# A Climate Change Report Card for Infrastructure

## Working Technical Paper

## Solid Waste: Disposal, thermal processes, biological and mechanical processing

**Geoff Watson and William Powrie**
**University of Southampton**
**University Road**
**Southampton SO17 1BJ**

**LWEC Partners**
Arts and Humanities Research Council • Biotechnology and Biological Sciences Research Council •
Department of Communities and Local Government • Department of Energy and Climate Change •
Department for Environment Food and Rural Affairs • Department of Health • Department for International Development •
Department for Transport • Engineering and Physical Sciences Research Council •
Economic and Social Research Council • Environment Agency • Forestry Commission • Local Government Association •
Medical Research Council • Met Office • Natural England • Natural Environment Research Council •
Northern Ireland Environment Agency • Scottish Environment Protection Agency • Scottish Government •
Technology Strategy Board • Welsh Government •

## Introduction

The aim of this paper is to explore the effects of climate change and severe weather on the solid waste infrastructure of the UK in the context of the UKCP09 scenarios (UKCP09). In recent years infrastructure has become a major research topic in both the UK and internationally. This has included investigations of the future of infrastructure and the resilience of infrastructure to climate change (e.g. Defra, 2011a). However, with some notable exceptions – the work of the Infrastructure Transitions Consortium (ITRC) and the recent work commissioned by Defra on improving the resilience of waste infrastructure (Winne *et al.,* 2012); the solid waste sector has typically been omitted from these studies.

## The solid waste sector

### The current situation

England currently produces about 177 million tonnes of waste a year (Defra, 2014a). In 2008, the UK's waste arisings were 289 Mt of which 101 Mt was construction and demolition wastes; 67.3 Mt was commercial and industrial wastes and 31.5 Mt household wastes, with the remainder consisting primarily of mining and quarrying wastes with smaller (<5%) amounts of agricultural wastes, sewage sludge and dredged material completing the picture. This paper will focus primarily on household and commercial and industrial waste, primarily because these are the waste streams that have been focused on by UK and EU legislation and because they are most likely to be affected by disruptions due to climate change.

### UKCP09 climate predictions

The outcomes of the UKCP09 modelling were summarised by Jenkins *et al.* (2009). The modelling and analysis in UKCP09 is complex and beyond the scope of this report but a brief mention needs to be made of the methods. Three emissions scenarios were analysed – high, medium and low, with medium being the most likely. For each scenario and climate-related parameter (e.g. summer peak temperature, annual mean temperature, mean winter rainfall), three estimates of change were produced. These were the central estimate (those at the 50% probability level); and changes which are very likely to be exceeded (10% probability level) and very unlikely to be exceeded (90% probability level). Projections were averaged over 30 year time periods, labelled by their central decade. Outputs on the UKCP09 website are usually given for the 2020s; 2050s and 2080s.
The most relevant predicted changes (relative to the 1961-1990 baseline) for the waste sector under the medium emissions scenario are that:

- summer, winter and annual mean maximum temperatures will rise, with the increase being greatest in southern England;
- mean minimum daily temperatures will rise, with the biggest increases in southern England;

- annual precipitation shows little change and no clear spatial pattern of change;
- winter precipitation increases in most areas, with the largest changes in the West;
- increase in peak winter precipitation;
- summer precipitation reduces in most areas with the largest changes in southern England.

These changes were predicted to become apparent in the 2050s and more pronounced in the 2080s.

## Solid waste infrastructure

The solid waste infrastructure system covers both waste *and* resource management - i.e. not only waste going to landfill but also resources reclaimed by recycling and processing. Recent publications by the government and NGOs on resource security (Defra, 2012a), resource efficiency (EC, 2011) and sustainable materials management (OECD, 2012) show that there is a move away from the linear view of resource management (extraction, manufacture, use, final disposal) towards a more circular view in which waste management becomes primarily a resource recovery operation (including energy recovery) and final disposal is necessary only for those materials from which further value can no longer be economically or technically extracted (Powrie & Dacombe, 2006). In the enhanced landfill mining (ELFM) concept, this is taken even further and landfill is viewed not as a final disposal route but as a "temporary storage place, awaiting future valorization" (Geysen *et al.,* 2009).

Solid waste infrastructure comprises transfer stations[1], material recovery facilities (MRFs)[2], recycling or other processing facilities (e.g. anaerobic digestion (AD)), landfills and incinerators[3]. There are three main sub-systems viz. collection, treatment and final disposal.

Waste tends to be categorised by generating sector, for example, household, commercial and industrial (C&I), construction and demolition (C&D), mining and quarrying and agricultural. Hazardous waste is categorized separately. For household waste, collection is from the kerbside or a bring site (e.g. bottle and textile banks; household waste recycling centre (HWRC)). Some commercial and industrial waste is collected along with green waste from parks and gardens or with household waste from the kerbside; this forms Local Authority Collected Municipal Waste (LACMW) formerly known as municipal solid waste (MSW). Licensed waste management companies collect the majority of the remaining commercial and industrial waste.

Until recently MSW was defined as waste collected by local authorities (Local Authority Collected Municipal Waste (LACMW)). This was changed in 2010 when the UK government

[1] i.e. sorting, recovering and consolidating waste prior to onward carriage to processors or disposal
[2] i.e. where waste is sorted prior to transport for recycling
[3] i.e. thermal treatment plant where waste is combusted usually to produce electricity in the UK

committed to the modification of reporting waste arisings to the EU and redefined MSW to include the parts of the C&I waste stream which has a broadly similar make-up to LACMW, particularly in terms of the biodegradable content. Together these are referred to as Local Authority Collected Waste (LACW). This was to ensure that the reporting of progress towards meeting targets for the landfilling of biodegradable waste as set out in the Landfill Directive (EC, 1999) was consistent across member states.. Under the new UK definition, MSW arisings have roughly doubled. LACMW recycling, recovery and disposal are the responsibility of local authorities, often county councils or unitary authorities. These bodies are also responsible for waste planning; providing facilities; assessing the suitability of sites; producing policy through their Development Plans and approving planning applications. LACMW collection is often the responsibility of district councils and unitary authorities, but much of this waste collection and the majority of waste treatment, recycling, recovery and disposal are actually carried out by large, multinational, waste management companies.

