste to local users
Increased demand for water supplies from all infrastructure sectors	Waste sector may have reduced access to water if it is diverted to emergency or higher priority uses	Develop onsite water supplies, for waste sector and for other local users
Lack of staff availability at other infrastructure services	Limited transport / power / water services available	
Impaired site access at other infrastructure sites	Limited transport / power / water services available	
Closure of local businesses	Reduction in waste arising while businesses closed, followed by spike as flooded property is cleared	Develop procedures to deal with spikes in demand to avoid over-use of landfill
Increased demand for health and emergency services	Potential for slower response rates in the case of site H&S emergencies	Continue drive to improved H&S, ensure emergency treatment available on-site

Waste infrastructure has key dependencies on all other infrastructure sectors (energy, transport, water, ICT), but is potentially most vulnerable to climate hazards through its reliance on transport. Currently the waste sector has a relatively low direct dependency on ICT (compared to other infrastructure sectors) but one that is likely to grow giving rise to a future potential failure linked to ICT. However there is very little information or data (beyond the anecdotal) for understanding and quantifying interdependencies of waste on other infrastructure sectors, and further analysis of the relationships may be required.

The current trend for co-location of waste infrastructure with other related facilities (for example, “eco-parks” bringing together waste treatment, water treatment and power-generation facilities) demonstrates interdependencies explicitly. Co-location brings economic and environmental benefits, and may make it easier for interdependencies to be understood, and for systemic planning, through communication and knowledge sharing, to take place.

Co-location can provide some additional local resilience, in that it can offer a level of independence from wider networks, and therefore protection from network failures. However, it may require a higher degree of physical protection from hazards in order to mitigate potential increase in geographic vulnerability.

Within the waste sector, a number of current trends seem to bring additional benefits of reduced vulnerability to other infrastructure risks. For example:

- Shorter transport distances and more local waste treatment – may reduce vulnerability to transport disruption
- Increased water efficiency – may reduce dependence on scarce water supplies
- Onsite renewable energy generation and closed-loop power system – may provide resilience from impacts affecting energy networks
- Increasing diversity of treatment technologies – may provide greater flexibility if some facilities are temporarily inaccessible.

While many of the larger waste infrastructure companies may have business continuity and risk management plans in place which could address many interdependency risks (though perhaps not in the context of increasing risk), it is not clear to what extent smaller operators in the waste sector have such systems and processes in place. Similarly, while large sites operated by large companies have the capacity to adopt relatively high levels of contingency (such as backup power and ICT) smaller sites may not be able to do so. Consequently, resilience across waste infrastructure may be correlated with scale.

4.2 International interdependencies

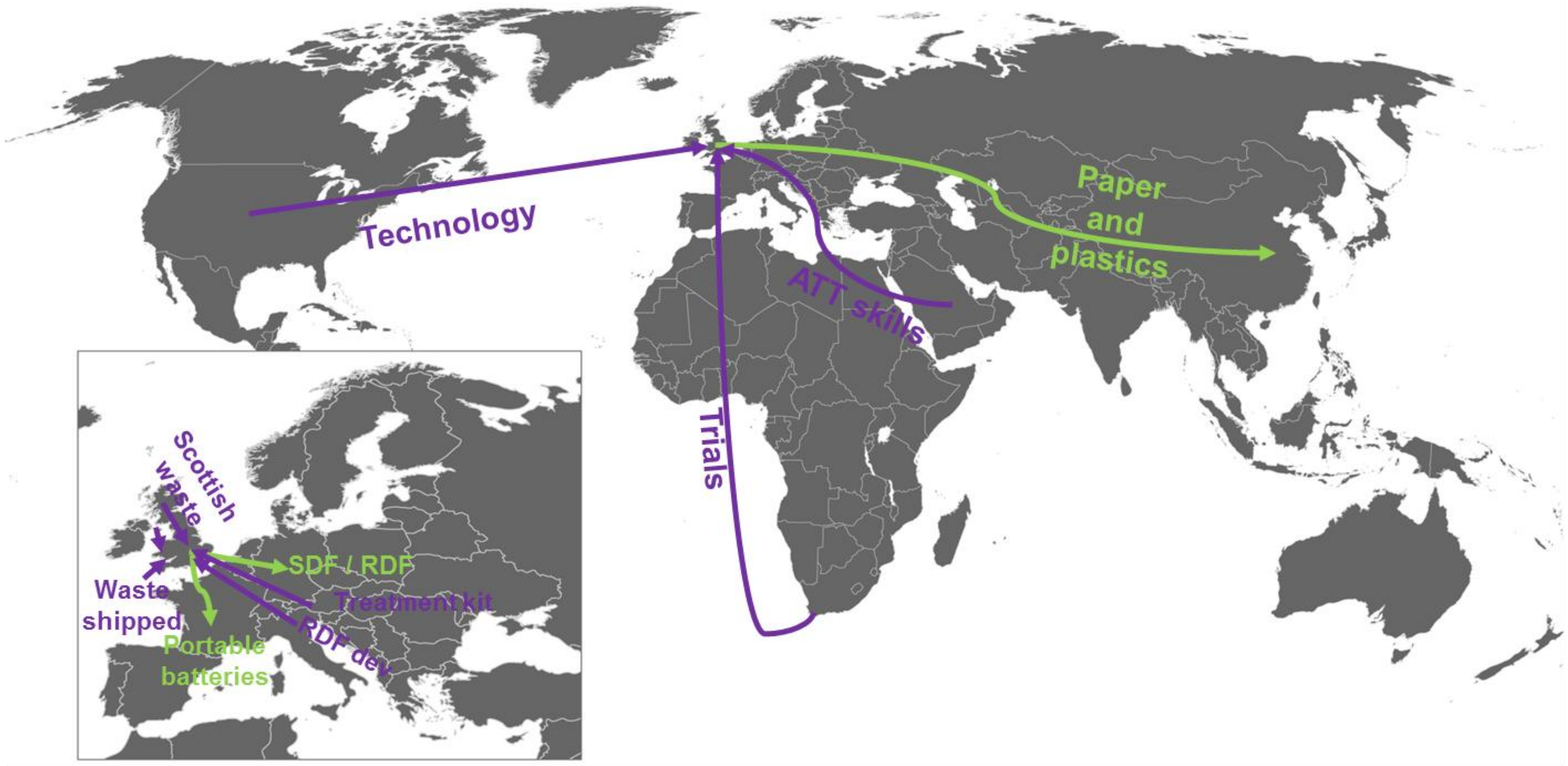
Waste infrastructure in England is part of a global network via supply chains and markets. Waste products are largely exported to those areas of the world where they can be manufactured into consumer products. There is also a complex set of connections around import and export of technology, skills, and materials. This means that the functioning of waste infrastructure in England is potentially vulnerable to climate hazards occurring in other parts of the world, insofar as those hazards impinge on critical supply chains and markets.

A total of 243.5 kt of notifiable wastes were exported from England and Wales in 2009 for recovery. Our biggest export markets were Germany (40 %), Belgium (22 %) and France (15 %). Unaudited 2010 data released by the Environment Agency showed an increase in overall exports[30], which included new exports of RDF to Poland, the Netherlands and Estonia.

Figure 7 presents the major international interdependencies of England's waste sector.

[30] Tolvik Consutling (June 2011) 2011 Briefing Report: UK Waste Exports: Opportunity or Threat?

Figure 7 Map showing international interdependencies of the UK waste industry



Exports

Paper and plastics - UK exports plastic recyclates to China
SDF/RDF - UK export SDF/RDF to European market
Portable batteries – exported to France

Imports

Trials - of new technologies often take place in in South Africa and the Far East
ATT skills - from Far East
Kit - MRF kit suppliers in US supply global market
RDF dev - RDF development currently going on in Europe
Scottish waste - 1 million tonnes per annum from Scotland to England
Waste shipped - Isle of Man and Channel Islands waste shipped to UK
Treatment kit – comes from Europe

Within this study, we explored three examples to consider the potential impacts of climate change internationally on the waste sector:

- Export of recovered paper and plastics to Far East;
- Export of RDF/SRF to Europe; and
- Importing MRF equipment from the United States.

The key messages from these examples are that costs related to import and export may increase, as a result of increased risk of disruption in-country or during transportation. In some cases, this may present an additional driver to increase capacity at home for the use of recovered materials, and to enhance the UK engineering and skills base to reduce external dependencies.

4.2.1 Export of recovered paper and plastics to Far East

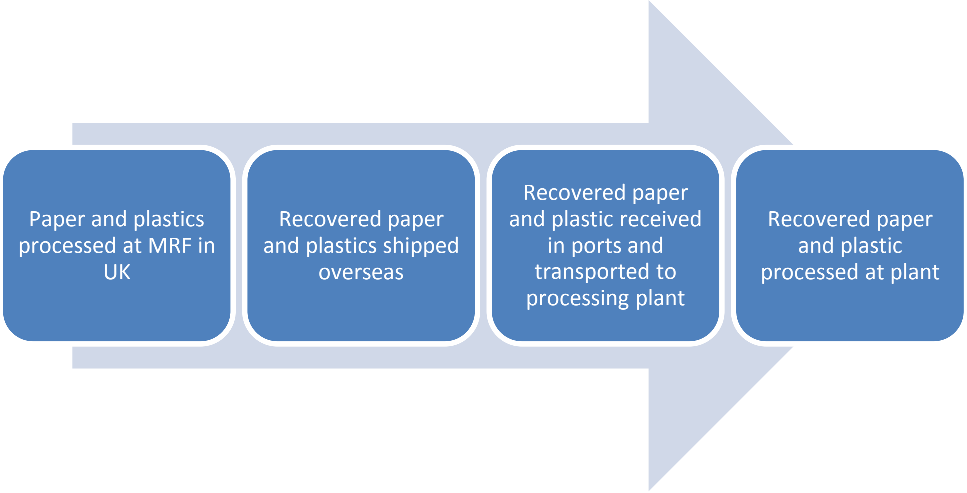
Summary of the interdependency

The UK's major trading partner of recovered paper and plastics is China.[31] China imports 11% of its recovered paper and 9% of recovered plastics from the UK. Of all the recovered plastics and paper exported from the UK in 2010, China received 88% and 61% respectively.[32] This means the UK is significantly more reliant on China as an overseas end-market than China is reliant on the UK as a source of imported recovered plastics and paper.

China's economy is forecast to continue to grow, and demand for recovered materials in China is also expected to grow. However reliance on imported recovered materials might begin to slow down as China develops its own collection and recycling systems and increases its self-reliance (WRAP, 2011). In response, the UK will need to ensure its recyclate remains competitive for export markets such as China, by developing domestic reprocessing infrastructure[33].

Figure 8 summarises the four stages of the export supply chain. The process begins at MRF plants in the UK, where paper and plastics are sorted ready for export. The recovered materials are then loaded onto shipping containers and transported to the export countries, where they are received in ports ready for onward transportation to processing plants[34].

Figure 8 Paper and plastic recyclate export supply chain



[31] Other countries import the UK's paper and plastics recyclate to a lesser extent, including Malaysia, India and Brazil. Source: Let's Recycle. Chinese demand for paper and plastics slows, 22 March 2011 [http://www.letsrecycle.com/news/latest-news/paper/chinese-demand-for-paper-and-plastics-slows].

[32] WRAP (2011) Market Situation Report: Chinese markets for recovered paper and plastics [http://www.wrap.org.uk/downloads/China_MSR_2011.223bcb17.10601.pdf]

[33] WRAP (2011) Market Situation Report: Chinese markets for recovered paper and plastics [http://www.wrap.org.uk/downloads/China_MSR_2011.223bcb17.10601.pdf]

[34] WRAP (2010) Municipal MRFs export study http://www.wrap.org.uk/downloads/MRF_Export_Study_Full_Report.924035ec.10918.pdf

Summary of relevant climate impacts

Climate change will be an important consideration for China. Due to its rapidly increasing and high population density, as well as its greater exposure to climate, China is more vulnerable to climate impacts than the UK. Impacts will affect shipping routes and ports, as well as people and processing infrastructure in China.

Shipping and ports

Across the world, severe tropical cyclones are expected to become more intense bringing stronger winds and heavier rainfall[35]. This is likely to cause damage and delays to shipping containers and the plastics and paper being shipped. This could potentially increase the cost of goods.

Sea level rise is projected to rise by between 18 and 24 cm by 2040 in the South China Sea[36], which could have a number of implications for ports[37]. Changes in erosion patterns and sedimentation could affect the size of boats entering the harbours. Port defences might need to be strengthened to cope with more damaging storm surges by the 2040s[38].

Wetter summers may become more likely in China[39] presenting an increased risk of flooding to port infrastructure as well as onward transport routes of paper and plastic recyclate to processing plants.

People, health and safety

Rising temperatures and more extreme stormy weather poses a threat to the health and safety of crew working on board shipping containers[40]. China has significant populations living in delta areas. Deltas are highly vulnerable to sea-level rise, storm surges and river flooding[41] increasing the risk of homes and businesses flooding and disrupting transport links, for example it could become more difficult for people to get to and from work.

Extremes of temperature such as heat waves and cold spells also increase the risk of mortality and infectious diseases in southern China[42]. Parts of China are likely to see temperature increases above those experienced elsewhere by 2040s[43]. Climate impacts such as these are likely to affect local air quality, putting additional stresses on the health of the population.

Process and infrastructure

Flood events accounted for 28% of the total economic losses due to meteorological disasters during 2004-2009 in China[44]. The frequency and magnitude of flood events is projected to increase in future, posing a threat to the processing infrastructure and the road and rail infrastructure which transports paper and plastic recyclate to processing plants.

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[35] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[36] Projected time-mean relative sea level rise for 2040, relative to the 1980-1999 average level. Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[37] Acclimatise (2011) Climate Risk and Business: Ports. International Finance Corporation, World Bank Group http://www.acclimatise.uk.com/login/uploaded/resources/IFC_Climate_Risk_Ports_Report.pdf

[38] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[39] Modelling carried out by Met Office Hadley Centre, T.N. & Räisänen, J. (2002), Quantifying the risk of extreme seasonal precipitation events in a changing climate. Nature, 415: 514-517, in Foresight Report (2011).

[40] Acclimatise (2011) Climate Risk and Business: Ports. International Finance Corporation, World Bank Group http://www.acclimatise.uk.com/login/uploaded/resources/IFC_Climate_Risk_Ports_Report.pdf

[41] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[42] Adapting to Climate Change in China (ACCC) Policy brief on Health vulnerability and risks, October 2011. http://www.ccadaptation.org.cn/en/NewsInfo.aspx?NId=1229

[43] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[44] Adapting to Climate Change in China (ACCC) Policy brief on Health vulnerability and risks, October 2011. http://www.ccadaptation.org.cn/en/NewsInfo.aspx?NId=1229

It is possible that plants will be affected by rising sea levels and coastal flooding. For example, 64% of China's EfW capacity is concentrated in eastern China, especially in the districts of the Changjiang and the Pearl River Deltas. In 2007, there were a total of 38 EfW plants across three provinces in these two districts[45].

Overall risk to UK waste sector

The export of paper and plastic recyclates from the UK to China could face higher risks in the future. Climate impacts on shipping routes, ports, people and the infrastructure required for reprocessing could stimulate demand for greater self-sufficiency in China, reducing the country's reliance on imports of paper and plastic. The UK may need to diversify the international markets for its paper and plastics, and could look for opportunities to make more use of this resource within the UK.

4.2.1 Export of RDF/SRF to Europe

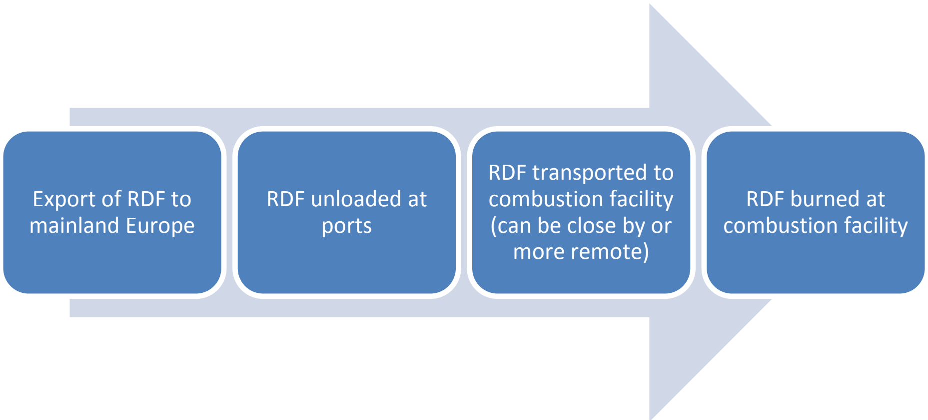
Summary of the interdependency

In recent years, Refuse Derived Fuel and Solid Recovered Fuel (RDF/SRF) exports to mainland Europe have been increasing due to the over-capacity of recovery facilities and low costs compared to those in the UK, where EfW plants are just beginning to be used. The main export markets for the UK's RDF/SRF are in Northern and Western Europe (the Netherlands, Denmark, Estonia, Latvia, Germany, Sweden and Portugal). Between January 1 and May 25 2011, 18 permits were issued for the export of RDF/SRF to seven different countries on the continent, with the Netherlands the prime location for material[46]. These permits are shared by 12 waste and recycling companies and cover a combined tonnage of 713,000 tonnes[47].

To illustrate the magnitude of this interdependency, approval was given for Shanks to export 40,000 tonnes of RDF from the UK during 2010 and 2011 to be used as feedstock by energy recovery plants in Germany and the Netherlands.

Figure 9 summarises the RDF export process. The process begins at MRF plants in the UK, where waste is sorted ready for export. The recovered materials are then loaded onto shipping containers and transported to the export countries, where they are received ready for transportation to combustion plants.

Figure 9 RDF export process



[45] Waste Management World, Waste to Energy in China, by **Nickolas Themelis and Zhixiao Zhang.** http://www.waste-management-world.com/index/display/article-display/0459492231/articles/waste-management-world/volume-11/Issue-4/Features/WTE-in-China.html
[46] Sloley, Chris. Waste exports soar to meet RDF demand. 6th June 2011. http://www.letsrecycle.com/news/latest-news/waste-management/rdf-story
[47] Sloley, Chris. Waste exports soar to meet RDF demand. 6th June 2011. http://www.letsrecycle.com/news/latest-news/waste-management/rdf-story

Summary of relevant climate impacts

The export of UK RDF to mainland Europe is likely to be most affected by climate impacts on shipping and at ports (from increased storminess and sea level rise) and on onward transport and processing infrastructure (from increased flooding). Climate change impacts on conditions at processing plants are also important for the health and safety of staff. As an illustrative example, we focus on the port of Amsterdam due the size of the Dutch market for UK RDF.

Shipping and ports

Sea level is projected to rise by between 12 and 18 cm by 2040 along the Dutch North Sea coast[48]. By the 2080s, sea level could rise by as much as 37cm[49]. This could cause disruption to Northern and Western European ports such as Rotterdam and Amsterdam, posing a risk to imported RDF from the UK. Rotterdam, Europe's biggest port, is already exposed to extreme weather. The port was forced to close its sea defence barrier for the first time in November 2007 when wind-driven storm swells and high tides lead to a fear of flooding, causing ships to be delayed[50]. As this type of event becomes more frequent, the export of RDF to mainland Europe could become more risky for the UK waste sector.

People, health and safety

In future, Northern Europe is projected to have wetter winters[51] and larger quantities of rainfall in shorter time periods[52], while sea levels continue to rise. This could exacerbate coastal, estuarine and river flooding which has social and economic implications for affected countries. Other economic consequences resulting from coastal flooding and sea level rise include damage to supply chains, the cost of moving and land loss[53]. These factors are likely to impact on the export of RDF from the UK to Western and Northern European countries such as the Netherlands.

In addition, the Netherlands can expect hotter, drier summers in the future[54]. This may lead to increased 'heat stress' of employees at ports, onward transportation and at processing plants, due to a lack of adequate shade and cooling. Demand for energy intensive air conditioning may increase thus reducing the sustainability of the RDF export interdependency.

Process and infrastructure

An increase in extreme rainfall is projected for Northern Europe by the 2040s[55]. This could present a threat to the road and rail infrastructure needed for the onward transportation of RDF from ports to energy from waste facilities. Flooding could affect depots and tracks,

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[48] Projected time-mean relative sea level rise for 2040, relative to the 1980-1999 average level. Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[49] For Europe, the mid-range projections for a medium to high emissions scenario (A1B(I)) suggest 37cm of rise

by the 2080s. Sea-levels will continue to rise into the 22nd century and beyond, and larger rises in sea level are possible, with rises of more than 1m being feasible by 2100. Under an E1 mitigation scenario, broadly consistent the EC's 2C target, the rate of rise is reduced, with 26cm projected by the 2080s.

[50] Acclimatise (2011) Climate Risk and Business: Ports. International Finance Corporation, World Bank Group http://www.acclimatise.uk.com/login/uploaded/resources/IFC_Climate_Risk_Ports_Report.pdf

[51] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[52] Rotterdam Climate Initiative (2009) http://www.rotterdamclimateinitiative.nl/documents/Documenten/RCP_adaptatie_eng.pdf

[53] Median estimates for the 2080s in Western Europe are around 400 deaths annually under A1B scenario (around 20 times the number seen at baseline) and a total of around 600 deaths for the whole of Europe. The estimated welfare costs associated with premature mortality are €700 million/year for the EU by the 2080s under the A1B scenario. Climate Cost

[54] Based on recent scenarios developed by the Royal Netherlands Meteorological Institute (KNMI) Netherlands Adaptation Strategy – Resume. http://www.maakruimtevoorklimaat.nl/fileadmin/user_upload/Documenten/PDF/Engelstalige_documenten/resume_nat._adaption_strategy_ENG.pdf

[55] Climate Cost (2011)

cause damage to bridges and increase subsidence of road and rail embankments[56] increasing the cost of transporting RDF.