## Potential impacts of climate change

The key weather and climate related impacts on the solid waste system are likely to be:

- precipitation (possibly in conjunction with wind)
- temperature
- coastal erosion

The changes in climate are likely to affect the waste infrastructure both by changes in the extreme conditions (e.g. the hottest summers and wettest winters) and shifts in mean temperatures and mean seasonal rainfall. The ways these changes are likely to affect the waste infrastructure are outlined below.

The effects of climate change are different across the UK with the biggest changes occurring in central and southern England where about 60% of the population is concentrated. According to Winne *et al.* (2012), 68% of all English “major waste sites” and 65% of planned waste sites are located in this area which is also the area likely to be most affected by climate change.

Recent changes in legislation have led to a move away from spatially dispersed facilities towards a limited number of specialised facilities, thus leading to increased system vulnerability due to both the limited number of facilities and the increased requirement for transportation.

### During extremes

– UKCP09 shows increase in winter rainfall as well as increases in peak winter rainfall, which are likely to lead to increasing incidents of flooding and in turn generate high levels of unforeseen waste arisings which are likely to require landfilling – the more modern, process based infrastructure is generally rate or capacity limited and is therefore unlikely to be able to deal with very high levels of waste produced in a short time without a mechanism for storage. Landfill could be used as a temporary store to smooth waste flow but this would require landfills to be publicly owned or have a means of income from this holding function

- Extreme wind events (possibly coupled with heavy rains) may lead to coastal flooding (storm surges) with the same consequences as above
- Extreme rainfall events may result in excessive runoff from capped landfills or excessive leachate generation; although the landfill itself will have a buffering capacity that can be assessed using recently developed tools on liquid storage and flow (White *et al*., 2011)
- Potential vulnerability of certain sites to flooding or coastal processes (e.g. erosion of coastal landfills). For modern landfills, there should be plenty of warning of this but for older, poorly documented sites, the first warning may be the appearance of waste on beaches (NERC, 2008).

**Shifts in the mean**

- Increases in mean temperature may require more frequent waste collection of putrescible wastes, as is the case in Mediterranean countries at present.
- Reduction in rainfall in some areas may affect use of water for cooling in Energy from Waste (EfW) plant (Sinton & Greenwood, 2009).
- Composting and AD processes require water which may be scarcer in the summer due to reduced rainfall and increasing temperature.
- Increases in mean summer temperature or peak summer temperatures may lead to increased frequency of fires in collection vehicles; MRFs; stockpiles of recyclables awaiting reprocessing (e.g. paper, plastics, tyres) and landfills. There were 59 fires at recycling facilities in the UK in 2012 (Ryan, 2012) and insurers say figures are under-reported (Hudson& Fulford, 2013). Foss-Smith (2010) states that there are around 300 landfill fires in the UK each year. Yesiller *et al.* (2005) found that internal landfill temperatures are related to the temperature during waste deposition so higher peak temperatures are likely to lead to elevated landfill temperatures, which increases the risk of fire.
- Increases in mean summer temperature may increase odour, dust and vermin in waste processing facilities leading to difficult working conditions.
- Changes in patterns of rainfall may affect landfill leachate balances, degradation and gassing and have implications for leachate management system loadings.

## Key Vulnerabilities

Solid waste infrastructure can be thought of as consisting of three subsystems, each of which will be discussed separately.

### *Collection and transportation*

As most waste is dealt with locally, collection and transportation involves, primarily the road network. Some large sites and co-combustion sites (those which burn waste along with other materials to generate electricity (e.g. coal fired power stations) or heat (e.g. cement kilns)) are located by railways or rivers (e.g. Rainham landfill and Belvedere EfW, London's largest MSW treatment plant, are both dependent on the Thames for the delivery of waste).

In the future, the availability of low energy transport options may be a requirement for siting of new plant; Winne *et al.*(2012) have suggested that this is already happening.

In general, collection and transportation are likely to be affected by any climate related event that affects roads (e.g. flooding; high temperatures; snow and ice and high winds); railways (e.g. flooding; high temperatures and snow and ice), canals (becoming unnavigable during floods or prolonged drought) and major rivers (e.g. high river levels and flows due to extreme rainfall; floods; melt water or storm surge; low levels due to prolonged dry periods). The combination of reduced summer rainfall and increased winter rainfall is likely to lead to greater road and rail disruption due to increasing subsidence and embankment failure (Pritchard *et al.,* 2014). It should be noted that the issues described above are far more likely to affect the transportation of waste rather than collection which tends to occur locally. Any disruption to local collection is likely to also cause disruption to the waste generating processes (e.g. local flooding may also lead to local evacuation, hence households are producing no waste, at least until the floodwaters have subsided).

A percentage of UK waste is transported overseas. This is typically in the form of refuse derived fuel (RDF) being shipped to Europe for use in EfW plant due to over-capacity in Europe (Date, 2013 & 2014), although Defra are encouraging the development of more domestic capacity (Defra, 2014b); and shipment of recyclables to China and elsewhere (WRAP (2011) & Sloley (2011)). This export may be affected by all the issues described above and additionally shipping will be directly affected by flooding, high winds, storm surges etc. in the receiving port; sea level rise and delays due to increased frequency and magnitude of storm events in the shipping lanes. Winne *et al,*(2012) go into somewhat greater detail of possible disruptions in China and elsewhere as a result of climate change.