The increased risk of flooding is likely to drive people and businesses to relocate to land above sea level. This may not be financially viable for existing EfW facilities and instead the sites might need to consider increasing the water retaining ability of surrounding land, and increasing on-site water storage[57].

Overall risk to the UK waste sector

The export of UK-sourced RDF to Northern and Western Europe may become less environmentally and economically sustainable as a result of the impacts of climate change, and the anticipated growth in UK markets for this material for domestic energy recovery. Damage to shipping containers and ports, combined with increased flood risk to transport and waste infrastructure could result in higher costs, making the UK RDF less attractive.

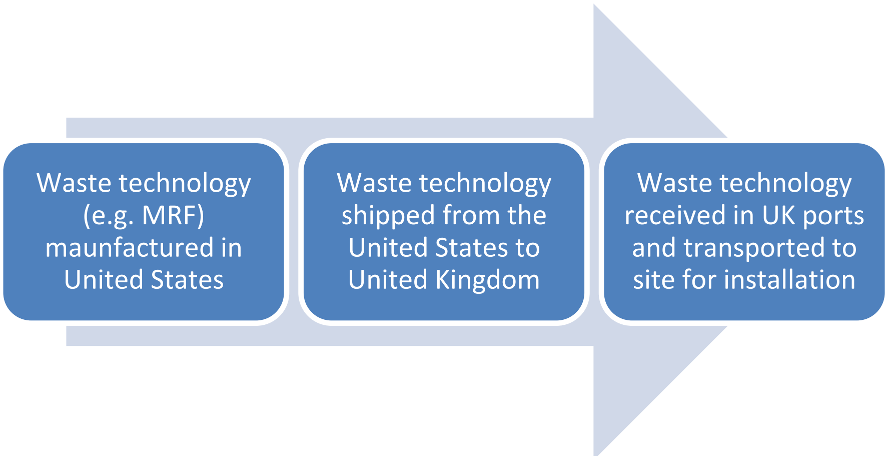
4.2.2 Importing waste technology (MRF equipment) from the United States

Summary of the interdependency

Some of the technologies which play a key role in England's waste infrastructure are imported, including Materials Recycling/Recovery Facility (MRF) technology from the United States. For example, the technology used in a Leicestershire MRF was manufactured in Oregon[58 59], and a California-based MRF technology manufacturer supplies the technology worldwide[60]. A dependence of the UK waste industry on technology imports from the US could be affected by climate change impacts in the US or during transportation.

Figure 10 summarises the stages of this technology import process. Following manufacture, plant is shipped from the United States to the UK where it is received ready for onward transportation to the installation site.

Figure 10: Waste technology import process (United States to UK)



Summary of relevant climate impacts

The United States is projected to experience a range of climate change impacts and these vary considerably from one region to another. For illustrative purposes, we focus on climate impacts in the state of California.

[56] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change
[57] Knowledge for Climate, Hotspot Dry Rural Areas http://knowledgeforclimate.climateresearchnetherlands.nl/hotspots/dry-rural-areas
[58] AEA's Waste and Resource Efficiency Knowledge Leaders
[59] Bulk Handling Systems, plant used in Leicestershire MRF http://www.bulkhandlingsystems.com/
[60] CP Manufacturing http://www.cpmfg.com/

Perhaps the greatest climate risk is the increase in extreme weather events. Flooding is likely to cause damage and delays to this supply chain through impacts on factories and transport infrastructure.

Shipping and ports

Severe tropical cyclones are expected to become more intense across the world in the future bringing stronger winds and heavier rainfall[61]. This could cause disruption to shipping and potential damage to the goods being transported, as well as delays to shipments on some shipping routes[62]. In addition, people working on board shipping vessels are likely to be more exposed to weather-related accident or injury.

Approximately 85 % of California's population live and work in coastal regions, making them vulnerable to sea level rise impacts. Sea level around California is projected to rise by up to 1.4 m by the end of the 21st century[63]. Although the frequency of large coastal storms and heavy rainfall events is not expected to change dramatically over this century for California, storms will still impact the California coast due to storm surges, inland flooding and erosion of the coastline[64].

People, health and safety

California is projected to experience longer dry spells during this century[65]. Limitations on water supply will be exacerbated by rising temperatures, reduced river flows and reduced rain and snowfall in the spring[66]. This could lead to increased competition for water, and water shortages for domestic as well as industrial use. Higher temperatures could present increased risks for outdoor workers.

Process and infrastructure

Flooding events are expected to increase in frequency as a result of climate and non-climate factors. Land-use changes resulting from declining vegetation cover, wildfires and loss of wetlands habitats contribute to reduced flood alleviation capacity. These changes are likely to be combined with a greater proportion of winter precipitation falling as rain leading to more rapid run off from slopes[67]. The potential for increased flood damage may cause businesses to consider relocating to other regions. Increased competition for water may have an impact on some industrial processes relevant to the manufacture of new waste infrastructure.

Overall risk to the UK waste sector

The dependence of the waste sector on importing US waste technology is unquantifiable. The largest risks are associated with increases in extreme weather, both in the US and during shipping, with the result that import costs may increase. However, these risks could potentially be avoided by buying waste technology from another country if needed.

[61] Foresight Report (2011) International Dimensions of Climate Change http://www.bis.gov.uk/assets/bispartners/foresight/docs/international-dimensions/11-1042-international-dimensions-of-climate-change

[62] Acclimatise (2011) Climate Risk and Business: Ports. International Finance Corporation, World Bank Group http://www.acclimatise.uk.com/login/uploaded/resources/IFC_Climate_Risk_Ports_Report.pdf

[63] Projections under the A2 emissions scenario by the end of this century 2009 California Climate Adaptation Strategy http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

[64] According to the 2009 Scenarios Project the frequency of large coastal storms and heavy rainfall events is not projected to change dramatically. 2009 California Climate Adaptation Strategy http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

[65] 2009 California Climate Adaptation Strategy http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

[66] Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T.Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger, 2008: Human-induced changes in the hydrology of the western United States. Science, 319(5866), 1080-1083.US Regional Climate Impacts – Southwest in http://www.globalchange.gov/images/cir/pdf/southwest.pdf

[67] Global Climate Change Impacts in the US (2009) http://www.globalchange.gov/what-we-do/assessment/previous-assessments/global-climate-change-impacts-in-the-us-2009

5 Resilience case studies

5.1 Veolia Energy Recovery Facility at Newhaven: Adaptation in practice

The Energy Recovery Facility (ERF) is situated at North Quay, Newhaven, on the banks of the River Ouse on the south coast of England. The plant will have the capacity to handle a nominal 210,000 tonnes of domestic waste each year (that which cannot be reused, composted, or recycled). Waste is combusted to generate electricity that supplies the national grid. The site was developed to be near to major areas of waste arisings to provide a balance between direct deliveries of waste and deliveries from transfer stations. After a long site acquisition and planning process the site is complete and began operations during the second half of 2011.

Figure 11 Veolia Energy Recovery Facility at Newhaven

Whilst it is not explicitly labelled 'adaptation', the design and construction techniques applied at Newhaven provide a good example of how consideration of climate risks can drive innovative, resilient infrastructure solutions.

This case study gives an overview of the challenges faced and solutions identified by Veolia and their key stakeholders. It is based on publicly available information from the Veolia and Environment Agency websites and an interview with Veolia's Director of Design, Engineering and Construction. It concludes that strong risk management processes and close consultation with stakeholders throughout the project lifetime are critical success factors for achieving resilience to climate change. The case study shows that high flood risks can be overcome via innovative design and engineering and careful risk management. It offers an optimistic example of how future projects may be managed to overcome the risks presented by a changing climate to increase the resilience of infrastructure systems in the UK. This is likely to have benefits beyond the immediate waste management sector.

5.1.1 Challenges & Solutions

	Key Challenges	Solutions
Design	• Current tidal and fluvial flood risk • Increasing future flood risk (climate change) • Local acceptance – specification to restrict building height (for aesthetic reasons)	• Raised site construction and levees to protect against flooding • SUDS & rainwater capture to reduce run-off • Plant partially 'buried' to reduce height above ground to meet customer's specification – water resistant housing for underground infrastructure

In many ways the site seems an unlikely choice for the construction of a multi-million pound infrastructure project; it is situated on estuary sands in a current flood risk zone. However, the site was identified in the waste Local Plan and in conjunction with East Sussex County Council and Brighton & Hove City Council (ESCC/BHCC) and was adopted for the project development. Veolia were selected as the preferred operator and began the process of design conception, planning and eventually construction.

The Council's specification restricted the height of the plant to mitigate local objections and limit the visual impact of the project; the implication was that the plant would need to be sunken into the ground to reduce its overall height. This further added to the design challenge by enhancing the already significant flood risk. An innovative design and engineering solution was required. Whilst the ERF technologies at the plant are standard for the industry, part of the combustion process in the Veolia design occurs 14m below ground level in a reinforced, flood-resistant housing. The site features perimeter flood defences to protect against a 1 in 200 year flooding event.

Construction	• Construction in a flood zone • Extreme weather interruptions	• Pioneering 2 phase construction technique – plant assembled behind sealed membrane away from river, then 'floated' into position and sunk into foundations • Additional temporary flood defence measures during construction phase

The ever-present risk of flooding at the site posed significant challenges during construction. Working with the construction contractor, the decision was made to build much of the ERF plant foundation above ground level away from the river bank and to move this huge section of the plant into its final position when complete (see photographs below). This technique reduced the risk of a large flood event damaging, delaying or destroying the facility during the construction phase. Project risk assessments also highlighted the need to implement additional flood defence mechanisms during construction, including rainwater drainage/ storage, pumps and flood barriers. Construction also had to contend with extreme weather conditions, including snow and ice, which serves as a reminder of the impact climate events can have on projects of this kind.

These photographs show the phased construction of the ERF plant on a raised platform, which was then floated into position and 'sunk' into its foundations [68]

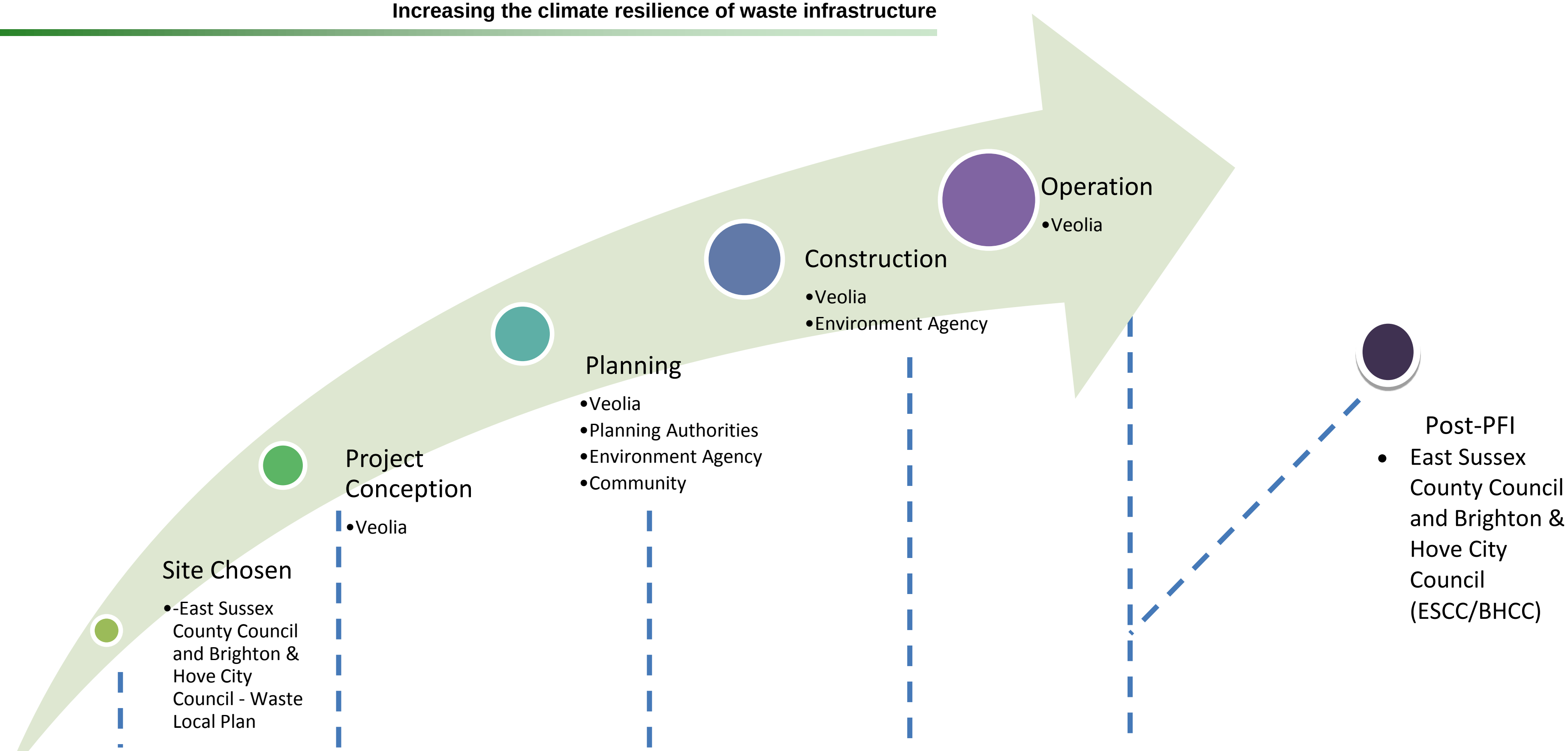
Were future climate risks considered? Yes. The site is built to withstand a 1/200 year flood + 20% climate change factor + a sea level rise scenario (as per Environment Agency guidance). The height of the perimeter levee in the original design was first calculated to protect against flood risk, but then raised to provide additional benefits by screening the view of the plant from the South Downs Area of Outstanding Natural Beauty.

Why? The risks posed by current and future flooding were identified by Veolia during the project conception phase as core 'business delivery risks'. Solutions to these risks were therefore a central part of the internal design brief at Veolia and an essential part of the business case put forward internally. The risks posed by current and future flooding were also raised by the local planning authorities, who required that the project follow Environment Agency guidelines to consider climate change in the site design.

In this way, the drivers that ensured the project considered climate risk were two-pronged: *internal drivers* applied via Veolia's own risk management system and *external drivers* exercised via the planning regime.

Which stakeholders were involved in the project and what were their roles? Although Veolia are the operators of the ERF at Newhaven under a PFI contract, the role of other stakeholders in considering climate risks has been important throughout the project. The diagram below shows the different stages of the project and briefly describes the roles of each stakeholder in relation to climate risks.

[68] Screen shots taken from Veolia construction video available at: http://www.veoliaenvironmentalservices.co.uk/southdowns/Facilities/Energy-Recovery-Facility/Construction-video1/



East Sussex County Council and Brighton & Hove City Council (ESCC/BHCC) and Brighton & Hove City Council (ESCC/BHCC) identified sites in its WLP on which to construct an Energy Recovery Facility (ERF). Veolia appointed PFI contractors.	Veolia identified business risks associated with the project including pollution, flooding, project delays, public perception, etc. Consultations with their insurers helped to frame and manage risks within Veolia's own processes.	During the planning stage Veolia developed all aspects of the site conception with stakeholders. These included relevant planning authorities, the Environment Agency, the local community contact group and local NGO's.	The site was constructed by Veolia's engineering contractor. Veolia were involved in all stages and held the insurance contract for the entire project. The EA granted certain consents during the construction phase.	The site became fully operational in Autumn 2011, and opened to the public in January 2012. The PFI is in contract for 25 years, after which East Sussex County Council and Brighton & Hove City Council (ESCC/BHCC) can take over the facility and therefore all risks associated with the site.

5.1.2 Lessons

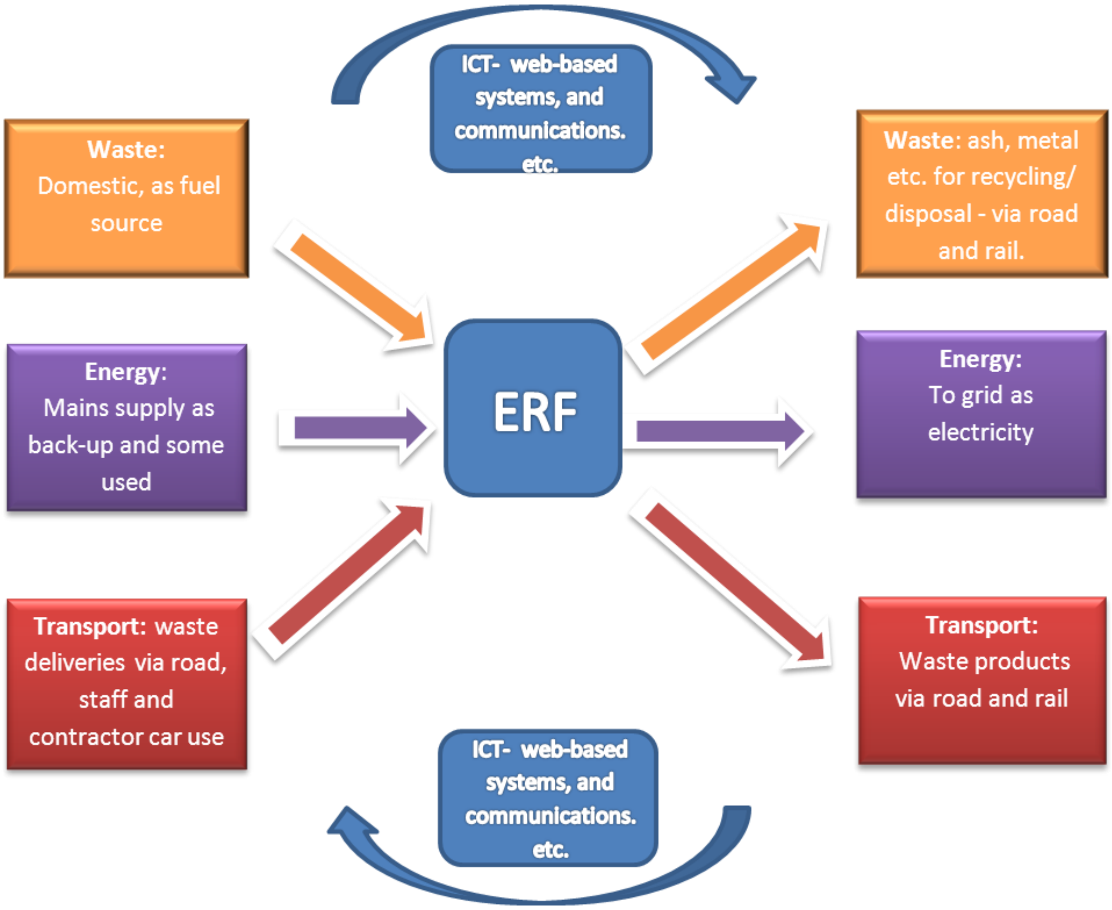
- Putting risk management at the heart of project management helps to identify risks at the outset of the project design phase so that effective solutions can be considered.
- Constant consultation with stakeholders helps to effectively manage risks, especially where ownership is unclear or shared. For example, weather risks during construction (including the possibility of the construction site being flooded by the River Ouse) were jointly owned by Veolia, the construction Contractor and Veolia's insurers. Regular dialogue between these three parties ensured that the right level of mitigation was in place to manage the risk to all groups' satisfaction.
- The Environment Agency guidelines on considering climate change in flood risk assessment were deemed to be sufficiently robust by Veolia and their insurers and were therefore taken as the standard for design.
- A combination of hard flood defence and high specification surface water management systems have been used to reduce flood risk at the Newhaven ERF site.
- The lessons learned at the company level from this kind of challenging design and engineering project are being used to inform new projects. Veolia is constructing other ERF plants and finding that each site faces its own set of risks, some of which are influenced by climate change. Veolia applies its risk management processes to all projects and, in partnership with its engineering contractors, are developing valuable expertise in relation to identifying and mitigating climate risks. This expertise may be of strategic value to both Veolia and UK PLC more broadly. The government may wish to assist UK companies to develop and promote this expertise in overseas markets.
- Throughout the long planning process at the Newhaven site (c.10 years) the awareness of climate change amongst all stakeholders, including the Environment Agency, local planning authorities, engineering firms and Veolia themselves, has improved notably[69].
- Whilst flood risk was thoroughly considered as part of this project, it is possible that additional operational risk, for example those relating to high temperatures and the efficiency of the energy recovery process, may affect ERF plants in future. These risks have received less attention, although Veolia are beginning to user higher specifications for air cooling systems to reduce this risk at new sites.
- The planning process is seen as a sufficient mechanism for integrating climate risks into projects of this kind.

[69] Observation made during interview by Veolia's Director of Design, Engineering and Construction.

Box: integrated infrastructure risks

The Newhaven site is an interesting example of integrated infrastructure: it is ostensibly a waste facility, operated by a waste company, but also functions as a mini-power plant and is reliant on local road and rail transport networks. As with all modern technology-dependent facilities, it also relies on an ICT network to operate.

Waste from local domestic collections (across Brighton & Hove, Hastings, Lewes and surrounding areas) is brought to the Newhaven site via road. The site itself is accessible via one access road (North Quarry Road), which is exposed to flood risk. Waste products are removed from the site via road and also rail (e.g. waste ash for recycling).



Integrated infrastructure makes sense

The Newhaven ERF is an example of the trend towards more integrated infrastructure systems. The benefits of this integration can be both environmental and economic, as well as potentially in terms of resilience. Overall greenhouse gas emissions can be reduced by recovering energy from the renewable fraction of domestic waste, rather than sending that waste to landfill; this can also help reduce our reliance on fossil fuels. Using *local* waste as a 'fuel source' at an Energy Recovery Facility reduces emissions from transport. Waste is also a 'free' energy resource, in the sense that costs associated with its collection are sunk and would occur anyway, although there may be costs associated with its preparation and treatment for recycling or energy recovery.

But does integrated infrastructure heighten risks?

If infrastructure is more connected then the system as a whole may be more vulnerable to disruptions at one particular site or 'node' within the system. If North Quarry Road is flooded, which local flood models suggest is likely under a 1/200 year flood event scenario[70], road access to the site could be lost. If prolonged, this flooding would disrupt operations and eventually stop energy generation at the ERF site. Likewise, widespread severe flooding elsewhere in the local area could restrict the flow of waste (i.e. 'fuel') to the site and slow down production.

If energy supply *to* the site was lost as a result of extreme weather, the site may need to shut down (even though some of the energy used in the process is provided directly by the ERF itself). Any disruption to the site's ICT system (e.g. loss of internet access, computer network failure) would also disrupt operations, potentially impacting the ability of the site to safely generate electricity or process waste.

As the diagram above demonstrates, the integrated nature of infrastructure systems means that any of these impacts may have knock-on effects for energy supply or waste management.

In the short to medium term, however, the resilience of infrastructure services in East Sussex is probably enhanced by the creation of the Newhaven ERF site:

- The new site is built to withstand current and medium term future flood risk
- The 'supply chain' of fuel (i.e. domestic waste) is very local and short and therefore less likely to be exposed to climate impacts than equivalent supply chains for alternative power generation technologies (e.g. gas, nuclear, coal).
- The energy produced by the site, whilst significant, is not critical to the local economy: the national grid will be able to cope with a shut-down at Newhaven.

Co-benefits of adaptation

The adaptation that has taken place at the Newhaven ERF site is likely to have also improved the resilience of local infrastructure systems in general, by offering a relatively robust source of energy and processing for local waste and a potential source of heat to some local consumers in the event of failure in the national electricity or gas infrastructure (i.e. system flexibility).

Long term risks

Over the longer term, however, there is a chance that severe flooding at Newhaven may present problems to waste and energy management in the area. This is partly due to the tendency of the flood risk at Newhaven to increase over time as a result of accelerating climate change and rising sea levels.

This is more likely over timescales that extend beyond the current PFI contract (i.e. more than 25 years) and are therefore the responsibility of the local council (who will resume ownership once the PFI contract expires) rather than Veolia.

As alluded to elsewhere, as the principal 'risk owners' throughout this process, Veolia have taken steps to manage all risks pertaining to their business (limited to the period of the PFI contract) driven by their internal risk management process. The strong inter-stakeholder communications that characterised the long design, planning and construction stages of the Newhaven ERF project may also be important for the management of risks during the transition to Council operation of the plant at the end of the PFI contract.

[70] Models suggest the road would flood by 1.1m for 4 hours in a 1/200 year event, see p.24 Non-technical summary, available at: http://www.veoliaenvironmentalservices.co.uk/Documents/Publications/South%20Downs/ERF/ERF_non_technical_summary.pdf

The *de facto* system for managing longer term risks has been the local planning process, although it is unlikely that long term integrated infrastructure risks were recognised or actively considered when applying the Environment Agency's standard guidance on climate change flood risk. The planning system may therefore not be adequate for managing longer term risks, for example those relating to major sea level rise and significant increases in flood risk. These risks extend beyond the PFI contract and have therefore not been 'owned' or managed directly by the project developers.

With thanks to Veolia for provision of information on this case study.

5.2 Landfills in the East of England: Planning for climate change

5.2.1 Context for case study

Landfill sites in South Essex in the East of England provide this project with a case to demonstrate how waste sites which have a long legacy and are vulnerable to inundation and flooding from tidal sea level rise and coastal erosion have the potential to be managed to achieve multiple win-wins over the longer term. Such sites may actually be more resilient due to changes in land use and the existence of longer term management plans that consider potential climate change impacts.

Table 5 *Reasons for selecting East of England landfills as a case study*

Context	Details
Where are the landfills located?	The South Essex landfills are situated in the East of England on the northern bank of the River Thames and subject to river and tidal conditions.
What main climate issues could the site face?	Primarily sea level rise and coastal erosion impacts alongside current tidal variability.
Why South East landfills?	Landfills have a long lifetime which means that existing sites will experience climates of 2050s or beyond. Although future waste strategy is looking to reduce the amount going to landfill significantly, the heritage of sites will still need to be managed. Some landfills along the South Essex coast have ceased, or are soon to cease taking waste. Their future management will include a change in land use and needs to consider climate change, potentially adaptation as well.

5.2.2 Case study background

Landfills in South Essex were created to service London and accept waste predominantly by barge from the River Thames. Often former gravel extraction pits, landfills in South Essex are decreasing in capacity and some have ceased taking waste or are soon to close. One of the principal reasons for this is the implementation of the European Landfill Directive. Many older landfill sites that did not meet the stringent requirements of the Directive had to close by July 2009 at the latest; diversion targets for biodegradable municipal waste to landfill increase year on year (Environment Agency, 2010).

5.2.3 Observed tidal flooding

Major tidal flooding along the east coast of England occurred in January and February 1953. The 1953 floods were caused by a major storm surge which coincided with a naturally high spring tide, and resulted in sea levels rising almost 3 meters above normal high water marks.

Most sea defences along the east coast of England were not designed for such events and most could not prevent the oncoming wave of water (Thames Estuary Partnership, 2011).

Today, most of the South Essex coastline along the River Thames tidal estuary is protected from a 1 in 1000-year tidal flood event under normal circumstances (Scott Wilson, 2009a). However, there is always a risk that the defences may be overtopped and/or breached; the presence of defences can only reduce, and not remove the risk of flooding (Scott Wilson, 2009b).

5.2.4 UK Climate Projections 2009 sea level rise projections results

Relative sea level rise is the change in the elevation of the water surface with respect to the level of adjacent land. The latest sea level projections from the UK Climate Projections 2009[71] (UKCP09) are based on combining estimates of absolute sea level for the UK as a whole with regionally-averaged projections of future land level changes, which in the UK are primarily due to isotactic adjustment following the last glacial period (UKCP09, 2010).

For landfills located in South Essex, relative sea level rise results (Appendix 5) show that under the Medium Emission Scenario by 2030, relative sea level rise is expected to be between 7 and 20 cm across the range of models. By 2050, relative sea level rise is expected to be between 10cm and 33cm across the range of models. By 2100, when the South Essex landfills will still be active, at the lower threshold 5% of models show a sea level rise of equal or less than 22cm. At the mid threshold, 50% of models show a sea level rise of equal or less than 47cm and at the higher threshold, 95% of the models show a sea level rise of equal or less than 73cm.

Landfills can take up to 100 years to stabilise, meaning that subsequent restoration and land use could be subjected to an increase of relative sea level rise up to 73cm by the end of the 21st Century.

Storm surge results for a representative grid square along the South Essex coast, under the Medium Emissions Scenario indicate that the climate change signal is not distinct from the climate variability signal (Appendix 5). No change to a slight negative trend (0-0.05mm/year) is projected for changes in storm surge height (with no mean sea level rise added). Although extreme sea levels have changed there is no observational evidence for regional trends in either storm surge frequency or magnitude over recent decades (Lowe *et al.,* 2009). The Thames Estuary 2100 case study in the UKCP09 marine and coastal projections report also found that 21st century increases in storm surge height and frequency in the southern North Sea are less likely than previously thought (Lowe *et al.,* 2009).

5.2.5 Climate change and planning

Guidance for Local Authorities on planning and flood risk - Planning Policy Statement 25 (PPS25) (DCLG, 2010) – advises that planning decisions take account of future flood risk from coastal flooding and erosion. Waste operators of current facilities are advised by the Environment Agency for coastal flooding to use the allowances in Table 6 for the East of England and are also the same as those given in PPS25 (DCLG, 2010). These allowances and sensitivity ranges were developed before the UK's latest climate projections UKCP09 were produced. The Environment Agency believes that in the light of UKCP09 they remain very reasonable estimates of change. However, they advise that if operator's sites are particularly vulnerable they should consider testing their vulnerability to higher allowances (Environment Agency, 2011).

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[71] Unlike some other components of UKCP09, the sea level projections are not probabilistic but instead provide a frequency distribution of projections. Also, the Low and High emission scenarios have been scaled from the Medium emission scenario for the sea level projections. For the sea level projections, the use of percentiles represents only the percentage of model simulations that give values less than or equal to that percentile, and contain no information on the probability or frequency of exceedance of that value (Lowe *et al.,* 2009).

Table 6: *Recommended contingency allowances for net sea level rise (DCLG, 2010; Environment Agency, 2011)*

Region	Net Sea Level Rise (mm/yr) Relative to 1990			
	1990 to 2025	2025 to 2055	2055 to 2085	2085 to 2115
East of England	4.0	8.5	12.0	15.0

N.B Vertical movement of the land is incorporated in the table and does not need to be calculated separately.

Using the allowances above to calculate relative sea level rise for South Essex as per Defra's Note to Operating Authorities (Defra, 2006) this would result in 94.5cm of relative sea level rise for the landfill sites by 2100 (Appendix 3). This is similar to the UKCP09 projections, extrapolated from the medium emissions scenario, for the high scenario at 89cm.

It is likely that local defences which are privately owned by waste management companies and are directly adjacent to the landfill sites, will also have to be maintained over the next 100 years, and potentially increased as projections of future sea level rise improve. Any subsequent landfill restoration or change in land use plans that replace a closed landfill site provides the opportunity to safeguard associated waste technologies on site, such as Materials Recovery Facilities and leachate treatment plants that are often set up adjacent to the landfill. They will also have to address the issues of future relative sea level rise and coastal flooding whilst protecting against any potential consequences of collapse, leaching, and flooding of gas extraction locations whilst the landfill stabilises.

5.2.6 Conclusions for coastal flood resilience

The majority of landfill sites are likely to be unaffected directly by future sea level rise mainly due to the artificial building up of the land from the landfill itself plus any future restoration that includes additional soil (to allow room for vegetation and building foundations) or the restoration of habitats. This will offer further protection to stabilising landfills in South Essex and their potential future uses.

However, it is evident from modelling undertaken by one Local Authority in South Essex (Thurrock) that areas of landfill sites on lower ground already prone to flooding such as access roads and site offices, could be subject to an increased area of flooding under climate change (Scott Wilson, 2009; Scott Wilson, 2010). Depending on the exact location of the landfill gas extraction areas across the sites and the infrastructure needed to deliver this to the national grid, this could also be subject to a greater area of flooding, disrupting the gas extraction process.

In planning for restoration of closed but still active landfill sites in a coastal location, site owners should consider the findings of the latest generation of Environment Agency Shoreline Management Plans (published in 2011) where coastal and tidal flooding from future climate change will be modelled and mapped.

This case study is a good example of how landfill sites in vulnerable locations could be managed over the long term to take appropriate consideration of future climate risks and relevant adaptation measures, whilst taking the opportunity to achieve multiple win-wins in terms of: improved landfill legacy management for the site owners, ensuring future landfill gas extraction exportation to the national grid, contributing to restoration and creation targets for UK habitats, providing additional semi-natural flood defence, and potentially supplying increased amenity and educational facilities to the local community.

5.3 Shanks: Water efficiency at anaerobic digestion plants

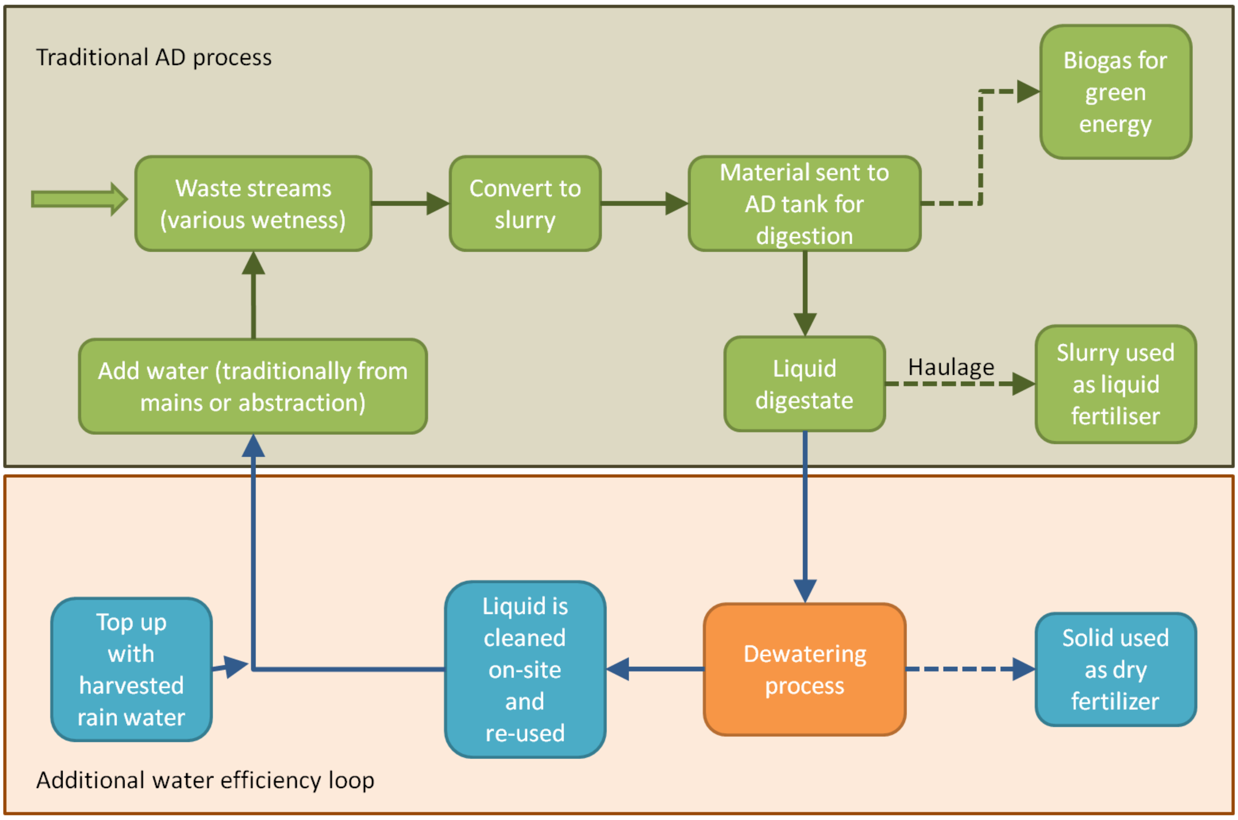
The construction and implementation of infrastructure to enable treatment of organic waste already brings many benefits, both in terms of overall waste strategy and climate change mitigation. For example, the treatment of food waste through aerobic (composting) and anaerobic processes can achieve:

- Reduction in biodegradable municipal waste going to landfill
- Increased energy security, sustainability and affordability through the production of green energy and heat
- Reduction in carbon footprint
- Increased support to the green economy
- Control of costs

Can such infrastructure also incorporate measures to increase climate resilience, and bring adaptation opportunities?

Shanks has been pioneering efforts to introduce greater water efficiencies into wet biogas Anaerobic Digestion (AD) facilities. The process traditionally requires additions of water to the incoming organic waste streams in order to create the right moisture content in the slurry mix which is treated in the AD tanks. At the end of the process, the resulting liquid digestate can be used as a fertiliser. New designs are now incorporating a much greater degree of water recycling into this process, as shown in Figure 12.

Figure 12 Integration of water efficiency into AD



A dewatering process after the AD treatment can be used to separate microorganism-rich liquids from solid: this reduces the amount of liquid slurry going to land, and generates a greater amount of solid digestate fertiliser instead. The liquid fraction can be cleaned on-site and recycled to the front of the process where it is added to incoming waste streams. This has some efficiency advantages since this liquid is already richer in AD microorganisms than alternative sources of water (e.g. from mains). Rainwater harvesting (e.g. collected from roofs) provides an additional top-up source of water to mix with incoming waste streams, if required.

From the additional investment of the dewatering process, multiple benefits are possible:

- Water efficiency improves economic and environmental sustainability and protects against risks. Recycling of water used in processes reduces the reliance on unsustainable water abstraction (and potential increases in water prices); it also reduces the use of potable water (and the embodied energy from water treatment), enabling that water to be used elsewhere; it makes the facility more self-sufficient, protecting against risks affecting public water infrastructure.
- Process efficiencies: the recycling of microorganism-rich liquids back through the process may mean that fresh inputs of microorganisms are reduced.
- Wider environmental advantages: with reduced volumes of liquid slurry (fertiliser) applied to land, pollution risks from run-off are reduced, and the environmental costs of haulage are reduced. On-site rainwater harvesting may provide some local protection from flash flooding.
- Economic benefits: the dewatering process provides increased production of solid digestate available to be sold as dry fertiliser.

The Environment Agency indicates that most of the south east and eastern England is currently seriously water stressed and highlights that there is an urgent need to target water efficiency measures[72]. For all of these reasons, designing water efficiency into wet AD makes sense *now*, which is why Shanks have already introduced these processes at a facility in Amsterdam, and have similar designs in place for new facilities opening in Bicester, planned in East London, and at earlier stages in development elsewhere in the country.

However, it has recently been recognised that these same measures are increasing the future climate resilience of the facilities too. They represent a step towards future-proofing of these new plants against a major climate risk associated with the potential for increased drought episodes in future.

Projections of climate change for the UK[73] show that under a medium scenario, parts of the far south of England could receive 40% less summer rainfall in the 2080s[74], compared to the current climate. Even by the 2050s, summer rainfall may have decreased by 30% in the Thames region. To an extent, this could be compensated by more rain in winter (and more intense rainfall)[75]. However, greater seasonal and annual weather variability leads to more very dry or very wet periods, culminating in droughts (and floods). Other research confirms that short-term summer drought is projected to increase in south east England. Modelling suggests that future climate change will bring more intense short-term droughts, although fewer longer duration events may be experienced[76].

Improved water efficiency at plants which are traditionally major water users also brings knock-on adaptation benefits to other sectors of society and the economy in a future where water is at a premium: minimising the use of potable water in AD processes will mean that more is available for other consumers.

With thanks to Shanks Group for provision of information on this case study.

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[72] Environment Agency (2008) water resources in England and Wales – current state and future pressures http://www.environment-agency.gov.uk/research/library/publications/100582.aspx

[73] The UK Climate Projections (UKCP09) Briefing report: Jenkins, G. J., Murphy, J. M., Sexton, D. S., Lowe, J. A., Jones, P. and Kilsby, C. G. (2009). UK Climate Projections: Briefing report. Met Office Hadley Centre, Exeter, UK.

[74] Under a medium emissions scenario by the 2080s, range is –65 to –6% in southern England; in the 2050s, the range is –40 to –20% in the Thames River Basin

[75] Climate projections show that in future the UK is expected to receive similar amounts of rainfall over a given year; the change projected under climate change is a change in when it will fall and the frequency and intensity in which it might fall, with less falling in summer and heavier downpours in winter.

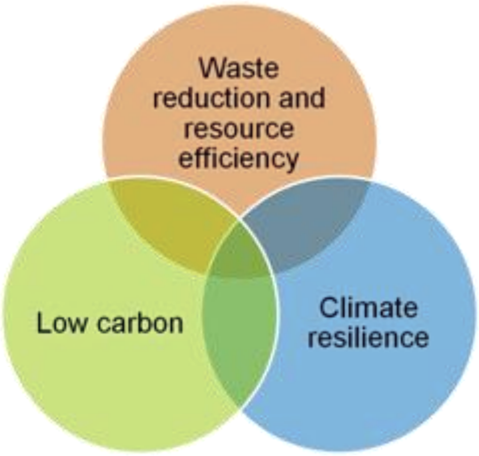
[76] Blenkinsop, S. and H.J Fowler (2007) Changes in drought frequency, severity and duration for the British Isles projected by the PRUDENCE regional climate models, Journal of Hydrology 342, 50– 71 http://www.staff.ncl.ac.uk/s.blenkinsop/drought_JH.pdf

6 Adaptation in the waste sector

This chapter explores the options available to mitigate the climate risks identified in this study and considers some of the challenges and barriers to adaptation in the waste sector.

As demonstrated in the case studies in Section 5, adaptation actions to address climate risks will rarely (if ever) be undertaken as a response to climate change alone. Rather, a combination of factors usually leads to adaptation, such as the desire to improve water efficiency, or make a process more cost effective. Findings from this study show that there is great potential for additional benefits in the form of win-wins, and even triple wins (Figure 13) that support and enhance development in line with national strategies of waste reduction, low carbon, and climate resilience.

Figure 13 Triple wins in future waste strategy



Adaptation for waste infrastructure aligns with current important themes for the sector, namely risk management, environmental sustainability and economic efficiency. This provides scope for innovation, a sound basis from which to mainstream adaptation and create realistic opportunities to deliver resilience and continuity more broadly. Waste infrastructure also has a role in providing adaptation solutions for others within the locality, such as restoring landfills in a way that provides opportunities for biodiversity, builds resilience to climate change, and provides local flood defence. Another example would be the improvement of local energy resilience through the provision of local heat and power, or improved plant water efficiency which increases local water availability for other consumers, as demonstrated by the case studies in Section 5 of this report.