### *Treatment*

All treatment facilities (e.g. MRFs, AD, composting facilities, mechanical biological treatment (MBT) & mechanical heat treatment (MHT) plant and EfW) have the potential to be affected by the climate related events outlined above. All of these facilities require that the incoming wastes are stored inside, usually with a restriction on the maximum length of time material can be retained prior to treatment. On-site storage in an enclosed space may be affected by increased summer temperatures giving rise to issues with vermin, dust, odour and pathogens all of which are likely to impact those who work in the facilities primarily. According to Winne *et al.* (2012), over two thirds of all major waste sites in England are located in southern and mid England which is likely to see a summer mean temperature rise of between 1 and 4C by the 2020s. By the 2050s, all major English facilities are likely to see mean summer temperature increases of 6 to 8C. Flooding will directly affect treatment facilities either by making it difficult for staff to access them (which is also likely to affect delivery of waste to the facility); increased demand due to flood-generated waste in the facility catchment area or by direct flooding of the facility itself. Examination of UKCP09 and the AEA database of waste facilities by Winne *et al.* (2012) showed that the picture for mean winter precipitation is less clear, with some areas showing increases and others decreases.

However by 2050 all UKCP09 scenarios show an increase of 10-20% of winter precipitation, at least for central and southern England where much of the waste infrastructure is located. Flooding of waste facilities in flood plains and in coastal areas may also increase the risk of contamination of surface and groundwater (Wilby *et al.*, 2005).

### *Final disposal*

Final disposal is to landfill. Bebb & Kersey (2003) suggested that flooding and increases in precipitation may disrupt leachate and gas collection. Increases in summer temperature and reduction in summer precipitation may also lead to increased risk of landfill fires due to wastes being drier when deposited and generally warmer (Moqbel *et al.*, 2010). As for other waste facilities, flooding of operational landfill may increase the risk of pollution incidents. (Laner *et al.*, 2009) examined the risk of flooding of landfills in Austria together with the potential emissions during flooding assuming “complete landfill leaching and erosion.” and found that whilst many landfills were vulnerable to flooding the environmental risk was relatively small. The Environment Agency has assessed the risk to groundwater of existing (open and closed) landfills (EA, 2010a & 2010b) but it is not clear if the additional risks posed by climate change have been taken into account.

Coastal erosion is likely to be exacerbated by sea level rise and increased frequency of storm, leading to an increased risk of exposure of waste in coastal landfill sites (Cooper *et al.* (2012) & Chancerel (2008)) as occurred on the south coast in 2008 (NERC, 2008).

Increased summer temperatures may damage landfill caps or exposed portions of clay liners by desiccating the clay cover leading to cracks appearing, allowing greater water ingress and potentially leading to a breach of permitting conditions unless the leachate pumping system is able to deal with the increased volume.

Bebb & Kersey (2003) suggested that the change in climate may change the flora and fauna populating a closed landfill although it is not clear if this would be beneficial or detrimental to the integrity of the landfill.

A potential issue with the long term storage of wastes in landfill is that the duration over which waste must be stored prior to reaching a condition of equilibrium with its environment (the “final storage” condition) is very much longer than the period modelled in UKCP09 (Hall et al., 2004).

**Table 1: Summary of potential impacts on the solid waste sector due to climate change.**

| Climate Impact | Waste Subsystem | Effects |
|---|---|---|
| Mean temperature rise | Collection | Increased collection rate for putrescible wastes.<br>Increased fire risk in collection vehicles. |
| | MRF | Increased fire risk in sorting lines and in |

| | | |
|---|---|---|
| | | recyclate stockpiles.<br>Increased problems of odour and vermin. |
| | Reprocessor | Increased fire risk in recyclate stockpiles. |
| | Landfill | Increased risk of landfill fires.<br>Increased problems of odour and vermin.<br>Increased risk of desiccation and cracking of clay liners and caps with associated pollution risks. |
| Peak daily temperature rise | Collection | Increased fire risk in collection vehicles.<br>Increased risk of disruption due to road damage. |
| | Transport | Increased risk of disruption due to road damage and rail buckling. |
| | MRF | Increased fire risk in sorting lines and in recyclate stockpiles. |
| | Reprocessor | Increased fire risk in recyclate stockpiles. |
| Mean and peak daily winter rainfall rise. | Collection | Increased risk of disruption due to flooding. |
| | Transport | Increased risk of disruption due to flooding. |
| | Treatment | Increased risk of disruption due to flooding preventing delivery of waste to site which may lead to plant being shut down and hence reductions in energy supply. |
| | Landfill | Increased risk of flooding requires use of landfill to deal with increased waste generation rates.<br>Extreme rainfall leading to increased runoff.<br>Increased risk of flooding of landfill leading to pollution events. |
| | EfW | May be limitations on extraction of river water for cooling. |
| Mean summer rainfall reduction | Composting and AD | Scarcity of water required for degradation. Plant may need to stop taking waste. |
| | River transport | Increased risk of disruption due to low water levels. |
| Coastal processes | Landfill | Increased risk of erosion could lead to exposure of waste at coastal landfills. |
| Extreme wind events | Landfill | Increased risk of flooding requires use of landfill to deal with peak waste generation rates. |
| Wetter winters and drier summers | Transport | Increased risk of damage to road and rail due to increased rates of embankment failure and subsidence. |

## Cross sectorial interactions

The primary interactions between the solid waste sector and other infrastructures have been investigated in the authors' work with ITRC (Hall *et al.,* 2012 & 2014 & Tran *et al.,* 2014) and are detailed below.

### *Transport*

The majority of waste is moved by road transport with refuse collection vehicles (RCVs) collecting from households and businesses and haulage vehicles moving consolidated wastes and treated recyclables for recovery or disposal. Increasing demand for waste management will therefore increase the number of vehicle movements but these are unlikely to make large demands on transport infrastructure. In the event of failure of road infrastructure (e.g. heavy and prolonged snow fall), delays in getting putrescible waste to treatment or disposal facilities may cause health or nuisance problems. However, if delays are caused by snow, the risks are at least partially mitigated by the accompanying low temperatures. It is likely that periods of disruption to collection (e.g. snow, floods, fuel shortages, etc.) would create a backlog of waste which treatment plants would struggle to clear, hence a requirement for landfill. As most waste is dealt with locally, this will primarily involve the road network, although as already mentioned waste is also transported by rail and river. Export of wastes to Europe and elsewhere would have some impact on the transport sector although it is not clear how large an impact.

### *Energy*

The solid waste infrastructure depends on the energy sector. For example, the failure of electricity would disrupt most waste treatment services (e.g. leachate and gas extraction from landfills; operation of MBTs, MRFs and EfW) and disruption to liquid fuel supplies would affect transportation and collection of wastes as well as site operations at most waste facilities, necessitating the storage or stockpiling of waste and disposal to landfill. It could also prevent leachate pumping in landfills, increasing the risk of pollution events. Waste management infrastructure uses energy (electricity, gas and liquid fuels), but energy is also recovered from waste by combustion, recovery of high calorie materials such as plastic and paper in the form of fuels and the generation of electricity from landfill gas or biogas from anaerobic digestion. Energy generated from waste forms almost a third of renewable energy (DECC, 2013) and about 3% of the UK's electricity. However, energy from waste may become more important in the drive to increase the use of renewable fuels. In addition, recycling saves energy compared with the use of virgin material; however, this will only appear to affect the UK directly if the recycled materials are utilised here (i.e. closed loop recycling). Energy outputs are primarily electricity with the potential for heat, biogas (from AD or landfill) and syngas (from gasification or pyrolysis) to become more important in the future. Energy also contributes to the cost of solid waste services, for transportation and processing of waste.

### *Water*

Some waste treatment facilities require a water supply for treatment of wastes, e.g. composting and anaerobic digestion, in which water is used to aid biodegradation. Failure of the water supply to such facilities would lead to cessation or a reduction of treatment capacity and the need to dispose of the waste by alternative means.

### *Waste water*

Landfill produces large amounts of potentially polluting leachate which is typically treated on site before being disposed of through the wastewater network or direct to surface water. If local wastewater treatment facilities failed, the leachate could be tankered to alternative plants (although there would be costs associated with this) or treated to a higher standard, so the impact on landfilling would be minimal. Changing waste streams may make the leachate impossible to treat with the current biological systems. Sewage AD plant could be used to process biodegradable municipal waste (BMW). This would significantly increase both the plant throughput and gas yields and would necessitate plant upgrades and probably upgrading the transport network but at present seems not to be cost effective due to the need to macerate the MSW first. It may be that AD systems suitable for solid wastes could be developed on sewage treatment sites which could than treat MSW without pre-treatment, as well as sewage, farm wastes and other material suitable for AD.

### *ICT*

It is possible that there will be increased reliance on ICT in the solid waste sector e.g. smart bins dynamically modifying logistics of collection rounds. However, the adoption of a default sequence would minimise the effect of a loss of ICT services.

### *Flood and coastal erosion management*

For there to be no future impact of flooding on the solid waste sector, flood defences and flood resistance of property would need to be modified such that there are fewer waste-generating flood events than in the 1990s (increased moves away from landfill as a means of final disposal has made the system less resilient to these events and this trend will continue). Siting of future waste infrastructure away from flood risk zones should reduce the risks of loss of service. Coastal erosion has the potential to expose coastal landfills with the risk of uncontrolled pollution incidents (NERC, 2008). Coastal erosion may also affect other waste infrastructure, unless it is sited away from vulnerable coasts.

## Assessment and management of climate change risks

### Costs and/or relative magnitudes of these impacts

The National Adaptation Programme (Defra, 2013) makes no mention of solid waste infrastructure. The UK government report on climate resilient infrastructure makes little mention of the solid waste sector other than to observe its non-consideration and to commission the research that resulted in the AEA Technology report on resilience of waste infrastructure (Winne *et al.*, 2012).

Winne *et al*. (2012) state that the potential costs of adapting to climate change were a serious concern to waste stakeholders. However there is no detail of costs in their report and they also state that “resilience measures do not necessarily imply increased costs”. Bebb & Kersey (2003) discuss costs but do not quantify them.

## Adaptation opportunities

Winne *et al.* (2012) included case studies in their report on waste sector resilience. One such study was the Newhaven EfW plant in the south of England. It is built adjacent to a river and is designed to withstand 1 in 200 year floods, as is the main access road to the site. Winne *et al.* (2012) argue that the plant can be considered as integrated infrastructure as it is both a waste disposal and energy generation site. It has been sited close to the waste feedstock to minimize transportation distances. They argue that short supply routes make it less likely that the flow of waste will be disrupted by disruptions to the transportation network but in the event of the main access road becoming inaccessible for any length of time, the area will lose its waste disposal facility and the grid will lose part of its energy feed. It is not clear whether or not the integrated nature of the site makes it more or less resilient.