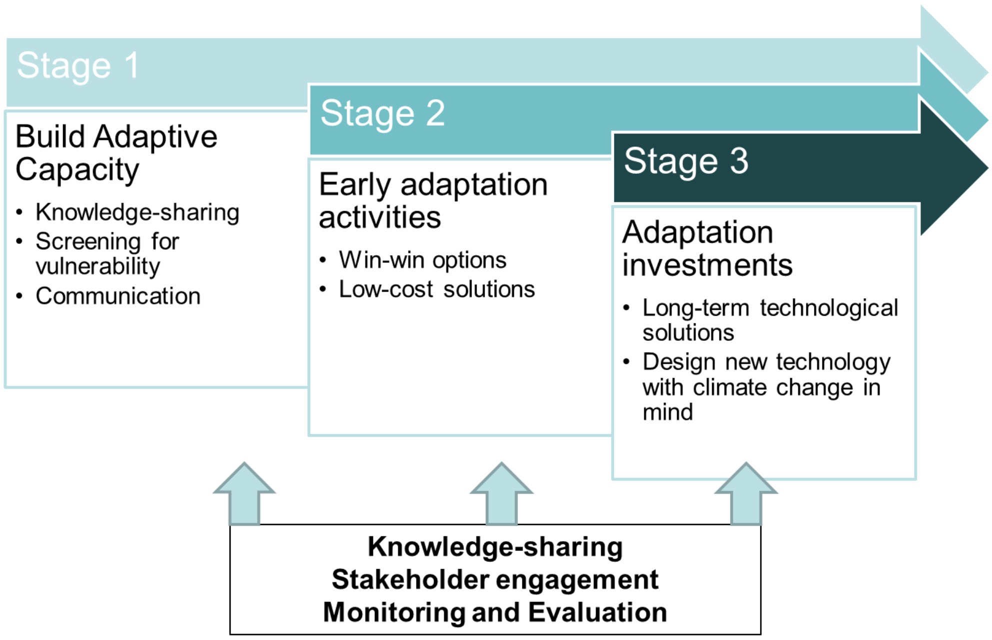
6.1 Adaptation options for waste

There are a number of adaptation options that have been identified through the course of this study which could help build resilience to climate change in the waste sector. The options are varied, in terms of what they would actually require, the timing of implementation, and the cost of implementation. They include adaptation options which require technological change or development, activities which focus on awareness-raising and information sharing of best-practice, options which require change to or development of regulations in the waste sector, options which relate to spatial planning or the procurement process, research activities, and options which relate to risk management or disclosure.

One issue that became apparent during the course of this study is that the potential cost of adapting to climate change is a serious concern for stakeholders in the waste sector. Whilst this is a common concern for many sectors, it is particularly important for waste sector stakeholders – waste infrastructure owners and operators cannot afford to increase their costs by addressing climate risks if their competitors are not. The current evaluation procedures typically applied during procurement would make it difficult for more expensive but more resilient proposals to be chosen over less expensive ones. The perception in the industry is that measures to increase climate resilience will always result in increased costs, and there is a general opinion that the cost-benefit case for adapting the waste sector to climate change has not yet been demonstrated.

In response to concerns about the cost and timing of implementing adaptation measures in the waste sector, we have categorised adaptation options below in a series of three stages. This emphasises that a number of adaptation options can be implemented for little or no cost initially; more complex and potentially costly adaptation solutions could then be implemented at a later stage if a specific risk is identified. Of course, given the lead times in designing, planning and constructing new infrastructure, the analysis required for many of the Stage 3 solutions will need to be underway now, in order for appropriate resilience and adaptation to be factored in.

Figure 14: Adaptation Options



It is important to note that elements such as knowledge-sharing, engaging with a wide range of stakeholders, and monitoring and evaluation of adaptation activities should occur throughout the process.

There are a wide range of potential climate risks identified (see Table 3), and the specific adaptation actions appropriate in each individual circumstance would need more detailed analysis based on the type of waste technology in question and/or the location and size of the site. The sections below give an overview of some of the relevant adaptation options according to the three stages summarised above.

6.1.1 Stage 1: Building Adaptive Capacity

One immediate way to build adaptive capacity in the sector is by **improving communication on the issue and sharing examples of good practice**, both internally and externally. Some waste service providers, such as those discussed in Section 5, have extensive experience in risk assessment and coping with weather events. Lessons learnt, such as those learnt by all involved in the 10+ years of planning the Veolia Newhaven ERF (Section 5), could be used to inform new projects and update risk assessment procedures.

Information sharing between larger and smaller waste operators could prove particularly useful. This issue was identified as a key area of research/engagement during the course of the study: there is a need to assess how to help smaller sites or businesses in the waste sector adapt to climate change. Many of the larger companies, such as Veolia and Shanks, already engage in extensive risk management and evaluation at their sites, and integrating climate risk into these procedures should be possible. Work is needed, however, to establish what help and information smaller companies may need to adapt to climate change. This could even include the development of simple screening tools to support the incorporation of climate risk into the risk management process.

There is also scope for raising awareness of, and providing information about, specific issues such as fire risk or odour and dust management, which pertain to smaller subsets of the sector. This could help inform operators of new methods and encourage them to take action on such issues.

In addition to information sharing within the sector, there is also an opportunity to build adaptive capacity by improving communication between the waste sector, other locally-based industry and local communities in general. Such partnerships are essential as infrastructure becomes more interdependent at the local level, and are needed to ensure an integrated approach to potential climate risks (perhaps especially responses to extreme weather impacts). Better information sharing in local contexts has multiple benefits, but could be used to identify ways in which adaptation choices taken by waste infrastructure owner / operators can increase resilience of the local community. Additionally, there is scope for knowledge sharing with organisations outside of the UK, in particular relating to technological learning to improve resilience. For instance, the UK could learn from the way technologies are used in other, warmer or drier climates in order to gain efficiencies. In some cases this kind of knowledge exchange may occur autonomously within one multinational company, (e.g. Shanks bringing experience from the Netherlands on water management into the UK), but a level of facilitation across the sector may be needed to enable all industry players to have access to relevant information.

Another immediate action to improve resilience to climate change in the waste sector relates to **the role of regulation**. There was a clear indication at the Industry Focus Group of the key role that regulation could play in improving the resilience of the sector to climate change. For example, stricter planning regulations could specify that no new sites can be built in flood plains. Regulations could also require that sites are located in spaces large enough to allow for features such as additional water or waste storage should the need arise. We expect permitting and licensing activities for all waste infrastructure in the future could cover aspects of resilience planning and contingency planning for extreme conditions. This issue is explored in more detail in Section 6.3.

There is also scope to address some of these issues through the **procurement process** – building resilience to climate change in the waste sector could be introduced as a requirement in the procurement process for new sites. For example, risk assessment during the procurement process and build phase could be expanded to include an assessment of climate risks (all potential climate risks, not just predominantly flooding as per the Veolia Newhaven ERF case study), and potentially even international risks which would have a knock-on effect to the waste sector in England. At the moment, flood risk is assessed at new sites using current flood risk levels: procurement requirements could help drive the development of this so that future flood risk and climate projections are also included in the flood risk assessment. Climate change risk assessment should be an on-going feature through all phases of procurement, design, construction, operation and decommissioning of waste facilities.

There is also scope for the waste sector to report under the **Adaptation Reporting Power**[77]. Organisations in the waste sector were not directed to report under the first round of the Reporting Power, although a number of organisations with responsibility for transport, energy, and water infrastructure (among others), were included. Government is currently reviewing how the Reporting Power may be used in a second round, but since the first round has, at the very least, served to raise the profile of climate risks and the need to build resilience among those involved, it may be a helpful measure to apply across waste infrastructure owners/operators in due course.

6.1.2 Stage 2: Early adaptation activities

There are a number of low cost or win-win adaptation actions which build on the activities under Stage 1.

Some **technological solutions** would be useful for increasing resilience to climate change; however, the majority of these solutions do not require extensive technological change, but rather small adjustments to existing methods and technologies. Suggestions were made at the Industry Focus Group that innovation in waste treatment would be useful in identifying ways to decrease odour and dust from waste sites. Similarly, there is scope for improved methods for controlling pests and vermin, and also for detecting fires in waste. Technological innovation in these areas would be useful in general, and would also build resilience to climate change.

Many technological solutions which are already being used in the waste sector actually provide adaptation benefits, even if adaptation to climate change was not their original intent. Landfill restoration schemes (such as those that exist in England already) should explicitly identify triple wins in terms of local adaptation benefits as well as climate risk management. Long-term site legacy management is an opportunity to restore, create and maintain new land uses such as habitats, amenity and flood defence. There is also scope for innovate spatial planning, such as co-location of sites within eco-parks to make use of water from other facilities. Improved awareness of climate change risks and adaptation in the sector (discussed under Stage 1) would ensure that maximum adaptation benefits could be achieved from the kinds of technological advances that are already planned or underway – either at research stage or in operational contexts.

In addition to technological innovation and improvement, ensuring that the designs of new (long-lifetime) infrastructure and technologies have some degree of **flexible pathway planning** would also build resilience. This means that resilience options are identified but not constructed until careful monitoring of environmental changes indicates that implementation of the option is now warranted. Including some flexibility in site design (for instance, allowing extra space onsite for additional water storage or multiple site access routes), would make those sites more adaptable to climate impacts if needed.

A number of suggestions for areas of further **research** have been made throughout the course of this project. Additional monitoring of climate impacts and climatic changes at the site level would be useful to enable decision-making, and to build a stronger cost-benefit case for adaptation. Monitoring would also be useful in relation to the causes of health and safety and/or operational incidents to understand the role of weather in those incidents.

Additionally, there are a number of ways that the **risk management process** could be expanded to include further assessment of climate risk. Site operators already have to disclose risk during the process of obtaining a permit – this could extend to climate risk as well. Links could be made at the local level to join up local strategic flood risk assessment for new facilities with risk management of existing sites. Additionally, improved emergency planning and contingency arrangements for extreme weather and flooding should be built

[77] Power available to Secretary of State for Environment, under Climate Change Act 2008, to require organisations to submit reports on the climate risks they face and the adaptation actions they are undertaking. The first round of reports were completed in 2011.

into the risk management and business continuity processes at both the site level and (in the case of larger owner/operators) company-wide.

6.1.3 Stage 3: Adaptation Investments

In the longer term, more substantial **technology improvements** and **engineering solutions** may be needed to ensure a greater level of resilience to climate change. Such improvements would most likely have to be designed for a specific site and would account for the climate impacts most relevant to that site. Examples are provided in the case studies explored in Section 5. However, a key conclusion from this study is that within the UK, adaptation in the waste sector is not limited by technology. Future climate conditions are unlikely to present insurmountable challenges to the waste technologies currently in use and planned. Rather, climate trends and extremes may contribute to a rising baseline of costs (e.g. increasing prices for vital commodities, more frequent maintenance and repair of facilities, increasing costs of environmental compliance, etc.) if technologies are not managed within a context of climate change.

Although technology improvements and innovations may be of greater cost initially, they can still bring ancillary benefits, immediately and in the future. For instance, some technological improvements have additional benefits such as improving resource efficiency, improving public opinion of the site, or encouraging biodiversity, as well as increasing resilience to climate change. The benefits of knowledge sharing internationally are likely to underpin technological improvements in the UK as owners / operators learn from the experiences of waste treatment processes in areas of the world already accustomed to the kinds of climates that the UK may expect in the future.

Understanding the longer term climate risks that are critical to a site requires more detailed **risk assessments** which consider climate impacts at different timescales. Putting risk management at the heart of the procurement process and project management would help to identify risks at the outset of the project design phase so that effective solutions can be considered. This is certainly true of the innovative flood resilient infrastructure at the Veolia Newhaven ERF. There are a number of climate risk assessment approaches and tools which could be made available more widely among waste infrastructure owners / operators, and appropriately tailored to the industry.

Some risks could also be managed by the potentially more drastic solution of **enclosing more waste facilities**. This would help to reduce noise, dust and odour for surrounding neighbourhoods. It would also enable greater temperature control in order to improve the comfort of workers.

6.2 Challenges and barriers

This study has identified the following as the main barriers to adapting waste infrastructure to the impacts of climate change:

1) Major infrastructure procurement process
2) Information and awareness
3) Physical barriers

Each of these barriers is explored in more detail below.

6.2.1 Procurement process

Discussions with stakeholders during the course of this project have made it clear there is a tension in the waste sector around the procurement process and regulation. To caricature the situation: an infrastructure operator will not include additional resilience in a design unless it is in the specification set by the Local Authority; the Local Authority will not include resilience in the specification unless the Environment Agency requires it because it adds cost; the Agency does not want to increase the regulatory burden and wants operators to show innovation; Central Government-led policy has not given sufficient signals to foster innovation in the sector, and so on.

Clearly this cycle does not always apply, but there is a tension due to the fact that site operators want regulation to “level the playing field” but regulators want operators to take initiative. In the current economic climate, it is considered impossible to choose a more expensive option unless there is a regulation which requires meeting a certain level of risk management. This shows the importance of demonstrating the business case of building in resilience in order to help overcome this tension.

As demonstrated in the Newhaven case study in Section 5.1, it is possible for the procurement process to allow and even encourage innovation in design which addresses at least the more obvious climate risks at site level.

6.2.2 Information and awareness

Although some waste operators are well informed about some aspects of climate risk, in general there is a lack of awareness about the scope of climate change risks and also the opportunities from adaptation. In particular, the specific impacts arising from changes in temperature, precipitation and weather extremes (such as outlined in Section 3) are not well recognised. The potential for indirect climate risks to affect the sector in general and sites in particular, arising through international impacts on supply chains, or, more likely, through extreme weather impacts on critical infrastructure on which the sector depends (especially transport) is very poorly understood. This may be due in part to the fact that the waste sector is not directly included in some of the existing infrastructure resilience fora, which may limit information sharing. Overcoming this barrier will be critical for improving resilience to the interdependency risks in particular, as discussed in Section 4.

There is also a lack of understanding about the business case for increasing resilience to climate change in the waste sector. There is a perception in the sector that addressing climate risks will be more costly than not addressing the risks. Overcoming this barrier by providing waste operators with the necessary information will be an important step in encouraging action to address climate risks.

The issue of demonstrating the business case for adaptation is particularly important in the current economic climate. For example, if an elected member of a local council makes the decision to approve a more expensive, but more resilient site option, then they would likely be challenged by competing contractors and other stakeholder groups.

As demonstrated in the case studies in Sections 5.2 and 5.3, actions taken at waste sites for other reasons (e.g. to improve water efficiency or restore habitats) sometimes have the additional benefit of building resilience to climate change. Demonstrating these win-win opportunities to waste operators will help overcome the perception that adaptation is prohibitively expensive.

6.2.3 Physical barriers

The main physical barrier to adapting waste infrastructure to climate change is the limited amount of space available at many waste sites. Several of the adaptation options discussed in Section 6.1 would require increasing the size of waste sites to allow for features like extra water storage, multiple access routes onto the site, or additional storage space for waste. While designing flexible sites in this way is a good idea in terms of building climate resilience, it is not always practically possible due to space limitations.

This barrier also links with the difficulty in retrofitting existing sites. While regulations could specify that new sites should allow for additional storage space or multiple access routes, this is not always feasible for existing sites.

Another related issue is that climate factors such as flood risk are just some of the many factors which must be considered when deciding where a waste site will be located. One important consideration is that certain types of sites, such as ERF facilities, must be located in major areas of waste arisings. From a climate resilience perspective, building in an area prone to flooding is not advisable; however, sometimes it is necessary given other criteria. As demonstrated in the Newhaven case study in Section 5.1, it is possible to manage flood risk through innovative engineering solutions and choose a site location which meets other criteria such as proximity to transfer stations and waste arisings.

6.3 Including Adaptation in Waste Legislation

Many of the adaptation options discussed in Section 6.1 could potentially be implemented or at least encouraged through existing waste legislation, regulations and corresponding guidance documents. In order to explore this possibility further, we reviewed over 50 different pieces of legislation, regulation and guidance which affect major waste infrastructure to determine the extent to which adaptation is, or could be, included. The full list of documents reviewed is provided in Appendix 6.

The review has shown that although the word "adaptation" is not explicitly used in current waste legislation, there are several guidance documents which could be expanded, reworded slightly, or reinterpreted in order to address climate risks and adaptation options under existing legislation and regulation. There are different climate considerations which would need to be covered within waste legislation in order to ensure that the sector addresses climate risk and improves its adaptive capacity. These can be summarised as:

1. Climate considerations for the assessment of **site impacts on the surrounding environment** - climate change will change the environmental baseline which means that the impact a site has on the surrounding environment may change over time (even if there are no changes to operations on site). Although a certain level of gas or waste water emissions from a site may be acceptable under current climatic conditions, those same levels may not be acceptable under future climatic conditions. For example, most EfW and MBT facilities have stacks to emit treated gases/process air. Stack heights depend on local conditions such as wind speeds and air temperatures to consider how the plume will lift and disperse to ensure no health or environmental impacts. A shift in local climate could affect the validity of modelling and result in local impacts.

2. **Climate risks to site selection** – climate change means that the risk of climate impacts such as flooding, heatwaves, storm surges, etc. will change and, in many cases, increase. Although planning regulations currently require the assessment of risks to proposed waste sites, ideally they should assess both the current level of risk and future levels of risk under climate change (as relevant to the lifetime of the site). For example, although a particular location may be suitable for a landfill at present time, increased risk of flooding may mean that site is no longer suitable in 50 years' time.

3. **Climate impacts on site processes** – climate change could affect the **operation and performance** of a waste site. Most existing regulation focuses on the impact that facilities may have on the surrounding environment. However, the surrounding environment, including climate, can also impact on the working conditions and operational performance at a facility; this is relevant to some guidance documents. A future perspective in any initial assessment is therefore required, and regular re-assessments should be used to ensure processes are still optimal. For example, changing temperatures may mean that the best techniques for waste incineration may be different in the future from those preferred today, or, working conditions on site may be different under future conditions and require enhanced management.

6.3.1 Results

Table 7 provides a summary of the ways in which climate considerations could be addressed within existing waste legislation. The right hand column refers back to the three aspects identified above. The documents included in the table are those which provide the best opportunity to introduce climate risks and adaptation through minor amendments in the future.

Table 7: Linking existing legislation with adaptation

Legislation	Guidance	Climate Consideration
The Environmental Permitting (England & Wales) Regulations 2010 (as amended)	Environmental Permitting Guidance – Core Guidance For the Environmental Permitting (England and Wales) Regulations 2010 (Version 3.2 September 2011) Defra	1. Site impacts on surrounding environment 2. Climate risks to site selection
	How to comply with your Environmental Permit (EPR 1.00) (Version 4 April 2011) Environment Agency	1. Site impacts on surrounding environment 3. Climate impacts on site processes
	Horizontal Guidance Note H1 Overview document	1. Site impacts on surrounding environment
	Reference Document on the Best Available Techniques for Waste Incineration (August 2006) EC	3. Climate impacts on site processes
	Reference Document on the Best Available Techniques for Waste Treatments Industries (August 2006) EC	3. Climate impacts on site processes
Government Planning Policy Guidance (PPG) and Planning Policy Statements (PPS)	Planning Policy Statement 1: Delivering Sustainable Development (2005) ODPM	*Already address climate risk and adaptation*
	Planning Policy Statement 10: Planning for Sustainable Waste Management (March 2011) DCLG	

The following sections provide further information on key documents that could address these themes and cover climate risk and adaptation.

The Environmental Permitting (England & Wales) Regulations 2010 (as amended)

The guidance documents that correspond with the Environmental Permitting (England & Wales) Regulations 2010 provide the best opportunities to incorporate adaptation and introduce a more comprehensive assessment of climate risks to waste sites.

For example, *Environmental Permitting Guidance – Core Guidance for the Environmental Permitting (England & Wales) Regulations 2010* (Version 3.2 September 2011), includes several sections which cover the assessment of "the environmental risk of the proposals including the risk under both normal and abnormal operating conditions."[78] These sections on environmental risk could be expanded to account for risk under current climatic conditions and also risk under future climatic conditions. If the environmental baseline changes in the future, certain sites could pose additional risk to the surrounding environment through waste water emissions or gas emissions which are no longer acceptable under future climate conditions.

Similarly, *Horizontal Guidance Note H1*[79] includes several sections which could be expanded to address climate risks and adaptation as well. Section 6.15 specifies that the risk

[78] Available from: http://www.defra.gov.uk/publications/files/pb13560-ep2010guidance-110909.pdf
[79] Available from http://publications.environment-agency.gov.uk/PDF/GEHO0410BSHR-E-E.pdf

assessment must be based on the natural setting and the properties of the location – this should include an assessment of the possible future properties of the location as well to determine whether the location will still be appropriate in 20, 50 or 80 years' time, depending on the lifetime of the site.

Guidance document *How to comply with your Environmental Permit* (EPR 1.00) provides information on ensuring that an adequate accident management plan is in place. The section specifies that the management plan should identify events or failures that could damage the environment, for example flooding, and assess how likely they are to happen and the potential environmental consequences. This section could certainly be expanded to also cover future (as well as current) climate risk and provide more guidance on the sorts of climate impacts that may increase in frequency in the future, thereby resulting in accidents with environmental consequences.