## Drivers of change in the solid waste sector

Figure 1 shows how UK MSW arisings have increased in the post-war period alongside the per capita GDP and population figures. Figure 2 shows per capita English MSW arisings since the early 90s and the apparent correlation between per capita GDP and per capita MSW arisings between 1995/6 and 2002/3. It is not clear whether or not a decoupling between waste generation and economic growth occurs after 2002/3, although the authors' work with ITRC would seem to indicate that regionally (the English government regions, Wales and Scotland), there have been reductions in waste arisings indicative of a decoupling from economic growth. A recent report by WRAP (2012) confirms this.

Over the last 15 years the increases in recycling and composting and the concomitant decrease in landfilling has been driven primarily by:

- European directives – the Landfill Directive (EC, 1999) and Waste Framework Directive (EU, 2008)
- The landfill tax and landfill tax escalator
- The 2000 and 2007 Waste Strategies (DETR, 2000 & Defra, 2007 respectively)

Research by SLR (2005) on behalf of the Chartered Institute of Wastes Management, showed that:

- a move to strategic regional planning authorities
- integration of planning across waste types
- compensation for communities hosting waste facilities (and other strategic infrastructure)

could significantly improve planning, remove the potential biases of some local authorities and ensure efficiencies of scale are accessed. An ad-hoc version of this has already developed in the South East with a group of five County Councils and two unitary authorities working in partnership (Defra, 2011). The ITRC Fast Track Analysis (Hall *et al.*, 2012) suggested that a single government department responsible for waste rather than the current split of departmental ownership of waste between planning (DCLG) and policy (Defra) could facilitate strategic planning.

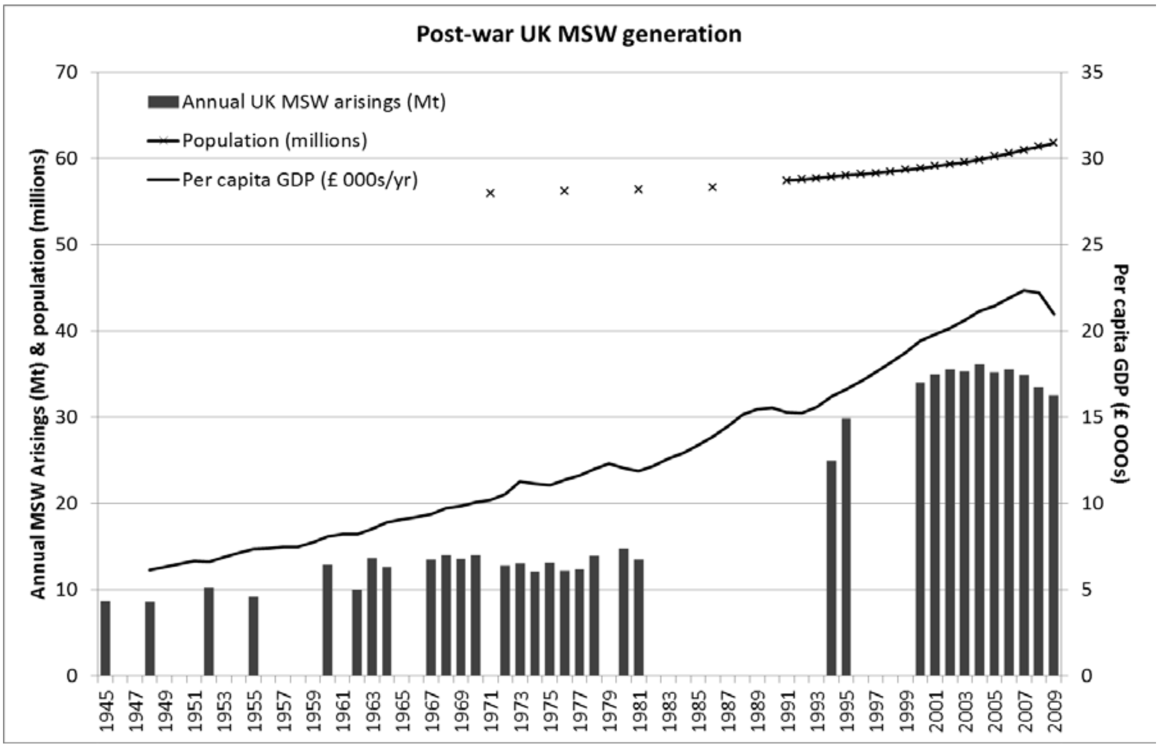


**Figure 1: Post-war UK MSW arisings (data from Brown *et al.*, 1993 and Defra)**

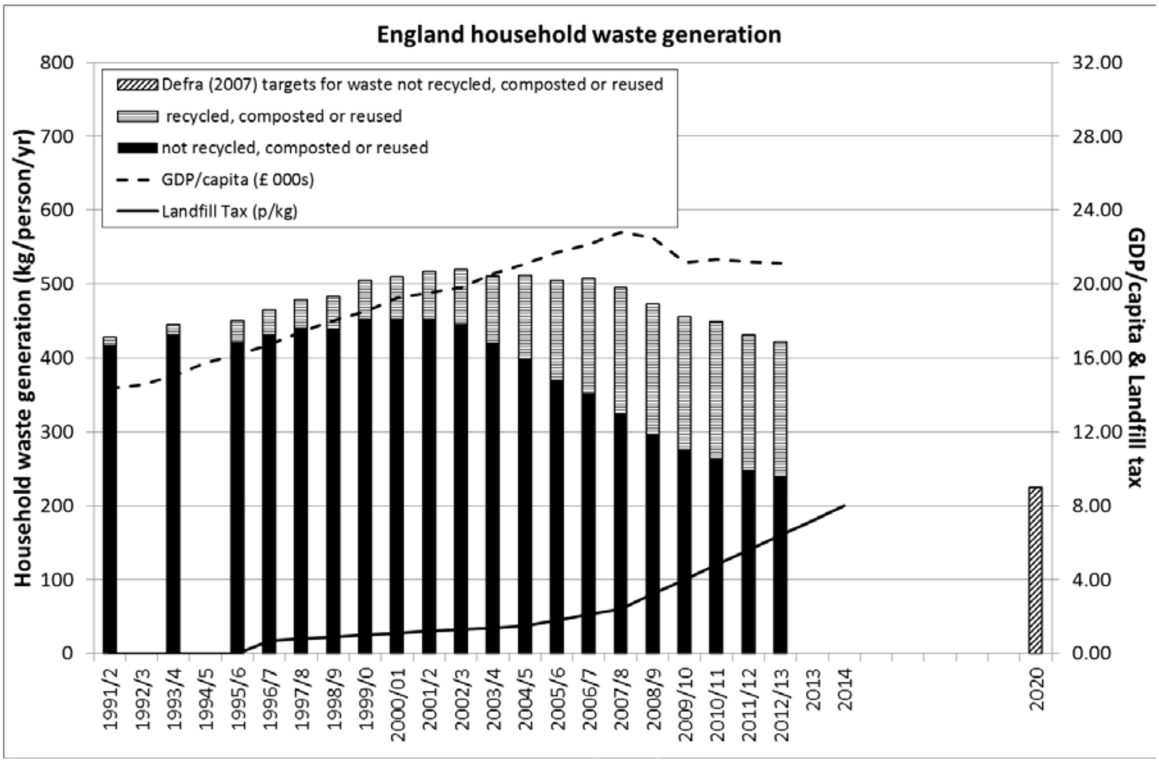


**Figure 2: Per capita household waste generation and GDP for England.**

At the end of 2013, Defra (Rogerson,2013) wrote to waste stakeholders stating that Defra will "not … take forward new policy work in areas such as commercial and industrial waste and construction and demolition waste, as well as proactive energy from waste policy development." The letter goes on to state that they will continue to invest in WRAP, which is encouraging given WRAP's success in working across sectors to reduce waste. According to WRAP's audited figures (WRAP, 2011), between 2008 and 2011, the organisation was responsible for diverting 12.3 Mtpa of waste from landfill and £2.2 billion of economic benefit per year. It is not clear, however, from WRAP's figures how much waste arisings have been reduced by their interventions.

What is clear from the Defra letter is that the Government is reducing its involvement in waste management. Hence it is likely that waste management policy, at least in England, will become increasingly localised and fragmented. It is also likely that without government targets and strategies, improvements in waste management - including the huge increases in recycling and composting that have happened this century - will slow dramatically.

## Understanding of the costs of impacts.

Clearly there are costs associated both with the impacts of climate change on solid waste infrastructure and the efforts that will be needed to mitigate these. Similarly, it is likely that extreme events (e.g. flooding and storm surges) will lead to increased waste arisings in the event locality, along with their associated costs for treatment and disposal. The costs associated with the latter tend to get lost in the overall costs of clean-up. For future infrastructure, it is clear that climate change will be taken into account during the planning stages and is likely to influence the siting of waste facilities and if necessary, stipulate means for the mitigation of climate related hazards e.g. bunds to reduce flood risk.

Winne *et al.* (2012) identified several impacts on UK waste management provision arising from climate change outside the UK, however with the exception of the impacts on the shipping of recyclables and RDF, it seems likely that these will not cause significant issues in the UK.
Disruption of the UK transport network will affect both the collection and transportation of wastes although it is not clear what the effects or costs will be to the waste sector. Disruptions to collections are likely to be localised.

## Confidence in the science.

Table 1 shows the likely effects of climate change on the solid waste sector along with the confidence in the likelihood of the climate-related events.

**Table 2: effects on solid waste management and infrastructure due to climate change and confidence in their likelihood.**

| Climate Factor | Effect | Confidence |
|---|---|---|
| Increased winter rainfall and/or increased peak winter rainfall | Increased waste arisings due to flood events | High |
| | Disruption to transport network due to flooding | High |
| | Flooding of landfill sites leading to increased risk of groundwater and/or surface water contamination | High |
| | Flooding of waste facilities leading to ground and /or surface water contamination | Med |
| | Disruption of energy supply leading to breaks in waste treatment services | Med |
| Increased frequency of winter storms | Increased storm damage to waste facilities | High |
| | Disruption to transport network | High |
| Sea level rise and increases in storm surge | Exposure of historic coastal landfill sites leading to pollution events | High |
| | Disruption to marine transportation of wastes | Med/High |
| Higher summer temperatures | Increased incidents of landfill fires | Med |
| | Increased incidents of fires in other waste facilities | Med |
| | More frequent waste collection required to reduce problems with vermin and odour | Med |
| | Disruption to transport network (e.g. rail buckling, highway damage) | Med/High |
| Increased frequency of | Shortage of water for AD and composting | Med |
| | Disruption to river and/or canal transportation due to | Med |

| | | |
|---|---|---|
| periods of drought | reduced water levels | |
| | Reduced river levels may lead to reduction in water available for cooling EfW plant | Low/Med |

## Research gaps and priorities

The 2012 Climate Change Risk Assessment (Defra, 2012b) did not include any assessment of solid waste infrastructure but stated that it “was not identified as a priority area as part of this first CCRA”. The Environment Agency has a document listing flood risks to regulated waste sites but this is not publicly available so it is unclear whether it lists risks to closed landfill sites which may number as many as 25 000 according to some sources (ESI, 2009). Many of these landfills are old and likely to be very largely inert; however, the EA regulates 2 600 of which 2 100 have closed in recent times, many of which will still be chemically and biologically active and hence capable of polluting the surrounding environment. It may be that research is needed to identify those at greatest risk.