The two BREF documents, *Reference Document on the Best Available Techniques for Waste Incineration* (August 2006) and *Reference Document on the Best Available Techniques for Waste Treatments Industries* (August 2006), are very relevant to the third point on understanding climate impacts on site processes. Section 4.3.9 of the *Reference Document on the Best Available Techniques for Waste Incineration* describes how colder temperatures yield better process efficiency; if average temperatures increase as a result of climate change then it is likely the best available techniques for waste incineration could need to be amended. Both of these guidance documents are due to be updated soon – waste incineration will be updated in 2013, waste treatments industries at the end of 2012[80]. This could provide an excellent opportunity to encourage the EU to add emphasis to these documents to enable operators to see that climate is changing and they should consider this in the selection of techniques and practices over the longer term.

Planning Policy Statements

This review of waste legislation has also noted that climate change and adaptation are explicitly covered in spatial planning documentation, in particular Planning Policy Statement 1 (PPS1) and Planning Policy Statement 10 (PPS10). Although these documents would apply to waste infrastructure planning, it would be logical to aim for consistent coverage of climate change risks across other waste sector legislation and regulation as well so that activities or potential impacts that fall under either the planning or permitting regime are captured.

6.3.2 Review conclusions

In summary, the review of existing legislation, regulation, and guidance documents indicates that there are several places (specifically within the guidance documents listed in Table 7) where amendments could be made to better incorporate the assessment of climate risks into existing legislation.

Not surprisingly, it is unlikely that documents that have recently been updated will be updated again soon, even to take account of climate risk. However, documents such as the BREF documents which will be updated soon should be noted so that wording to cover climate risk and adaptation could be added to the revised documents.

The incorporation of climate risk/adaptation activities could also be relevant to the development of the 'National Waste Management Plan' for England which is due to be delivered by spring 2013.[81]

[80] http://eippcb.jrc.es/reference/

[81] National Infrastructure Plan 2011, available from: http://cdn.hm-treasury.gov.uk/national_infrastructure_plan291111.pdf

7 Conclusions and recommendations

7.1 Conclusions

This study has found that:

- Climate impacts affect waste infrastructure at a local level, and are unlikely to present a *simultaneous* threat to all waste infrastructure nationwide.
- England's waste infrastructure is already under pressure in many places, and vulnerable to weather-related hazards.
- Increases in the frequency and severity of extreme weather, rather than gradual trends in averages, present the greatest challenge from climate change.
- Technology is not a limiting factor; information, and appropriate incentives and drivers to enhance resilience appear to be lacking.
- All waste infrastructure is dependent upon transport links.
- Consequences of climate impacts in the sector go beyond the direct physical problems.
- Climate impacts occurring outside the UK could also have a significant effect on the UK's waste sector.
- The stakeholder landscape is extremely complex, and progress in climate resilience will require comprehensive and cooperative action between central government, private sector, and local authorities.
- Innovative solutions which enhance climate resilience are already being demonstrated in some new waste infrastructure projects.
- Resilience measures do not necessarily imply increased cost.
- Climate risk and resilience could be integrated into existing enterprise risk management processes for large waste infrastructure companies.

England's waste infrastructure is already under pressure in many places and vulnerable to weather-related hazards. As discussed in Section 3.2, there are a significant number of waste sites that are located in areas prone to flooding; this situation is likely to become more serious in the future, requiring management.

Increases in the frequency and severity of extreme weather, rather than gradual trends in averages, present the greatest challenge from climate change. As discussed in Section 3, there are multiple ways in which weather can affect waste infrastructure and related processes. Extreme weather events (in particular, flood events, heatwaves, and winter storms) present more of a problem than gradual changes in climate variables.

Climate impacts affect waste infrastructure at a local level, and are unlikely to present a *simultaneous* threat to all waste infrastructure nationwide. However, there is potential for some cascading of risks beyond the immediate geographical area affected. While climate change is unlikely to present a very significant risk to waste infrastructure at the national level, climate impacts on waste infrastructure at the local level may have much more disruptive effects. This demonstrates the importance of contingency planning and flexibility, and the role of the procurement process at the Local Authority level to address these issues. For example, if a key regional facility is closed or inaccessible as a result of climate impacts, how easily can waste streams be diverted to alternative facilities, and what would be any additional related costs?

Technology is not a limiting factor; rather, information, and appropriate incentives and drivers to enhance resilience appear to be lacking. In general, there is not a technology issue around adaptation for waste infrastructure in the UK. A wide range of appropriate technologies exist, and lessons can be learned from other countries where needed. Some of the larger multinational waste companies are able to translate experience from different countries into the UK. Many technologies are still in a phase of rapid development, and there are opportunities to incorporate innovative design features to enhance resilience. However, there is still a need to do more to build climate resilience in the waste sector. As discussed in Section 5, these activities could include awareness-raising, building the evidence base, building adaptation into the procurement process, etc.

All waste infrastructure is dependent upon transport links: climate impacts on transport may present higher risk than direct impacts in some cases. In general, the issue of interdependencies with other sectors is a particularly important one for the waste sector, which has critical links with water and energy infrastructure as well as transportation infrastructure.

Consequences of climate impacts in the sector go beyond the direct physical problems and can result in increases in operating costs, health and safety problems for workers and people in neighbouring communities, a reduction in the availability or quality of services, or a negative impact on the operator's reputation.

Climate impacts occurring outside the UK could also have a significant effect on the UK's waste sector. This means that we can no longer view England's provision of waste management as independent from the rest of the world. There is little evidence that major infrastructure suppliers currently address these issues – this is understandable as it is difficult to quantify or fully understand the indirect consequences that climate impacts abroad may have on the waste sector in the UK.

The stakeholder landscape is extremely complex, and progress in climate resilience will require comprehensive and cooperative action between central government, private sector, and local authorities. Wider stakeholders including the financial sector (investors and insurers), business and industry, and local communities may also have influential roles in encouraging climate resilience.

Innovative solutions which enhance climate resilience are already being demonstrated in some new waste infrastructure projects as demonstrated by the case studies conducted through this study. However, it is unlikely that such solutions will ever be driven by climate requirements alone.

Resilience measures do not necessarily imply increased cost, and in many cases can provide economic (process) efficiencies and additional environmental and sustainability benefits.

Climate risk and resilience could be (and to an extent already are) integrated into existing enterprise risk management processes for large waste infrastructure companies. The larger waste operators already undertake extensive risk assessments of new sites in order to minimise the risk that future weather events may have on those sites. What is less certain is whether such risk assessments cover the full range of potential climate impacts, and whether smaller waste companies are undertaking any similar risk assessments: it is likely that SMEs will require additional support and incentives to do so.

7.2 Roles and responsibilities

Section 2 illustrated the complex stakeholder landscape surrounding waste infrastructure. While all stakeholders can to an extent drive an appetite for increased resilience, the key actors needed to introduce a step change in approaches to climate resilience are 1) private sector infrastructure owners/operators 2) local authority waste service procurers 3) the industry regulator (Environment Agency) and 4) national policy-makers (Defra/DCLG).

A collaborative approach will be required. In general terms there is better awareness and preparedness in respect of flood risk, particularly among operators who have had sites affected by flooding. Conversely there is relatively little awareness or preparedness in relation to other climate variables or from operators who are yet to be affected. It is likely that larger operators are more aware and better prepared than smaller operators, particularly for more immediate and obvious threats such as flooding.

By addressing the risks of climate change, in infrastructure design, operations and contingency planning, the private sector will benefit from more climate resilient infrastructure, enhanced security of supply and/or service delivery and reduced costs[82]. However the nature of climate change risks is that they generate social and economic externalities, which the private sector may not always take fully into account. In particular, in the absence of legislative or regulatory intervention, private sector companies may be prepared to live with a level of climate change risk that is unacceptable to society[83].

With national policy lead for both adapting to climate change and waste, Defra has the key role of ensuring that new waste policy appropriately promotes the need for climate resilient infrastructure, and of removing policy conflicts. The provision of relevant information is also needed. Two key opportunities to emphasise climate resilience in waste infrastructure in national policy documents are coming up, with the National Adaptation Programme expected in late 2012 and the National Waste Management Plan expected in 2013.

The Environment Agency has a role to play in enhancing the delivery of climate resilience in the waste sector, primarily through its role in permitting. As the industry regulator for the waste sector in England it has interaction and communication with every regulated site. The Agency has also recently taken on an enhanced role in adaptation on behalf of Defra. The Agency therefore has an opportunity to bring practical guidance to help the waste industry adapt to climate change impacts.

In its Adaptation Reporting Power report, the Environment Agency identifies actions to ensure that the sites it regulates manage their climate risks[84]. One of these actions is to investigate levels of awareness of risks and working with regulated businesses to help them adapt. Indeed it is important that waste management policy makers and regulators are engaged in on-going dialogue with climate change policy makers to develop effective policy responses.

7.3 Recommendations for action

The study has identified recommendations in the following areas:

- Research and data development
- Policy development
- Awareness-raising and engagement within the waste sector
- Enhancing resilience of waste infrastructure
- Engagement beyond the waste sector

These recommendations are summarised in the table below, which also suggests which actors should be involved in each.

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[82] HM Government (May 2011) Climate Resilient Infrastructure: Preparing for a changing climate.
[83] Price Waterhouse Cooper and Defra (2010) Adapting to climate change in the infrastructure sectors: Maintaining robust and resilient infrastructure systems in the energy, transport, water and ICT sectors
[84] Environment Agency Adaptation Reporting Power http://publications.environment-agency.gov.uk/PDF/GEHO0111BTJW-E-E.pdf

Table 8: Summary Recommendations

Recommendation	Policy (Central Government)	Environment Agency	Local authorities (procurers and advisers)	Infrastructure owners / operators	Research community & consultants
Research and data development					
Conduct an evidence review of the impact of past weather events on waste infrastructure.	✓		✓		✓
Conduct further research on the potential outcome of climate impacts (e.g. fire risk, changes to waste composition).					✓
Undertake vulnerability mapping to provide more detail on the current and future vulnerability of (current and planned) regulated sites to physical climate impacts.		✓	✓		✓
Examine the business case for adaptation in the waste sector.	✓			✓	✓
Conduct further research on international impacts, integrating potential climate impacts into a broader study of future global markets for key waste products.	✓				✓
Policy development					
Conduct a policy study to review the key stakeholder relationships and procurement/service provision models.	✓		✓		✓
In the new waste strategy, include climate resilience alongside low carbon as two major drivers of future waste infrastructure.	✓	✓			
Explore the way in which the spatial planning process for major waste infrastructure already does, or could do more to, ensure appropriate consideration of future climate risks.	✓	✓			
Consider the waste sector more fully under the infrastructure theme of the National Adaptation Programme.	✓	✓			
Consider the benefits of applying the Adaptation Reporting Power within the waste sector.	✓	✓			
Awareness-raising and engagement within the waste sector					
Develop guidance for the waste sector, aimed at sites operators, and examples of adaptation opportunities.	✓	✓			✓
Undertake activities to engage with and raise awareness across waste sector of the potential impacts of climate change.		✓			✓
Establish what effort is needed to engage appropriately with SMEs.		✓		✓	✓
Use existing fora to engage with facilities managers on a couple of key topics such as water use in the sector, the challenges of retrofitting, etc. This is potentially an action for waste sector trade bodies.			✓	✓	
Enhancing resilience of waste infrastructure					
Extend facility level contingency and emergency recovery plans to cover a full range of weather events.			✓	✓	

Recommendation	Policy (Central Government)	Environment Agency	Local authorities (procurers and advisers)	Infrastructure owners / operators	Research community & consultants
Use the procurement process as an opportunity to require innovation in climate resilient solutions and flexible contingency arrangements.			✓	✓	✓
Integrate climate risks within enterprise risk management and corporate responsibility programmes.				✓	
Take advantage of immediate opportunities to introduce low-cost, win-win, or no-regret measures to enhance site level management of climate risks.				✓	
Consider how the waste sector may be drawn into the Critical Infrastructure Resilience Programme in the future.	✓				
Develop a simple screening tool for vulnerability assessment at site level.	✓	✓			✓
Engagement beyond the waste sector					
Include the waste sector within future cross-Government work exploring interdependencies and climate resilience.	✓				
Improve the coordination of emergency response and local authority resilience plans with waste infrastructure owners / operators.		✓	✓	✓	

We offer the following recommendations for research and data development:

- Conduct an evidence review of the impacts of past weather events on waste infrastructure in order to improve the monitoring of site-level impacts. This could involve building up the regional-level data relevant to Local Authority partnership procurement or linking with the Local Climate Impacts Profile (LCLIP) tool.[85]
- Additional research is needed on specific issues where there is disagreement over the potential outcome of climate impacts. Such issues identified during this study include whether climate change will significantly increase the risk of fire in waste; also, whether climate change will affect future waste composition (and whether that affect could be detected alongside other drivers).
- Vulnerability mapping (potentially GIS-based) would be useful to provide more detail on the current and future vulnerability of (current and planned) regulated sites to physical climate impacts. This would be particularly useful for assessing the vulnerability to fluvial, pluvial, or coastal flooding.
- Research is needed (perhaps using on a case study approach) to assess the business case for adaptation in the waste sector and the possible costs of adaptation.
- Further research is needed on the international impacts; this could include integrating potential climate impacts into a broader study of future global markets for key waste products.

[85] More information available from http://www.ukcip.org.uk/lclip/

We offer the following recommendations on policy development:

- Conduct a policy study to review the key stakeholder relationships and procurement/service provision models in the context of enhancing climate resilience of waste infrastructure. This should include reviewing and understanding the role of government, the regulator, LAs, the private sector, and so on, in the waste sector.
- New waste strategy should include building climate resilience alongside low carbon as two major drivers of future waste infrastructure.
- Commission a study to explore the way in which the spatial planning process for major infrastructure already does, or could do more to, ensure appropriate consideration of future climate risks. The case studies included in this report have demonstrated that the spatial planning process is a significant tool in the waste sector – is it being used to greatest effect?
- The National Adaptation Programme is being drafted during 2012 and should cover the waste sector, even though it is not covered in the Climate Change Risk Assessment (CCRA).
- Plans for the future use of the Adaptation Reporting Power should consider the benefits of applying it within the waste sector to provide the opportunity to raise awareness of adaptation and build adaptive capacity among waste infrastructure owner/operators.

We offer the following recommendations on awareness-raising and engagement within the waste sector:

- The development and publication of adaptation guidance for the sector would help to raise awareness of the issue. This would build on the findings of this study and would be aimed at sites operators to provide guidance on: the potential risks of climate change, a recommended approach which infrastructure owner/operators can adopt to build climate resilience, and examples of adaptation opportunities.
- More activities are needed to engage with and raise awareness across waste infrastructure operators of the potential impacts of climate change; this could particularly look to use the Environment Agency's enhanced delivery role in adaptation. Communication should focus on the themes that have been identified in this study – using the language of sustainability, efficiency, opportunity for enhanced resilience, etc.
- Specific effort is needed to engage appropriately with SMEs, through existing channels. This could include combining advice on climate resilience with broader advice on sustainability, resource efficiency, and so on.
- Use existing fora, workshops or training events to engage with facilities managers on a couple of key topics such as water use in the sector, the challenges of retrofitting, etc. This is potentially an action for waste sector trade bodies.

We offer the following recommendations on enhancing the climate resilience of waste infrastructure:

- Facility level contingency and emergency recovery plans should be extended to cover a full range of weather events and to consider climate change.
- Local Authorities should use the procurement process and specification as an opportunity to require (or at least encourage) innovation in climate resilient solutions and flexible contingency arrangements.
- Large waste companies should integrate climate risks within enterprise risk management and corporate responsibility programmes. This could include

integrating with existing corporate responsibility, environmental risk assessments, and health and safety risk strategies.

- At the individual facility level, operators should take advantage of the immediate opportunities to introduce low-cost, win-win, or no-regret measures to enhance site level management of climate risks. For example, this could include having more enclosed containers or implementing changes in site management practices. Operators should also start designing in measures which bring multiple benefits, including enhanced climate resilience, for future development.
- Central and Local Government should consider how the waste sector may be drawn into the Critical Infrastructure Resilience Programme in the future, alongside other national infrastructure. This could include increasing the involvement of waste infrastructure owners/operators in local resilience planning fora.
- Develop a simple screening tool (perhaps available via WRAP or ESA trade association website) that would allow site operators to conduct a vulnerability assessment at the site level – this could be based on the asset metrics approach used in this study.

We offer the following recommendations on engagement beyond the waste sector:

- The waste sector should be included within future cross-Government work exploring interdependencies and climate resilience. In particular, this should focus on the energy-waste relationship (given growing importance of this) and on transport-waste links.
- There is a need for improved coordination of emergency response and local authority resilience plans with waste infrastructure owners / operators – to what extent can large waste facilities make positive contributions to local communities in enhancing resilience?

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Appendices

Appendix 1: Glossary

Appendix 2: Additional information on the waste sector in England

Appendix 3: Additional information on climate change in the UK

Appendix 4: Previous literature on climate impacts on waste infrastructure

Appendix 5: Additional Information on the East of England landfills case study

Appendix 6: Review of waste regulations, legislation and guidance documents

Appendix 1: Glossary

Glossary: Adaptation and Waste terms and definitions

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Advanced Thermal Treatment (ATT) Gasification and pyrolysis are main technologies covered under the ATT description. Gasification is the conversion of a solid or liquid feedstock into a gas by partial oxidation under the application of heat. Pyrolysis is thermal degradation of a material in the complete absence of an oxidising agent (e.g. air or oxygen). This results in the production of gas, liquid and char. These products can have several potential uses depending on the nature of the feedstock, however for waste based feed stocks the most likely use is as a fuel for energy generation.

Anaerobic Digestion (AD): The process works by bacteria which thrive in the absence of oxygen breaking down the bio-degradable fraction of the waste to produce a stable residue. AD is carried out in a closed vessel or vessels. Main outputs are biogas (energy source) and digestate (possible soil conditioner).

Autoclaving: A mechanical method of treating waste. The wastes are 'steam cleaned' and physically degraded at a high temperature in a sealed container similar to a pressure cooker. The aim of the autoclaving process is to produce a cellulose product (paper/putrescible pulp) from the waste that can be used as a fuel for combustion. Inert materials such as glass, ferrous and non-ferrous metals can be separated for recycling.

Civic Amenity (CA) Site / Household Waste Recycling Centre (HWRC): Local waste recycling and disposal site. Waste delivered by public (can be private also) and placed in relevant skips i.e. green waste, rubble, landfill, wood, paper or oil, before onward transport to treatment/disposal.

Climate: Refers to the average weather experienced in a region over a long period, typically at least 30 years. This includes temperature, wind and rainfall patterns.

Climate change: Refers to any change in climate over time, whether due to natural variability or as a result of human activity.

Climate impact: A specific change in a system caused by its exposure to the climate. Impacts may be harmful (impact) or beneficial (opportunity).

Climate resilience: *Resilience* to *climate impacts*. The ability of a system to absorb climate-related disturbances while retaining the same basic structure and ways of functioning.

Critical national infrastructure: Those infrastructure assets (physical or electronic) that are vital to the continued delivery and integrity of the essential services upon which the UK relies, the loss or compromise of which would lead to severe economic or social consequences or to loss of life.

Composting: The aerobic decomposition by micro-organisms of biodegradable material to produce a residue called compost. Two main types exist: windrow/open and in-vessel composting (IVC).

Energy from Waste (EfW): Energy recovery is the combustion of waste under controlled conditions in which the heat released (energy) is recovered for a beneficial purpose. This may be to provide steam or hot water for industrial or domestic users, or for electricity generation. Combined heat and power (CHP) energy recovery facilities provide both heat and electricity at very high efficiencies.

Landfill: A disposal site where solid waste is buried. Modern landfills are often lined with layers of absorbent material and sheets of plastic to keep pollutants from leaking into the soil and water. Landfill can be inert, non-inert or hazardous depending on the material accepted.

Materials Recovery/Recycling Facility (MRF): Mixed waste stream (usually co-mingle dry recyclables) is sorted using a range of technologies (magnets, eddy current separator, infra-red, trammels, air classifiers) to separate the materials into different streams, usually paper, plastic, metal, glass and textiles.

Mechanical Biological Treatment (MBT) / Biological Mechanical Treatment (BMT): A generic term that encompasses a wide range of technologies that aim to process waste by a mixture of biological treatment and mechanical separation. In MBT the biodegradable fraction is treated post sorting, whilst in BMT the biological treatment or a thermal treatment such as autoclaving or thermal drying of the waste in undertaken prior to the sorting of the waste. Main outputs from the various MBT/BMT processes are recyclables (paper, plastic, metal), organic rich fraction (composted or digested to generate a compost product), fuel fraction (Refuse derived fuel (RDF) or solid recovered fuel (SRF)) combusted on or off site) and a residue fraction (landfilled).

National Infrastructure: Those facilities, systems, sites and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the UK depends.

Resilience: An infrastructure element is resilient when, although dependent on other systems, it can continue to function effectively when one or more of those dependencies are broken. It can do this because there are multiple paths to enable its operation such that no single dependency failure can prevent its operation. "The ability of a system or organisation to withstand and recover from adversity". A resilient organisation is one that is still able to achieve its core objectives in the face of adversity through a combination of measures (Cabinet Office, 2010)

Risk Hazards: Events that could have an impact on exposure to danger or loss. Climate risks are additional risk to investments (such as buildings and infrastructure) and actions from potential *climate impacts*.

Transfer Station: Waste delivered to site and stored in bays before been bulked up for onward transport. Can contain some basic sorting equipment (metal recovery or aggregate sorting). Can cover range of transport methods e.g. road, water or rail.

UKCP09 weather generator and threshold detector: A downscaling tool that can be used to generate statistically plausible daily and hourly time series comprised of set of climate variables at a 5 km resolution that are consistent with the underlying 25 km resolution climate projections.

Vulnerability: The degree to which systems are susceptible to, and unable to cope with, adverse impacts.

Weather: Refers to the state of the atmosphere as experienced now, with regard to temperature, cloudiness, rainfall, wind, and other meteorological conditions.

Waste transport options

Road: Main form of transport in waste sector and almost always primary method for collection from waste sources (household, or businesses). Typical road vehicles are RCV's (refuse collection vehicles – used for residual, co-mingles dry recyclables, food and green waste), kerbside sorting vehicles (dry recyclables), hook lift (moves large containers typically from CA/bring sites) and bulk haulage vehicles (large arctic trucks).

Rail: ISO containers often used in combination with rail network to move waste and processed materials i.e. SRF/RDF fuel. Often moving waste from conurbations (high waste arising and minimal treatment capacity) to more rural areas where treatment facilities often sited.

Water: Inland barges for moving waste along rivers (predominantly in London) to treatment facilities. Cargo ships moving products (plastic film, SRF fuel) from facilities to other countries worldwide. China is a significant importer. Cannot ship raw untreated waste to other countries.

Appendix 2 – Additional information on the waste sector in England

Key legislation affecting waste sector in England

EU Directives

Much of the waste legislation in the UK is directed by the European Commission, and includes:

- Revised Waste Framework Directive (2008/98/EC)
  - recycling targets, strict hierarchy, end-of-waste
- Landfill Directive (1999/31/EC): BMW diversion targets
- Producer Responsibility Directives for waste streams:
  - Packaging and Packaging Waste Directive (94/62/EC)
  - WEEE Directive (2002/96/EC)
  - ELV Directive (2000/53/EC)
  - Batteries Directive (2006/66/EC)
- Waste Shipments Regulation (1013/2006)

English legislation

Waste is a devolved issue in the UK and each of the four devolved administrations has different legislation to enforce and comply with. Key English legislation includes:

- The Environmental Protection Act 1990
- The Controlled Waste Regulations 1992 (to be replaced) (covers Duty of Care, Waste Management licensing, waste collection)
- The Packaging Regulations 1997 (as amended)
- The Waste and Emissions Trading Act 2003 (set up LATS)
- The Household Waste Recycling Act 2003 (requires all LAs to collect 2+ materials for recycling by end 2010)
- The Environmental Permitting (England & Wales) Regulations 2010 (integrates WM licensing & PPC)
- The Waste (E&W) Regulations 2011

The export of waste to other countries is controlled by the Transfrontier Shipment of Waste (Amendment) Regulations 2008.

Environmental Permitting (England & Wales) Regulations 2010

English legislation includes requirements for permitting and licensing of waste management facilities. The Controlled Waste Regulations 1992 (to be replaced) specify the need for Duty of Care and Waste Management licensing. The Environmental Permitting (England & Wales) Regulations 2010 (EP Regulations) integrate Waste Management licensing and Pollution Prevention and Control. These set out:

- which facilities need an environmental permit ("regulated facilities") or need to be registered as exempt;
- how to apply for, change, extend and surrender a permit and register an exemption;
- how the environmental protection requirements set out by European Directives and national policy are implemented within the conditions of the permits;
- a streamlined permitting system which uses standard rules;
- powers and functions of the regulators, the Secretary of State and the Welsh Assembly Government;
- transition to the new regime; and
- provisions for appeals against permitting decisions

The following sections provide a short summary of the main waste technologies currently in use. All are dependent on transport of waste on and off site, and almost all depend on energy for operations (though this may in some cases be generated on site). Most of the numbers of the main technologies come from Defra's Waste Infrastructure Delivery Programme[86] (WIPD) records, or the Government's Anaerobic Digestion Strategy and Action Plan (Defra and DECC, 2011).

[86] http://www.defra.gov.uk/environment/waste/local-authorities/widp/

Civic Amenity sites and Household Waste Recycling Centres

These provide local waste recycling and disposal facilities. Waste is usually delivered by the general public (can be private also) and separated into different skips (such as for green waste, rubble, landfill, wood, paper or oil) before onward transport to treatment or disposal. Facilities are typically found in every local authority and range in size from one or two skips to large modern multi-skip covered centres. The sites are operated privately (by small, medium or large companies) or by the local authority.

Materials Recovery/Recycling Facilities

Mixed waste stream (usually co-mingled dry recyclables) is sorted using a range of technologies (magnets, eddy current separator, infra-red, trommels, air classifiers) to separate the materials into different streams, typically paper, plastic, metal, glass and textiles. The range of materials collected is increasing as sorting technologies improve and markets for materials develop. Increasingly different collection methods are being considered to collect greater quantities and types of dry recyclables, including co-mingled collections and segregated collections. The importance of MRFs to sort co-mingled collections before the onward journey to recyclate processing facilities is therefore increasing.

The number of MRF facilities is increasing with the current number operational in the region of 100 and another 40 in the pipe line (proposal to commissioning). They tend to be owned and operated by medium to large private companies. Sites tend to operate at the 30 to 100 ktpa capacity range although there are some larger facilities within the UK (such as the Crayford MRF, which processes 500 ktpa of recyclate). Technology providers for the equipment can include international companies, particularly from the US.

Mechanical Biological Treatment

These encompass a wide range of technologies that aim to process waste by a mixture of biological treatment and mechanical separation. In MBT the biodegradable fraction is treated after mechanical sorting. Depending on the technology type, significant water is likely to be required. Main outputs from the various MBT processes are recyclables (paper, plastic, metal), organic rich fraction (composted or digested to generate a compost product), fuel fraction (refuse derived fuel (RDF) or solid recovered fuel (SRF)) combusted on or off site and a residue fraction (typically put in landfill).

The number of MBT facilities is increasing with around 11 currently operational in England, but a further 35 expected (in proposal to commissioning stage). They tend to be owned and operated by medium to large private companies. Sites tend to operate at the 50 to 350 ktpa capacity range. Technology providers for the equipment can include international companies, particularly from Europe where the technology is more established. The technology is developing rapidly as increased material separation is achieved and markets for the products are established.

Autoclaving/Mechanical heat treatment (MHT) facilities

In autoclaving facilities, the wastes are ‘steam cleaned’ and physically degraded at a high temperature in a sealed container similar to a pressure cooker. The aim of the autoclaving process is to produce a cellulose product (paper/putrescible pulp) from the waste that can be used as a fuel for combustion. Inert materials such as glass, ferrous and non-ferrous metals can be separated for recycling. There are currently 2 facilities operational in the England (in Rotherham and Wakefield), but a further 8 are in the pipe line (proposal to commissioning). They tend to be owned and operated by medium to large private companies. The technology also requires significant water to operate. Sites tend to operate at the 50 to 100vktpa capacity range although larger sites of around 350ktpa are being considered.

Composting (including open and in-vessel plants)

Composting involves the aerobic decomposition by micro-organisms of biodegradable material to produce a residue. Two main types exist: windrow/open and in-vessel composting (IVC), and depending on the technology type, water is likely to be required as an input. The composting process is most effective when the oxygen, moisture, carbon and nitrogen are in balance. When the ratios and balances are significantly out of balance the composting process becomes inhibited and slows down and potentially reduces the quality of the end product. Around 70 composting facilities are operational in the UK, but a further 20 are in planning (proposal to commissioning), and they can be owned and operated by private companies of any size. Sites tend to operate at the 10 to 50 ktpa capacity range although larger sites of around 120 ktpa are operational.

Anaerobic Digestion plants

Anaerobic digestion (AD) is the breakdown of organic material in the absence of air. This process turns residues from livestock farming, organic waste and food processing industries into three products: biogas (rich in methane) which can be used to generate green electricity and heat, fibre which can be used as a nutrient-rich soil conditioner, and digestate slurry which can be used as high quality liquid fertiliser on agricultural land. Wet AD requires the addition of water for the treatment process.

The source segregation of food waste is increasing in England as Local Authorities look to divert biodegradable waste from landfill (driven principally by the increasing landfill tax), and in this regard AD is strongly advocated in the National Infrastructure Plan (2010).

There are around 54 (as of April 2011) major AD waste processing facilities operational in the UK but a further 50 are planned (proposal to commissioning) (Defra and DECC, 2011). They can be owned and operated by private companies ranging in size from small agri-businesses to large multinationals. Sites tend to operate at the 20 to 50ktpa capacity range although larger sites of around 165ktpa planned.

Advanced Thermal Treatment plants

Gasification and pyrolysis are the main technologies considered as ATT. Gasification is the conversion of a solid or liquid feedstock into a gas by partial oxidation under the application of heat. Pyrolysis is thermal degradation of a material in the complete absence of an oxidising agent (e.g. air or oxygen). Water may be required in some processes. End products from ATT are gas, liquid and char. These have several potential uses, depending on the nature of the feedstock, though for waste-based feedstocks the most likely end-use is as a fuel for energy generation. There is only one large scale facility operational (in the Isle of Wight) with a number of trial plants also operations in England. A further 20 are in the pipe line (proposal to commissioning). They tend to be owned and operated by medium to large private companies. Sites tend to operate at the 80 to 150ktpa capacity range although larger sites have planning permission. The technology suppliers for ATT tend to be located outside the UK.

Energy from Waste plants

Energy recovery is the combustion of waste under controlled conditions in which the heat released (energy) is recovered for a beneficial purpose. This may be to provide steam or hot water for industrial or domestic users, or for electricity generation. Combined heat and power (CHP) energy recovery facilities provide both heat and electricity at potentially high efficiencies. For some processes, large volumes of water are likely to be required.

Recovering energy from waste is commonly known as energy from waste (EfW). EfW will enable more sustainable use of material resources (‘other recovery’ in the waste hierarchy diagram) when used to avoid disposal and is an important trend in the waste sector for the coming years. When recovering energy from residual waste it is only partially renewable due to it containing fossil based materials. Central government policy widely recognises the role that EfW, as part of a sustainable waste strategy, has to play in meeting renewable energy targets. Therefore it will be important to ensure EfW plants are able to adapt to a changing climate.

There are approximately 20 EfW facilities currently operating in the England, but a further 80 are in planning stages, 50 of which are in the process from proposal to commissioning, and these facilities are owned and operated by medium to large private companies. Sites tend to operate at the 100 to 450 ktpa capacity range although larger sites (up to 800 ktpa) are planned or becoming operational. The technology suppliers tend to be outside of the UK.

Landfill sites

Landfill provides the final option for material that cannot be recycled, with burial the last means of disposal. Modern landfills are highly engineered, including layers of specialist materials to keep pollutants from leaking into the soil and water. Methane capture systems are also in place which reduced the greenhouse gas emissions and in some cases generates electricity. Landfill can be inert, non-inert or hazardous depending on the material accepted. Landfill sites are found across the country and they tend to be owned and operated by medium to large private companies.

Waste sites in England (taken from AEA's database of large waste sites)

	Major waste treatment sites in England	Waste technology type								
Number of large waste sites in England	**Status category**	**Anaerobic digestion**	**Advanced thermal techniques**	**Combustion**	**Compost**	**Mechanical and biological treatment**	**Mechanical heat treatment**	**Other**	**Materials recovery facilities / waste transfer stations**	**All technologies**
England	Operational	27	2	32	45	11	2	31	70	220
	Planned	18	22	58	13	26	9	12	10	168
	Closed	0	0	0	0	0	1	3	0	4
	Total	**45**	**24**	**90**	**58**	**37**	**12**	**46**	**80**	**392**
South West	Operational	7	1	2	6	2	0	1	1	20
	Planned	3	3	9	3	3	0	0	0	21
	Closed	0	0	0	0	0	0	0	0	0
	Total South West	**10**	**4**	**11**	**9**	**5**	**0**	**1**	**1**	**41**
South East	Operational	2	0	4	6	0	0	4	15	31
	Planned	3	3	9	2	2	0	1	2	22
	Closed	0	0	0	0	0	0	1	0	1
	Total South East	**5**	**3**	**13**	**8**	**2**	**0**	**6**	**17**	**54**
London	Operational	3	1	2	2	2	0	2	7	19
	Planned	0	2	1	0	2	2	2	2	11
	Closed	0	0	0	0	0	0	0	0	0
	Total London	**3**	**3**	**3**	**2**	**4**	**2**	**4**	**9**	**30**
East of England	Operational	3	0	3	13	0	0	1	12	32
	Planned	5	1	7	4	2	1	1	1	22
	Closed	0	0	0	0	0	0	1	0	1
	Total East of England	**8**	**1**	**10**	**17**	**2**	**1**	**3**	**13**	**55**
East Midlands	Operational	5	0	1	5	2	0	11	10	34
	Planned	1	3	7	0	2	0	0	1	14
	Closed	0	0	0	0	0	0	0	0	0
	Total East Midlands	**6**	**3**	**8**	**5**	**4**	**0**	**11**	**11**	**48**

	Major waste treatment sites in England	Waste technology type								
Number of large waste sites in England	**Status category**	**Anaerobic digestion**	**Advanced thermal techniques**	**Combustion**	**Compost**	**Mechanical and biological treatment**	**Mechanical heat treatment**	**Other**	**Materials recovery facilities / waste transfer stations**	**All technologies**
West Midlands	Operational	4	0	5	3	0	0	5	4	21
	Planned	3	1	6	1	3	2	1	2	19
	Closed	0	0	0	0	0	0	0	0	0
	Total West Midlands	**7**	**1**	**11**	**4**	**3**	**2**	**6**	**6**	**40**
Yorkshire & Humberside	Operational	3	0	4	5	1	2	0	9	24
	Planned	2	5	13	1	2	2	2	2	29
	Closed	0	0	0	0	0	0	0	0	0
	Total Yorkshire & Humberside	**5**	**5**	**17**	**6**	**3**	**4**	**2**	**11**	**53**
North West	Operational	0	0	9	4	1	0	3	9	26
	Planned	1	2	3	2	9	0	3	0	20
	Closed	0	0	0	0	0	1	1	0	2
	Total North West	**1**	**2**	**12**	**6**	**10**	**1**	**7**	**9**	**48**
North East	Operational	0	0	2	1	3	0	4	3	13
	Planned	0	2	3	0	1	2	2	0	10
	Closed	0	0	0	0	0	0	0	0	0
	Total North East	**0**	**2**	**5**	**1**	**4**	**2**	**6**	**3**	**23**

	Status category	Anaerobic digestion	Advanced thermal techniques (energy from waste)	Combustion	Compost	Mechanical and biological treatment	Mechanical heat treatment	Other	Materials recovery facilities/waste transfer stations	All technologies	All compared to England
Total for Southern and Mid England	Operational	24	2	17	35	6	0	24	49	157	71%
	Planned	15	13	39	10	14	5	5	8	109	65%
	Closed	0	0	0	0	0	0	2	0	2	50%
	Total	**39**	**15**	**56**	**45**	**20**	**5**	**31**	**57**	**268**	**68%**

N.B *Other* includes: covers a wide range of other plants, including biomass burners, cement kilns, bottom ash reprocessors and material-specific recyclers, treating materials such as plastics, wood and nappies.

Asset metric vulnerability screening of technology types

Waste asset screening matrix

Summary matrix

			Waste asset or process										
			Advanced Thermal Treatment (ATT) Gasification and pyrolysis	Anaerobic Digestion (AD)	Autoclaving	Civic Amenity (CA) Site / Household Waste Recycling Centre (HWRC)	Composting - enclosed	Composting - Windrow	Energy from Waste	Landfill	Materials Recovery/Recycling Facility	Mechanical Biological Treatment (MBT / BMT)	Transfer Station
Non-climate criteria	Physical and economic	What is the lifetime of the technology?	✓✓	✓✓	✓✓	✓✓	✓	✓	✓✓	✓✓✓	✓✓	✓✓	✓✓
		Gate fee (£/tonne)	✓✓✓	✓✓	✓✓✓	✓	✓	✓	✓✓✓	✓✓✓	✓	✓✓✓	✓
	Operational	International dependencies, e.g. Transport	✓✓✓	✓✓	✓✓	✓	✓	✓	✓✓	✓	✓✓✓	✓✓	✓
		Dependence of technology on transport	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓✓	✓	✓✓	✓✓	✓✓
		Technology energy input	✓✓	✓✓	✓✓✓	✓	✓	✓	✓✓	✓	✓✓	✓✓	✓
		Technology energy output	✓✓✓	✓✓	N/A	N/A	N/A	N/A	✓✓	✓✓	N/A	✓	N/A
		Information communication technology (ICT) dependencies?	✓✓✓	✓✓	✓✓	✓	✓	✓	✓✓✓	✓	✓✓	✓✓	✓
		Water dependencies	✓✓	✓✓✓	✓✓✓	✓	✓✓	✓✓	✓✓	✓	✓	✓	✓
	People	Staff working conditions, e.g. outdoor or indoor, cramped spaces, labour intensive?	✓	✓	✓	✓✓	✓	✓	✓	✓✓	✓✓	✓	✓✓
Climate criteria	Sea level rise	Capacity to cope with gradual sea level rise	✓	✓	✓	✓	✓	✓	✓	✓✓✓	✓	✓	✓
		Capacity to cope with storm surges	✓✓	✓✓	✓✓	✓✓✓	✓	✓✓	✓✓	✓✓✓	✓✓	✓✓	✓✓✓
	Temperature	Capacity to cope with gradual temperature rise	✓	✓✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓✓
		Capacity to cope with extreme temperature rise/fall	✓✓	✓✓✓	✓	✓✓✓	✓✓	✓✓	✓✓	✓	✓✓	✓✓	✓✓✓
	Precipitation	Capacity to cope with gradual increase in rainfall	✓	✓	✓	✓✓	✓	✓✓	✓	✓✓	✓✓	✓	✓✓
		Capacity to cope with extreme increase in rainfall	✓	✓	✓	✓✓✓	✓	✓✓✓	✓	✓✓	✓✓✓	✓	✓✓✓

✓	Low impact
✓✓	Medium impact
✓✓✓	High impact

Appendix 3 – Additional information on climate change in the UK

Further information on climate change and waste infrastructure

Climate trends in the UK

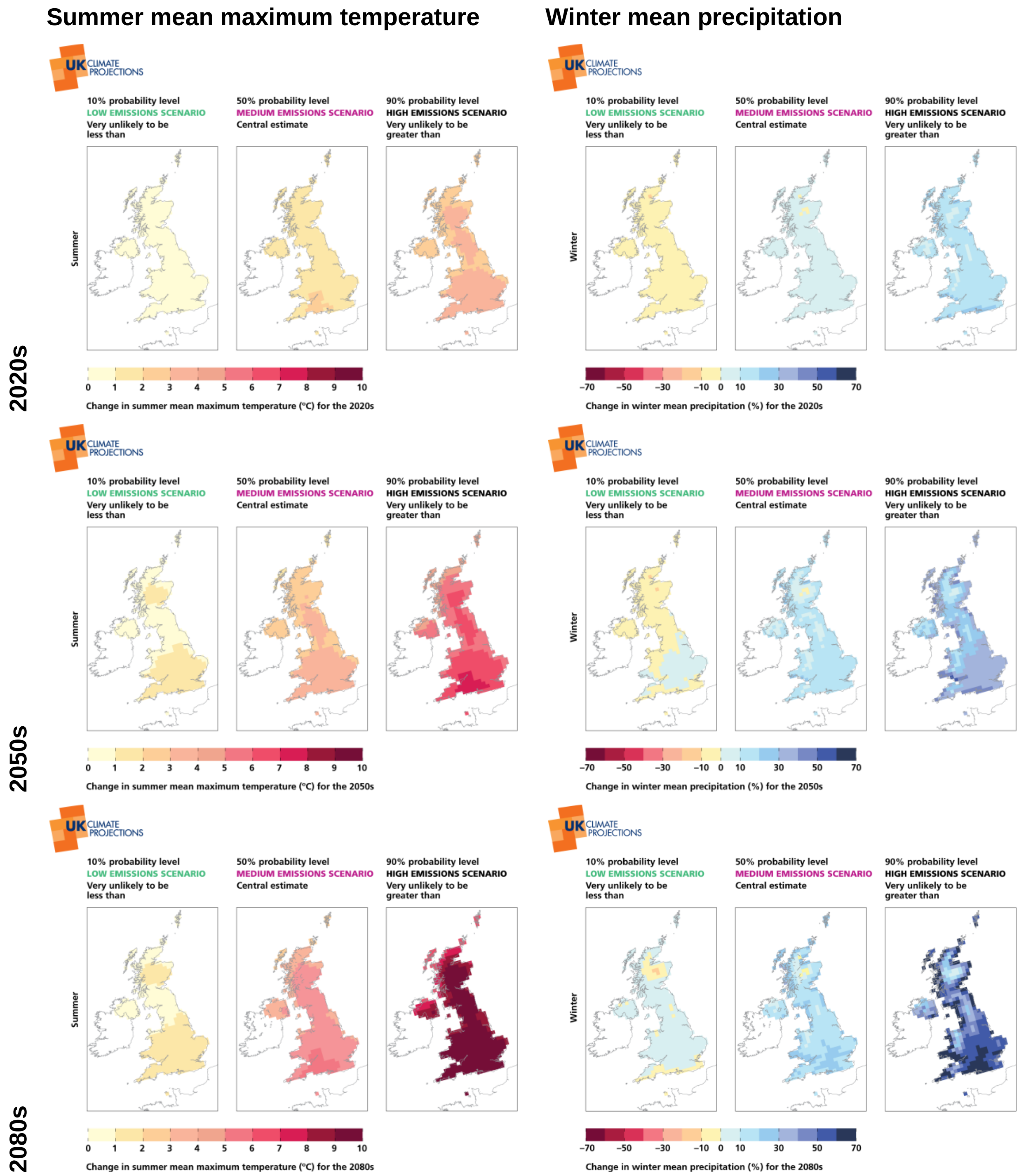
The table below summarises key results from studies of recent trends in UK climate by the UK Climate Impacts Programme and the Met Office (Jenkins *et al.,* 2009).