There appears to have been little study on the economic effects of climate change on the waste sector or the sector’s resilience to changing climate. Winne *et al.* (2012) recommended that “the waste sector should be included within future cross-Government work exploring interdependencies and climate resilience”.

Further work is needed to quantify the likely frequency of some of the incidents described earlier.
There is a need for further research on the effects of flooding on both the magnitude of flood related waste arisings and their composition which is likely to differ significantly from the normal waste stream.

## Conclusions

It has been seen that changes in the climate and the weather will affect the solid waste infrastructure. It is likely that the main effects to the solid waste sector will be due to localised disruption of the transport networks affecting collection and transportation of wastes. Flooding is likely to lead to a localised increase in waste arisings. These flood events are likely to become more frequent. Disruptions to the supply of wastes to energy generating waste facilities (e.g. AD and EfW plant) could lead to a cessation of energy generation and hence a reduction of supply to the grid.
Increases in the summer temperature may require changes to collection practices towards the end of the century. Further research is needed to quantify the increase in waste arisings due to flood events and to determine the costs to increase the resilience of the waste sector.

## References:

**Bebb, J. & Kersey, J**. (2003). *Potential impacts of climate change on waste management*, Environment Agency, Bristol.

**Brown, K. A., Smith, A., Burnley, S. J., Campbell, D. J. V., King, K. & Milton, M. J. T. (1993).** *Methane emissions from UK landfills*. AEA Technology, London.

**Chancerel, R. (2008).** *A Preliminary Investigation of the Risks Associated with Marine Hazards for Coastal Waste Sites in the South East of England over the 21st Century.* MSc, University of Southampton.

**Cooper, N. J., Bower, G., Tyson, R., Flikweert, J. J., Rayner, S. & Dhv, H. A. O. R. H. (2012).** CIRIA 718: Guidance on the management of landfill sites and land contamination on eroding or low-lying coastlines London: CIRIA.

**Date, W. (2013)** *Sharp rise in RDF exports during 2012* [Online]. Available: http://www.letsrecycle.com/news/latest-news/energy/sharp-rise-in-rdf-exports-during-2012. [Accessed 11/3/13].

**Date, W. (2014).** *RDF exports top 1.5 million tonnes in 2013* [Online]. Letsrecycle.com. Available: http://www.letsrecycle.com/news/latest-news/energy/rdf-exports-top-1.5m-tonnes-in-2013.

**DECC (2013).** *Renewable sources of energy: chapter 6, Digest of United Kingdom energy statistics (DUKES).* Department for Energy & Climate Change, HMSO, London.

**Defra (2007).** *Waste Strategy for England 2007*. Department for the Environment, Food and Rural Affairs, HMSO, London. p.127.

**Defra (2011a).** Climate resilient infrastructure: preparing infrastructure for a changing climate. The Stationery Office, London.

**Defra (2011b).** *Government review of waste policy in England 2011*. Department for Environment, Food and Rural Affairs. London.

**Defra (2012a).** *Resource security action plan: making the most of valuable materials*. Department for Environment, Food and Rural Affairs. London.

**Defra (2012b).** *The UK Climate Change Risk Assessment 2012 Evidence Report* Defra, London. HMSO.

**Defra (2013).** *The National Adaptation Programme - Making the country resilient to a changing climate*. Defra, London: The Stationery Office.

**Defra (2014a).** *Reducing and managing waste.* [Online] https://www.gov.uk/government/policies/reducing-and-managing-waste [Accessed 30 May 2014]

**Defra (2014b).** *Energy from Waste: A guide to the debate*. Defra, London. The Stationery Office.

**DETR (2000).** *Waste Strategy 2000*. Department for Environment, Transport and the Regions, HMSO, London. p.54.

**EA (2010a)**. *Closed landfill initial screening exercise*. Environment Agency, Bristol.

**EA (2010b).** *Update 2 regulation of closed landfills*. Environment Agency, Bristol.

**EC (1999).** *Directive 1999/31/EC on the Landfill of Waste*. Official Journal of the European Communities.

**EC (2011).** *Roadmap to a resource efficient Europe*. European Commission, Brussels

**ESI (2009)**. *A number of recent developments will affect the management of closed landfills* [Online]. Available: http://esinternational.com/news/closed-landfills/ [Accessed 20 May 2014].

**EU (2000).** *Waste incineration directive*. 2000/76/EC. Official Journal of the European Union.

**EU (2008).** *Directive 2008/98/EC on waste*. Official Journal of the European Union.

F**oss-Smith, P. (2010)** *Understanding landfill fires.* Waste management World. [Online] http://www.waste-management-world.com/articles/print/volume-11/issue-4/Features/understanding-landfill-fires.html

**Geysen, D., Jones, P., Van Acker, K., Van Passel, S., Crabs, M., Eyckmans, J., De Blonde, M., Vrancken, K., Laenen, B., Laevers, P., Ballard, M., Bijnens, S., Sips, K., Umans, L. And Roos, J. (2009)**. Enhanced landfill mining - a future perspective of landfilling, in *Proceedings Sardinia 2009, Twelth International Waste Management and Landfill Symposium*. 2009. S. Margherita di Pula, Cagliari, Italy: CISA, Environmental Sanitary Engineering Centre, Italy.

**Hall, D. H., Gronow, J. R., R., S. & Blakey, N. (2004)**. Achieving equilibrium status and sustainable landfill — the holy grail? *Waste 2004 Conference Integrated Waste Management and Pollution Control: Policy and Practice, Research and Solutions.* Stratford-upon-Avon, Warwickshire: The Waste Conference Limited.