Recent changes in UK climate

Recent trends in UK climate	
Climate variable	Observed trend
Temperature	• Central England Temperature has risen by about 1 °C since the 1970s, with 2006 being the warmest year on record. • Temperatures in Scotland and Northern Ireland have risen by about 0.8 °C since about 1980.
Precipitation	• Annual mean precipitation over England and Wales has not changed significantly since records began in 1766. • Seasonal rainfall is highly variable, but appears to have decreased in summer and increased in winter, although with little change in the latter over the last 50 years. • Over the last 45 years, all regions of the UK have experienced an increase in the contribution to winter rainfall from heavy precipitation events; in summer all regions except North East England and Northern Scotland show decreases. • South East England has seen the greatest decline in the number of days of rain annually, leading to increased drought conditions
Storms	• Severe windstorms around the UK have become more frequent in the past few decades, though not above that seen in the 1920s.
Sea level rise	• Sea level around the UK rose by about 1mm/yr in the 20th century, corrected for land movement. The rate for the 1990s and 2000s has been higher than this.
Sea surface temperature	• Sea-surface temperatures around the UK coast have risen over the past three decades by about 0.7 °C.

Figure A3.1 shows UKCP09 mapped results for two climate variables across the UK, summer mean maximum temperature and winter mean precipitation, across three time periods and the three emissions scenarios.

Figure A3.1: UK climate projected changes for two climate variables



Appendix 4: Previous literature on climate impacts on waste infrastructure

Previous literature on climate impacts on waste infrastructure

We have identified two reports commissioned by the Environment Agency which examine the potential impacts of climate change on the waste sector[87] and on waste regulation[88]. The impact of climate change and extreme weather on waste regulation and waste management sites can cause disruption to the operation of the sites themselves and alter the demands for the services those sites offer. This was observed most recently from the flooding of waste sites in England during the two major 2007 flooding events in Yorkshire and Gloucestershire, although the likelihood and severity of impacts will differ on a site by site basis. Key impacts on the waste sector can be summarised as follows:

- disruption to supporting waste and transport infrastructure;
- leachate risk;
- storm damage to buildings;
- intolerable temperature, UV, pathogen, vermin related health risks;
- disamenity, odour and dust;
- inundation and erosion; and
- constraints on ecological restoration.

The following climate change impacts have been categorised according to whether they affect infrastructure, waste processes, society and economy or the environment.

Infrastructure

- Flooding could disrupt on-site facilities such as offices and weighbridges. It could also affect the road and rail infrastructure which enables delivery of waste to processing facilities. At landfills, gas and leachate collection schemes would be severely affected by flooding. This would lead to increased pollution and land contamination from gas and leachate migration.
- Flooding and/or erosion of low lying coastal sites due to sea level rise will also be a major impact.
- Risk of subsidence and slope instability due to more frequent wetting and drying of soils. Similarly, soil erosion would become an issue for landfills, particularly in terms of intermediate and final cover requirements.
- Increased precipitation could erode bunds and capping layers.
- Strong winds and more frequent and intense storms may result in damage to buildings infrastructure, as well as affecting transport by road, rail and sea. Strong winds could also mean that increased containment is required for any materials stored on site whether in a reception area within the building or outside.
- Some of the London waste sites have canal access and use barges to transport waste. Water retention in canals could be a big issue.
- Higher temperatures could reduce disruption to transport infrastructure by snow and ice.
- Landfill sites, energy from waste and material recovery facilities remain active after closure and can be operational for decades. There is a need therefore to consider long term climate change impacts.

Process

[87] Jonathan Bebb, Jim Kersey (2003) Entec and Environment Agency. Potential impacts of climate change on waste management
[88] Claire Barnett, Karen Phillipson, Suzanne Walsh (2008) Entec and Environment Agency. The impact of climate change on waste regulation, Science Report – SC030305.

- Changing rainfall patterns could affect site hydrology and site management processes such as dust suppression. Volume and strength of leachate could also change, e.g. increased leachate production in winter months. This in turn would affect treatment processes which may have the knock on effect of requiring changes to discharge standards.
- Decreased summer rainfall could lead to a growing demand for water for workers and processes and an increased concentration of leachate.
- Garden waste forms a high proportion of household waste and waste uplifted from Councils land use services. Changing rainfall patterns would affect moisture rates in such organic waste streams which will have implications for waste processing facilities. As droughts become more common, there are concerns about the implications for in-vessel composting reprocessors, which will lose feedstock and income[89].
- Domestic and municipal collection methods will require changes, e.g. enclosed containers for paper and card to prevent them from becoming waterlogged. This has a knock on effect for existing facilities which may not be able to be able to process collected materials with serious contractual implications.
- Changing temperature and rainfall patterns could affect waste decomposition rates and biological processes such as anaerobic digestion and composting.
- Lower heat demand may affect combined heat and power (CHP) processes and district heating. There may need to be a diversification so that CHP heat is only provided to industrial process instead of domestic, where the load required will be lower in summer than in winter.
- Changing demand for meat and other resource intensive food could alter the composition of waste. This could lead to changes in the inputs and outputs to/from waste facilities leading to a shift in the types and capacities of organics treatment facilities. It will be necessary to consider the implication of markets for related outputs along with facilities change. In addition, shifts in climate patterns could radically alter producer economies such as China and India which would severely impact the off-take of materials for reprocessing.

<u>Social</u>

- Impact on neighbourhood from increased odour, vermin and dust during hot, dry weather. There could be a decline in local air quality. Windblown litter would become a more common problem leading to increased storm water pollution and pollution of natural water bodies. This would also have a severe impact on biodiversity.
- Health impacts on workers from higher temperatures and exposure to UV radiation; associated increase in vermin (flies, rats) and pathogens. There will be cost implications here for companies needing to supply additional or modified personal protective equipment such as long sleeve high visibility clothing and potentially sun cream and hats.
- Reduced comfort of workers resulting from higher summer temperature, leading to loss of productivity. This will be a big issue and alternative working hours and air conditioning (infrastructure changes) may have to be considered.

<u>Environmental</u>

- Impact on biodiversity living on or around waste facilities, e.g. from lack of water. Biological restoration of decommissioned landfill sites could be affected by climate change.

[89] Ward, Phillip. Crunch time on climate. MRW, 27 January 2011.

- Higher summer temperatures and drought could place stress on vegetation used for screening waste facilities, offering less protection from noise and odour.

Waste infrastructure and flooding

McBain et al (2010)[90], using a Flood Risk Vulnerability Classification, deemed landfill and waste sites as 'more vulnerable' and waste treatment sites as 'less vulnerable' to flooding. The classification used is based on PPS25 (Planning Policy Statement 25: Development and Flood Risk) and indicates which land uses are considered appropriate in different flood zones in England. The flood zones and their annual probability of being flooded are shown in the table below.

Table A4.1 Flood zones in PPS25 (McBain et al, 2010)

Zone	Annual probability of a flood occurring or being exceeded
Zone 1	Less than 0.1% (1 in 1000)
Zone 2	Between 0.1% and 1% (1 in 100) for river flooding, between 0.1% (1 in 1000) and 0.5% (1 in 200) for flooding from the sea
Zone 3a	Greater than 1% (1 in 100) for river flooding and greater than 0.5% for flooding from the sea
Zone 3b	Function floodplain.

Landfill and waste sites require an 'exception test' before being developed in zone 3a but they should not be permitted in zone 3b. Waste treatment sites can be developed in zones 1, 2 and 3a but should not be permitted in zone 3b.

Opportunities

Various opportunities exist to integrate climate change impacts with waste regulation and permitting. Some of these are discussed below.

Site or operations extensions

Mucking, one of Europe's largest landfill sites, lies on the Thames Estuary in Essex. The site is prone to flooding when there is a storm surge in the River Thames, leading to severe marine pollution and loss of biodiversity. It is when sites such as Mucking apply for an extension to the site or operations that the local planning authority or the EA has an opportunity to assess future risks[91]. This is a proactive solution rather than a reactive solution and it is worth considering whether possible climate risks could be included in the Environmental Permitting regulations in the future.

Flexible permitting

In cases where storm and flood related wastes cannot be treated or disposed of quickly, EA officers have negotiated temporary relaxation of licence conditions with site operators. The aim is to find the best practical solution to minimise risk to the environment or human health and to restore normal business operations. Although this is a flexible regulatory approach to climate change adaptation, it is only a temporary solution. Increasing extreme weather may increase demand for flexible permitting and this may no longer be a practical solution.

In its Adaptation Reporting Power report, the Environment Agency outlines a commitment to consider climate change when reviewing permits, assessing operator compliance and issuing

[90] McBain, W, Wilkes,D and Retter, M (2010) Flood Resilience and Resistance for Critical Infrastructure. Report by ARUP for CIRIA Project RP913.
[91] Claire Barnett, Karen Phillipson, Suzanne Walsh (2008) Entec and Environment Agency. The impact of climate change on waste regulation, Science Report – SC030305.

guidance to our staff and operators. In addition, the Environment Agency commit to ensuring that approaches such as Best Available Techniques (BAT) take account of climate change[92].

Site waste management strategies

In their climate change adaptation strategy, the Environment Agency state that a changing climate will pose a direct risk to their core business, in terms of delivering corporate targets and the service it provides to customers and stakeholders. This includes more pollution incidents from waste sites[93]. This highlights the demand for waste management strategies to include details of adaptation responses to climate risks (e.g. under the Climate Change Act[94]). In future, it will be increasingly important to consider how the Environment Agency implements and monitors this requirement in order to minimise the burden on waste management companies to carry out climate risk assessments.

Risk boundaries and inspection changes

EA could consider the proximity of waste management sites to sensitive receptors such as SSSIs, or hospitals, schools and housing. In case of close proximity, there may be a need to demonstrate that adequate adaptation measures are in place to minimise risk. A greater emphasis on climate risk is likely to alter inspection frequency for some sites. This could affect source protection zones (SPZs) – the Edmonton energy from waste facility in London is situated within a SPZ.

There are several challenges to overcome in the future design of waste regulation and permitting in response to climate impacts. These are summarised below.

Data sets

More comprehensive data is needed on the impact of extreme weather on the regulation of waste management facilities[95]. More sophisticated ways of reporting non-compliance now exist such as the Compliance Classification Scheme and National Incident Reporting System databases. This will help the Environment Agency to fulfil its commitment to examine how compliance information is recorded and monitored to ensure that causal links between climate change and permit breaches or pollution incidents can be identified.

Impact on other regulation

It will be necessary to consider how changes to waste permitting and regulation might affect other legislation, e.g. habitats and ecosystems. This will require greater cross-sectoral policy and decision making.

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[92] Environment Agency Adaptation Reporting Power http://publications.environment-agency.gov.uk/PDF/GEHO0111BTJW-E-E.pdf
[93] Environment Agency, Climate Change Adaptation Strategy (2008-2011) http://www.environment-agency.gov.uk/static/documents/Climate-Change_Adaptation_Strategy2008_11.pdf
[94] http://www.legislation.gov.uk/ukpga/2008/27/contents
[95] Claire Barnett, Karen Phillipson, Suzanne Walsh (2008) Entec and Environment Agency. The impact of climate change on waste regulation, Science Report – SC030305.

Appendix 5 – Additional information on the East of England landfills case study

Relative sea level rise results for a representative South Essex location from the UK climate projections (UKCP09)

UKCP09 12km coastal grid square: 23519									
Relative Sea Level Rise in meters	**2030**			**2050**			**2100**		
Emissions Scenario	**5th percentile**	**50th percentile**	**95th percentile**	**5th percentile**	**50th percentile**	**95th percentile**	**5th percentile**	**50th percentile**	**95th percentile**
Low	0.06	0.12	0.17	0.10	0.19	0.27	0.20	0.40	0.59
Medium	0.07	0.14	0.20	0.11	0.22	0.33	0.22	0.47	0.73
High	0.07	0.16	0.25	0.12	0.26	0.40	0.24	0.57	0.89

N.B. Low and High emission scenarios have been scaled from the Medium emission scenario for the sea level projections.

The range of projections of absolute sea level derived from different IPCC global climate models has not been constrained i.e. modified based on comparison with observations of current-day global sea level.

Storm Surge results for a representative South Essex location from the UK climate projections (UKCP09)

Plot Details:

Data Source: Storm Surge

Variables: skew_surge_trend

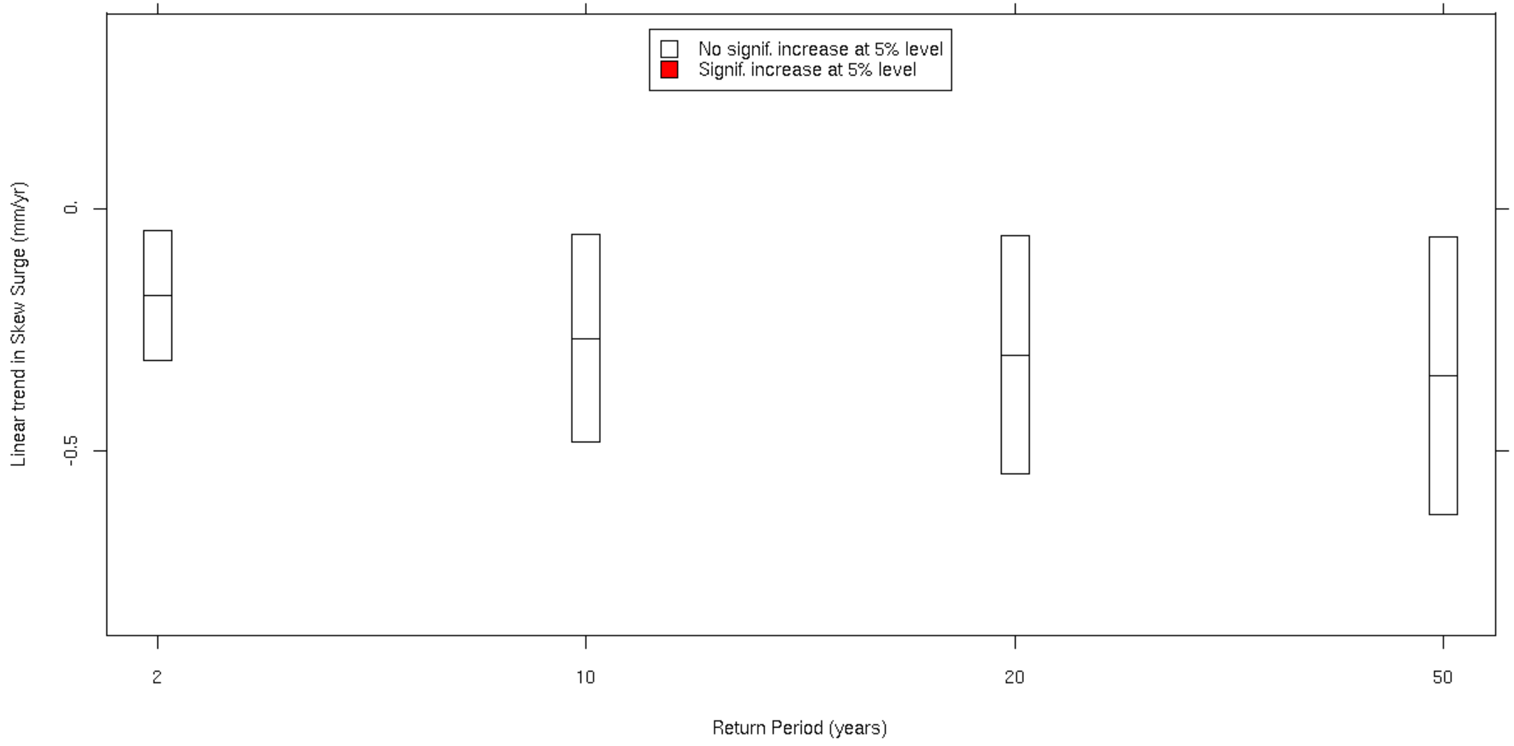
Location: Grid Box No. 15525

Emissions Scenario: Medium

Boxes define: 5%ile, 50%ile, 95%ile

Note: An H++ surge component has been calculated and is available in the Marine Report

Note: This plot does not include changes in local mean sea level



Net Sea Level Rise calculation as per Planning Policy Statement 25 allowances

For South Essex in the East of England by 2100

4mm/yr between 1990-2025 = 140mm
8.5mm/yr between 2026-2055 = 246.5mm
12mm/yr between 2056-2085 = 348mm
15mm/yr between 2086-2100 = 210mm

Total = 140 + 246.5 + 348 + 210 = **944.5mm (94.5cm)**

Appendix 6 – Review of waste regulations, legislation and guidance documents

Ref	Legislation	Guidance	Link	Relevant text
1	Environmental Protection Act 1990	N/A	http://www.legislation.gov.uk/ukpga/1990/43/contents	
2	Environment Act 1995	N/A	http://www.legislation.gov.uk/ukpga/1995/25/contents	
3	The Producer Responsibility Obligations (Packaging Waste) Regulations 1997	Yes	http://www.legislation.gov.uk/uksi/1997/648/contents/made	
4		*Applying for an accreditation to reprocess or export UK waste packaging* (ACC-GN01 Version 6, July 2010) EA, SEPA, NIEA (13 pages)	http://www.sepa.org.uk/pdf/ACC-GN01_accreditation.pdf	What 'broadly equivalent' means If you export waste packaging, it should be treated and recovered at sites where the processes meet environmental standards that are 'broadly equivalent' to the standards that apply in the European Union. This means that the country the site is in must have standards in place to make sure waste is recovered or disposed of without: putting people's health in danger; or using processes or methods which could harm the environment, in particular without: – harming water, air, soil and plants and animals; – causing a nuisance through noise or smells; or – having a negative effect on the countryside or places of special interest. Places may be of 'special interest' if they have special cultural, architectural, historical, scientific or other interests. Annex F of the document - contains a template letter outlining the information that will be required from the overseas reprocessor to demonstrate that they are 'broadly equivalent' to UK standards.

5	The Landfill (England & Wales) Regulations 2002 (as amended)	Yes	http://www.legislation.gov.uk/uksi/2002/1559/contents/made	SCHEDULE 2 Regulations 5 and 8(3)(a)(i) 1.—(1) The location of a landfill must take into consideration requirements relating to— (a) the distances from the boundary of the site to residential and recreational areas, waterways, water bodies and other agricultural or urban sites; (b) the existence of groundwater, coastal water or nature protection zones in the area; (c) the geological or hydrogeological conditions in the area; (d) the risk of flooding, subsidence, landslides or avalanches on the site; and (e) the protection of the natural or cultural heritage in the area. (2) A landfill permit may be issued for the landfill only if— (a) the characteristics of the site with respect to the requirements in sub-paragraph (1); or (b) the corrective measures to be taken, indicate that the landfill does not pose a serious environmental risk. 3.—(1) The landfill must be situated and designed so as to— (a) provide the conditions for prevention of pollution of the soil, groundwater or surface water; and (b) ensure efficient collection of leachate as and when required by paragraph 2. 5.—(1) Measures must be taken to minimise the nuisances arising from the landfill in relation to— (a) emissions of odours and dust; (b) wind-blown materials; (c) noise and traffic; (d) birds, vermin and insects; (e) the formation of aerosols; and (f) fires.
6		*Government Interpretation of the Landfill (England and Wales) Regulations 2002 (As Amended)* (December 2005) Defra (44 pages)	http://www.tbcrecycling.com/PDFs/Landfill_Regulations_2002.pdf	4. REGULATION 5: PLANNING PERMISSION 4.1 Introduction Regulation 5 places a specific responsibility on Waste Planning Authorities (WPA) to consider the requirements of Schedule 2, paragraph 1(1) of the Regulations (distances from residential and recreational areas; the proximity to water sources; geological and hydro-geological conditions; the risk of natural disasters; and protection of the site's heritage). The location of a landfill must take into consideration requirements relating to – a) the distances from the boundary of the site to residential and recreational areas, waterways, water bodies and other agricultural or urban sites; b) the existence of groundwater, coastal water or nature protection zones in the area; c) the geological or hydro geological conditions in the area; d) the risk of flooding, subsidence, landslides or avalanches on the site; and e) the protection of the natural or cultural heritage in the area.
7		*Waste Acceptance at Landfills* (November 2010) Environment Agency (46 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO1110BTEW-E-E.pdf	

8		*Regulatory Guidance Series, No LFD 1 Understanding the Landfill Directive* (Version 2 March 2010) Environment Agency (32 pages)	http://www.environment-agency.gov.uk/static/documents/Business/RGN_LFD1_Landfills_(v2.0)_30_March_2010.pdf	The Environment Agency will object to any proposed landfill site in groundwater Source Protection Zone 1. For all other proposed landfill site locations, a risk assessment must be conducted based on the nature and quantity of the wastes, and the natural setting and properties of the location. Where this risk assessment demonstrates that active long-term site management is essential to prevent long-term groundwater pollution, the Environment Agency will object to sites: - below the water table in any strata where the groundwater provides an important contribution to river flow or other sensitive surface waters; - on or in a Major/Principal Aquifer; - within Source Protection Zones 2 or 3.
9	REGULATION (EC) No 1013/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 June 2006 on shipments of waste		http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:190:0001:0098:EN:PDF	Article 49 Protection of the environment 1. The producer, the notifier and other undertakings involved in a shipment of waste and/or its recovery or disposal shall take the necessary steps to ensure that any waste they ship is managed without endangering human health and in an environmentally sound manner throughout the period of shipment and during its recovery and disposal. In particular, when the shipment takes place in the Community, the requirements of Article 4 of Directive 2006/12/EC and other Community legislation on waste shall be respected. 3. In the case of imports into the Community, the competent authority of destination in the Community shall: (a) require and take the necessary steps to ensure that any waste shipped into its area of jurisdiction is managed without endangering human health and without using processes or methods which could harm the environment, and in accordance with Article 4 of Directive 2006/12/EC and other Community legislation on waste throughout the period of shipment, including recovery or disposal in the country of destination; (b) prohibit an import of waste from third countries if it has reason to believe that the waste will not be managed in accordance with the requirements of point (a).
10	The Transfrontier Shipment of Waste 2007 and Transfrontier Shipment of Waste (Amendment) Regulations 2008	Yes	http://www.legislation.gov.uk/uksi/2008/9/contents/made	Protection of the environment 17. A person commits an offence if he fails to comply with Article 49(1) (the management of shipments of waste in an environmentally sound manner and without endangering human health).
11		*Safer waste cleaner world Moving waste between countries: determining the controls on waste exports* (June 2007)	http://publications.environment-agency.gov.uk/PDF/GEHO0607BMXC-E-E.pdf	

		Environment Agency (4 pages)		
12		*Safer waste cleaner world Moving waste between countries: determining the controls on waste imports* (June 2007) Environment Agency (4 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO0607BMXE-E-E.pdf	
13		*Safer waste cleaner world Moving notified waste between countries A guide* (June 2007) Environment Agency (21 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO0607BMXB-E-E.pdf	
14		*Safer waste cleaner world Exporting recyclable waste for recovery in non-OECD countries* (June 2007) Environment Agency (8 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO0607BMXG-E-E.pdf	3. Can you show that the waste will be recovered in an environmentally sound manner? You must know where the waste is going to be recovered before you export it. The proposed recovery facility must be capable of recovering the waste in an environmentally sound manner without putting people's health at risk. Generally, the recovery facility should be licensed or permitted in some way by the relevant local regulatory authorities. Ideally, you should be able to show that it is operated according to human health and environment protection standards that are broadly equivalent to the standards within the UK. You should get evidence to support your assessment of the proposed recovery facility. You will not need to routinely provide this information to the regulators, but you may be asked for it if a consignment of waste is inspected on route to the recovery facility. As the UK's competent authorities, we must prohibit exports of waste to non-OECD countries if we believe the waste will not be managed in an environmentally sound manner. If we inspect a consignment of waste in transit and no evidence is available about the operating standards at the recovery facility, we may have to prevent the waste being exported.
15	The Environmental Permitting (England & Wales) Regulations 2010 (as amended)	Yes	http://www.legislation.gov.uk/ukdsi/2010/9780111491423/contents	Surrender applications 14.—(1) The regulator must accept an application for the surrender of an environmental permit in whole or in part under regulation 25(2) if it is satisfied that the necessary measures have been taken— (a) to avoid a pollution risk resulting from the operation of the regulated facility; and (b) to return the site of the regulated facility to a satisfactory state, having regard to the state of the site before the facility was put into operation. (2) Sub-paragraph (1) does not apply to an application for the surrender of any part of an environmental permit (or if applicable, the whole permit) that authorises the carrying on of a radioactive substances activity at a nuclear site. T

16		*Guidance for the Recovery and Disposal of Hazardous and Non Hazardous Waste* (Sector Guidance Note IPPC S5.06 December 2004) Environment Agency (142 pages)	http://www.environment-agency.gov.uk/static/documents/Business/sgn_issue_4_968872.pdf	
17		*Environmental Permitting Guidance – Core Guidance For the Environmental Permitting (England and Wales) Regulations 2010* (Version 3.2 September 2011) Defra (82 pages)	http://www.defra.gov.uk/publications/files/pb13560-ep2010guidance-110909.pdf	What is environmental permitting? 2.1. Some facilities could harm the environment or human health6 unless they are controlled. The Environmental Permitting Regime ('the Regime') requires operators to obtain permits for some facilities, to register others as exempt and provides for on-going supervision by regulators. The aim of the Regime is to: • protect the environment so that statutory and Government policy environmental targets and outcomes are achieved • deliver permitting and compliance with permits and certain environmental targets effectively and efficiently in a way that provides increased clarity and minimises the administrative burden on both the regulator and the operators • encourage regulators to promote best practice in the operation of facilities • continue to fully implement European legislation.
18		*How to comply with your Environmental Permit (EPR 1.00)* (Version 4 April 2011) (102 pages) Environment Agency	http://publications.environment-agency.gov.uk/PDF/GEHO0411BTSP-E-E.pdf	you must put in place and implement management arrangements to ensure that you identify the risks that your activities pose to the environment and take all reasonable actions to prevent or minimise those risks. Accidents You must have an accident management plan and implement it if an accident occurs. You will have to review this plan at least every four years. As soon as practicable after an accident you will have to analyse the reasons why the accident happened and whether your response was adequate. You will have to change the plan if necessary. To produce an accident management plan, you should: • identify events or failures that could damage the environment, for example flooding; see 'A' • assess how likely they are to happen and the potential environmental consequences; see 'B'
19		*How to comply with your environmental permit: Additional guidance for: The Incineration of Waste (EPR 5.01)* (March 2009) Environment Agency (87 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO0209BPIO-E-E.pdf	

20		*Regulatory guidance series, No RGN 4 Setting standards for environmental protection* (Version 3 November 2011) Environment Agency (27 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO0112BUKP-E-E.pdf	
21		*Regulatory guidance series No RGN 6 Determinations involving sites of high public interest* (Version 4.1 October 2011) Environment Agency (15 pages)	http://publications.environment-agency.gov.uk/PDF/GEHO1111BUKC-E-E.pdf	
22		*Regulatory Guidance Series, No RGN 8 Substantial changes in operation at installations, mining waste facilities and other facilities involving solvents and combustion* (Version 3 March 2011) Environment Agency (25 pages)	http://www.environment-agency.gov.uk/static/documents/Business/RGN_8_Substantial_Change.pdf	
23		*Regulatory Guidance Note, RGN 9 Showing that land and groundwater are protected at: installations; waste facilities; mining waste operations; non-nuclear radioactive substances facilities and mobile apparatus* (Version 2 April 2010) Environment Agency (22 pages)	http://www.environment-agency.gov.uk/static/documents/Business/RGN_9_Surrender_(v2.0)_30_March_2010.pdf	

24		*Regulatory Guidance Series, No EPR 12 Statutory Periodic Permit Reviews* (Version 1 November 2010) Environment Agency (9 pages)	http://www.environment-agency.gov.uk/static/documents/Business/RGN12.pdf	1.5 The permit review process includes 1. **checking a permit or group of permits to see whether they 'remain adequate' in ensuring the operator achieves the relevant environmental and regulatory objectives**… 2. Revising individual permits if necessary. Key influences on review for waste infrastructure include (Table 3.1) change to environmental risk. 3.11 We will review bespoke waste operations permits every 8 years as a minimum. **Key drivers are environmental risk** and techno-economic changes affecting the cost-effectiveness of measures to control environmental risk. 3.17 In some specific circumstances we may need to review individual permits or groups of permits outside of a planned programme e.g. when the pollution caused by the permitted activities is found to be of such significance that the existing permit conditions need to be revised.
25		*Regulatory Guidance Series, No EPR 13 Defining Waste Recovery: Permanent Deposit of Waste on Land* (Version 1 March 2010) Environment Agency (21 pages)	http://www.environment-agency.gov.uk/static/documents/Business/RGN13_Defining_Waste_Recovery_v1.0.pdf	4) 5) A particular consideration for large scale deposits is that they are designed and will be constructed in such a way that the operation does not cause… increased flooding risk to the surrounding area.'
26		Environmental Permitting Guidance Statutory Nuisance s79(10) Environmental Protection Act 1990	http://archive.defra.gov.uk/environment/policy/permits/documents/ep2010stat-nuisance.pdf	Qualifying nuisance (a) the statutory nuisance is listed in section 79(10)9, EPA 1990. For ease of reference these are: · smoke emitted from premises so as to be prejudicial to health or a nuisance; · any dust, steam, smell or other effluvia arising on industrial, trade or business premises and being prejudicial to health or a nuisance; · any accumulation or deposit which is prejudicial to health or a nuisance; · artificial light emitted from premises so as to be prejudicial to health or a nuisance; or · noise emitted from premises so as to be prejudicial to health or a nuisance.
27		PPC Sector Permitting Plan - Waste Disposal and Recovery	http://www.environment-agency.gov.uk/static/documents/Business/permitting_plan__1026810.pdf	
28		How to comply with your environmental permit Additional guidance for: Landfill (EPR 5.02)	http://publications.environment-agency.gov.uk/PDF/GEHO0409BPUT-E-E.pdf	
29		How to comply with your environmental permit Additional guidance for inert waste	http://publications.environment-agency.gov.uk/PDF/GEHO0509BPWJ-E-E.pdf	

30		Regulatory Guidance Series, No LFD 1 Understanding the Landfill Directive	http://www.environment-agency.gov.uk/static/documents/Business/RGN_LFD1_Landfills_(v2.0)_30_March_2010.pdf	The Environment Agency will object to any proposed landfill site in groundwater Source Protection Zone 1. For all other proposed landfill site locations, a risk assessment must be conducted based on the nature and quantity of the wastes, and the natural setting and properties of the location. Where this risk assessment demonstrates that active long-term site management is essential to prevent long-term groundwater pollution, the Environment Agency will object to sites: - below the water table in any strata where the groundwater provides an important contribution to river flow or other sensitive surface waters; - on or in a Major/Principal Aquifer; - within Source Protection Zones 2 or 3. Principal Aquifers and Source Protection Zones 2 and 3 6.15. As well as the nature and quantity of wastes, the risk assessment must be based on the natural setting and the properties of the location. Principal Aquifers (formerly referred to as Major Aquifers) and designated Source Protection Zones represent the areas of our groundwater resources that are critical to existing or future public water supplies. In these areas we would normally wish to preserve the high quality of the groundwater immediately under a proposed landfill site. Risk screening should identify the Aquifer and Source Protection Zone designation.
31		Horizontal Guidance Note H1 Overview document	http://publications.environment-agency.gov.uk/PDF/GEHO0410BSHR-E-E.pdf	We regulate many activities that present different types of risk to the environment, including: • Odour • Noise and vibration • Accidents – accidental harm could result from most activities • Fugitive emissions to air and water – uncontrolled releases such as dust, volatile organic compounds (VOCs), run-off from operational areas but not controlled releases from point-sources and problems with mud, pests or litter • Controlled releases to air – planned and managed releases associated with an activity • Controlled discharges to surface waters - planned and managed releases associated with an activity • Controlled discharges to ground or groundwater - planned and managed releases associated with an activity • Global warming potential – some sectors will need to reduce their greenhouse gas emissions (Table 1 will explain if you need to think about this) • Site waste – may need to be recovered or managed in a controlled manner (Table 1 will explain if you need to think about this) You should now complete the assessment annexes for your activity as shown in Table 1. You should then carry on with Step 3 below when you have finished them. 2.3 – Justify appropriate measures You will need to show us that you have managed risks from your activity appropriately for us to issue you with a permit. In most cases, it will be enough for you to implement the indicative control measures set out in Technical Guidance Notes and show that the residual risk is acceptable (i.e. through the risk assessments you carried out in Step 2). In some cases, you may need to carry out an options appraisal or cost-benefit analysis to justify your choice of control measures: • if risk assessment shows that risks from your activity are not acceptable and you need to look at costs and benefits of further measures to control the risk

32		H1 Annex A – Amenity & accident risk from installations and waste activities	http://publications.environment-agency.gov.uk/PDF/GEHO0410BSIG-E-E.pdf	
33		H1 Annex G – Disposal or recovery of waste produced on site	http://publications.environment-agency.gov.uk/PDF/GEHO0410BSIM-E-E.pdf	
34		H5 - Environmental Permitting Regulations Site condition report – guidance and templates	http://www.environment-agency.gov.uk/static/documents/Business/h5_scr_guidance_2099540.pdf	
35		H4 Odour Management How to comply with your environmental permit	http://publications.environment-agency.gov.uk/PDF/GEHO0411BTQM-E-E.pdf	
36		H1 Annex H – Global Warming potential	http://publications.environment-agency.gov.uk/PDF/GEHO0410BSIN-E-E.pdf	
37		H1 Annex I - Landfill	http://publications.environment-agency.gov.uk/PDF/GEHO0410BSIO-E-E.pdf	
38		Exemption S1 - Secure storage of waste in containers	http://www.environment-agency.gov.uk/static/documents/Business/S1_exemption.pdf	N/A
39		Exemption S2 - Secure storage of waste in a secure place	http://www.environment-agency.gov.uk/static/documents/Business/S2_exemption.pdf	N/A
40		Non- Waste Framework Directive (NWFD) exemptions Temporary storage at a collection point	http://www.environment-agency.gov.uk/static/documents/Business/NWFD_3.pdf	N/A

41		T4 – Preparatory treatments (baling, sorting, shredding etc.)	http://www.environment-agency.gov.uk/static/documents/Business/T4_exemption.pdf	N/A
42		T5 – Screening and blending of waste	http://www.environment-agency.gov.uk/static/documents/Business/T5_exemption.pdf	N/A
43		T13 – Treatment of waste food	http://www.environment-agency.gov.uk/static/documents/Business/T13_exemption.pdf	N/A
44	Directive 2008/98/EC on waste and repealing certain Directives [The Waste Framework Directive]	N/A	http://www.environment-agency.gov.uk/static/documents/Business/WFD.pdf	
45	The Waste (England & Wales) Regulations 2011	Yes	http://www.legislation.gov.uk/uksi/2011/988/pdfs/uksi_20110988_en.pdf	3. [Protection of human health and the environment] To ensure that waste management is carried out without endangering human health, without harming the environment and, in particular— (a) without risk to water, air, soil, plants or animals; (b) without causing a nuisance through noise or odours; and (c) without adversely affecting the countryside or places of special interest.
46		*Guidance on applying the Waste Hierarchy* (June 2011) Defra (14 pages)	http://www.defra.gov.uk/publications/files/pb13530-waste-hierarchy-guidance.pdf	2.1 The ranking of the various waste management options are based on current scientific research on how the options impact on the environment in terms of climate change, air quality, water quality and resource depletion.
47		*Environmental Permitting Guidance The Waste Framework Directive For the Environmental Permitting (England and Wales) Regulations 2007* (Version 2 October 2009) Defra (37 pages)	http://www.defra.gov.uk/publications/files/pb13569-wfd-guidance-091001.pdf	4.8 [Requirements for all waste operations] The obligation provided by Article 4 of the Directive is to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular: • without risk to water, air, soil, plants or animals; or • without causing nuisance through noise or odours; or • without adversely affecting the countryside or places of special interest.

48	Directive 2000/76/EC on the incineration of waste	Yes	http://eur-lex.europa.eu/LexUriServ/site/en/oj/2000/l_332/l_33220001228en00910111.pdf?lang=_e	
49		*Environmental Permitting Guidance The Waste Incineration Directive For the Environmental Permitting (England and Wales) Regulations 2010* (Version 3.1 March 2010) Defra (96 pages)	http://www.defra.gov.uk/publications/files/pb13639-ep2010wasteincineration.pdf	4.71 A risk assessment process should be used to determine the volume of storage that is required to contain fire water.
50	The Waste Incineration (England and Wales) Regulations 2002		http://www.legislation.gov.uk/uksi/2002/2980/contents/made	
51	The Pollution Prevention and Control (England and Wales) Regulations 2000	Yes	http://www.legislation.gov.uk/uksi/2000/1973/contents/made	
52		*Reference Document on the Best Available Techniques for Waste Incineration* (August 2006) EC (602 pages)	http://eippcb.jrc.es/reference/BREF/wi_bref_0806.pdf	3.1.4 describes emissions relevant to climate change; Table 3.3.8 describes climate as an influence on process design (e.g. heat from CHP for heating or to drive chillers); 4.3.9 describes effect of temperature of cold source at turbine outlet on efficiency (higher efficiency in colder climates); Several other examples of climate effects on performance e.g. in relation to preferred emissions abatement system

53		*Reference Document on the Best Available Techniques for Waste Treatments Industries* (August 2006) EC (592 pages)	http://eippcb.jrc.es/reference/BREF/wt_bref_0806.pdf	2.1.4 Storage and handling. 'An important safety consideration... is fire prevention and protection.' 4.1.7 Techniques to prevent accidents and their consequences; 'IPPC requires.. Necessary measures should be taken to prevent accidents which may have environmental consequences... a. producing a structured accident management plan... identifying the hazards posed to the environment by the installation. Particular areas to consider may include... extreme weather conditions e.g. flooding, very high winds. Other references to waste auto-igniting especially where high organic content but unrelated to climate; numerous references to fire control etc.
54		*Environmental Permitting Guidance The IPPC Directive Part A(1) Installations and Part A(1) Mobile Plant For the Environmental Permitting (England and Wales) Regulations 2010* (Version 3 March 2010) Defra (66 pages)	http://archive.defra.gov.uk/environment/policy/permits/documents/ep2010ippc.pdf	
55	Directive on industrial emissions (integrated pollution prevention and control) [COM(2007)843] Proposed	No	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0844:FIN:EN:PDF	
56	Government Planning Policy Guidance (PPG) and Planning Policy Statements (PPS)	N/A	http://www.communities.gov.uk/planningandbuilding/planningsystem/planningpolicy/planningpolicystatements/	

57	N/A	*Planning Policy Statement 1: Delivering Sustainable Development* (2005) ODPM (17 pages)	http://www.communities.gov.uk/documents/planningandbuilding/pdf/planningpolicystatement1.pdf	13. (ii) Regional planning bodies and local planning authorities should **ensure that development plans contribute to global sustainability by addressing the causes and potential impacts of climate change** – through policies which reduce energy use, reduce emissions (for example, by encouraging patterns of development which reduce the need to travel by private car, or reduce the impact of moving freight), promote the development of renewable energy resources, and take climate change impacts into account in the location and design of development. 20. **Development plan policies should take account of environmental issues such as:** **– mitigation of the effects of, and adaptation to, climate change** through the reduction of greenhouse gas emissions and the use of renewable energy; air quality and pollution; land contamination; the protection of groundwater from contamination; and noise and light pollution... – the potential impact of the environment on proposed developments by avoiding new development in areas at risk of flooding and sea-level rise, and as far as possible, by **accommodating natural hazards and the impacts of climate change**... 27. In preparing development plans, planning authorities should seek to... (x) Address, on the basis of sound science, the causes and impacts of climate change...
58	N/A	*Planning Policy Statement: Planning and Climate Change - Supplement to Planning Policy Statement 1* (December 2007) DCLG (22 pages)	http://www.communities.gov.uk/documents/planningandbuilding/pdf/ppsclimatechange.pdf	Whole document relevant - following with specific relevance to waste/adaptation. 9. [Key planning objectives] To deliver sustainable development, and in doing so a full and appropriate response on climate change, regional planning bodies and all planning authorities should prepare, and manage the delivery of, **spatial strategies that**... respond to the concerns of business and **encourage competitiveness and technological innovation in mitigating and adapting to climate change**. 10. [Decision-making principles] Regional planning bodies and all planning authorities should apply the following principles in making decisions about their spatial strategies... **mitigation and adaptation should not be considered independently of each other, and new development should be planned with both in mind**... 13. [Integrating climate change] Climate change should be a key and integrating theme of the RSS... In particular, regional planning bodies should... **bring forward adaptation options for existing development in likely vulnerable areas**. 14. [Managing performance] Regional planning bodies should consider the likely performance of the RSS on **mitigating climate change and in adapting to the impacts of likely changes to the climate**. This should be a key part of the sustainability appraisal...

59			-	24. [Selecting land for development] planning authorities should take into account… the capacity of existing and potential infrastructure (including for... **waste management**...) to service the site or area in ways consistent with cutting carbon dioxide emissions and **successfully adapting to likely changes in the local climate**... 42. [Designing environmental performance into proposed development] In their consideration of the environmental performance of proposed development, **taking particular account of the climate the development is likely to experience over its expected lifetime**, planning authorities should expect new development to... **provide for sustainable waste management**... 46. [Compliance and enforcement] Planning authorities in considering their approach to compliance and, when necessary, whether it is expedient to take enforcement action, should **have particular regard to the highest priority placed by Government on mitigating climate change and successfully adapting to the unavoidable consequences**.
60	N/A	*Planning Policy Statement 9: Biodiversity and Geological Conservation* (August 2005) ODPM (7 pages)	http://www.communities.gov.uk/documents/planningandbuilding/pdf/147408.pdf	2. [Regional spatial strategies] Regional planning bodies should liaise closely with regional biodiversity fora or equivalent bodies… Over time the distribution of habitats and species, and geomorphological processes and features, will be affected by climate change and such change will need to be taken into account.
61	N/A	*Planning Policy Statement 10: Planning for Sustainable Waste Management* (March 2011) DCLG (27 pages)	http://www.communities.gov.uk/documents/planningandbuilding/pdf/1876202.pdf	Annex E [Locational Criteria] In testing the suitability of sites… waste planning authorities should consider… a. protection of water resources. Considerations will include the proximity of vulnerable surface and groundwater. For landfill or land-raising, geological conditions and the behaviour of surface water and groundwater should be assessed both for the site under consideration and the surrounding area. The **suitability of locations subject to flooding will also need particular care**.

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