**Hall, J. W., Henriques, J. J., Hickford, A. J. & Nicholls R. J. (eds)** (2012). *A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Technical report*. Environmental Change Institute, University of Oxford.

**Hall, J., Henriques, J., Hickford, A., Nicholls, R., Baruah, P., Birkin, M., Chaudry, M., Curtis, T., Eyre, N., Jones, C., Kilsby, C., Leathard, A., Lorenz, A., Malleson, N., McLeod, F., Powrie, W., Preston, J., Rai, N., Street, R., Stringfellow, A., Thoung, C., Tyler, P.,Velykiene, R., Watson, G., and Watson, J.** (2014). *Assessing the Long-Term Performance of Cross-Sectoral Strategies for National Infrastructure.* J. Infrastruct. Syst., ASCE.

**Hudson, J. & Fulford, J. (2013).** *Arson about?* [Online]. Available: http://www.isonomia.co.uk/?p=2242

**Jenkins, G. J., Murphy, J. M., Sexton, D. M. H., Lowe, J. A., Jones, P. and Kilsby, C. G. (2009).** *UK Climate Projections: Briefing report*. Met Office Hadley Centre, Exeter, UK.

**Laner, D., Fellner, J. & Brunner, P. H. (2009).** Flooding of municipal solid waste landfills — An environmental hazard? *Science of The Total Environment,* 407**,** 3674-3680.

**Moqbel, S., Reinhart, D. & Chen, R.-H. (2010)**. Factors influencing spontaneous combustion of solid waste. *Waste Management,* 30**,** 1600-1607.

**NERC (2008)**. *Scientists to probe landfill exposed by coastal erosion* [Online]. Available: http://planetearth.nerc.ac.uk/news/story.aspx?id=205 20 May 2014].

**OECD (2012).** *Working party on resource productivity and waste: Sustainable materials management - a synthesis*. OECD

**POWRIE, W. & DACOMBE, P. 2006.** Sustainable waste management—what and how? *Waste and Resource Management,* 159**,** 101-116.

**Pritchard, O**., **Hallett, S. and Farewell, T. (2014).** Cracking up in Lincolnshire*. Geoscientist*, 24, 2, 14-19.

**Rogerson, D. (2013)**. Letter from Dan Rogerson to waste stakeholders dated 6/11/13 downloaded from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/255508/waste-stakeholder-letter-131106.pdf 14/1/14

**Ryan, S. (2012).** *Interactive: Map of fires at recycling centres.* [Online]. Available: http://www.mrw.co.uk/news/interactive-map-of-fires-at-recycling-centres-this-year/8640581.article

**Sinton, P. & Greenwood, R. (2009)**. *Tees Valley – Energy from Waste Facility 2009 Annual Performance Report*. Sita.

**Sloley, C. (2011)**. *Chinese demand for paper and plastics slows* [Online]. Available: http://www.letsrecycle.com/news/latest-news/paper/chinese-demand-for-paper-and-plastics-slows [Accessed 19/5/14.

**SLR (2005).** Delivering key waste management infrastructure: lessons learned from Europe. Chartered Institute of Waste Management, London.

**Smith, A., Brown, K., Ogilvie, S., Rushton, K. & Bates, J. (2001).** *Waste management options and climate change: Final report to the European Commission*, European Commission.

**Tran, M., Hall, J., Hickford, A., Nicholls, R., Alderson, D., Barr, S., Baruah, P., Beavan, R., Birkin, M., Blainey, S., Byers, E., Chaudry, M., Curtis, T., Ebrahimy, R., Eyre, N., Hiteva, R., Jenkins, N., Jones, C., Kilsby, C., Leathard, A., Manning, L., Otto, A., Oughton, E., Powrie, W., Preston, J., Qadrdan, M., Thoung, C., Tyler, P., Watson, J., Watson, G. and Zuo, C. (2014)**. *National infrastructure assessment: Analysis of options for infrastructure provision in Great Britain, Interim results*. Environmental Change Institute, University of Oxford.

**UKCP09 (2009)** *UK Climate Projections 2009*. From: http://ukclimateprojections.defra.gov.uk/

**White, J. K., Beaven, R. P., Powrie, W. & Knox, K. (2011)**. Leachate recirculation in a landfill: some insights obtained from the development of a simple 1-D model. *Waste Management,* 31**,** 1210-1221.

**Wilby, R. L., Hedger, M. & Orr, H. (2005)**. Climate change impacts and adaptation: A science agenda for the Environment Agency of England and Wales. *Weather,* 60**,** 206-211.

**Winne, S., Horrocks, L., Kent, N., Miller, K., Hoy, C., Benzie, M. & Power, R. (2012).** *Climate resilient infrastructure: preparing infrastructure for a changing climate.* Final report under Defra contract ERG1102, Defra, London.

**WRAP (2010).** *Comparing the cost of alternative waste treatment options*. Waste & Resources Action Programme, Banbury.

**WRAP (2011).** *Market Situation Report: Chinese markets for recovered paper and plastics - an update* [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/China%20-%202011%20update.pdf [Accessed 19/5/14].

**WRAP (2012).** *Decoupling of Waste and Economic Indicators.* [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/Decoupling%20of%20Waste%20and%20Economic%20Indicators.pdf [Accessed 22/5/14].

**Yesiller, N., Hanson, J. L. & Liu, W.-L. (2005**). Heat Generation in Municipal Solid Waste Landfills. *Journal of Geotechnical and Geoenvironmental Engineering,* 131**,** 1330-1344.