Sustainable and Resilient Infrastructure

ISSN: 2378-9689 (Print) 2378-9697 (Online) Journal homepage: https://www.tandfonline.com/loi/tsri20

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To cite this article: Phil Purnell (2019) On a voyage of recovery: a review of the UK's resource recovery from waste infrastructure, Sustainable and Resilient Infrastructure, 4:1, 1-20, DOI: 10.1080/23789689.2017.1405654

To link to this article: https://doi.org/10.1080/23789689.2017.1405654

SUSTAINABLE AND RESILIENT INFRASTRUCTURE
2019, VOL. 4, NO. 1, 1–20
https://doi.org/10.1080/23789689.2017.1405654

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On a voyage of recovery: a review of the UK's resource recovery from waste infrastructure

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ABSTRACT
This paper presents an overview of the U.K.'s Resource Recovery from Waste (RRfW) infrastructure. It introduces the waste management sector and its evolution into a resource recovery industry supporting a circular economy, and analyses key public-domain sources to review existing and planned infrastructure investment, regulation, capacity and new technologies. Most commentators predict a gap between capacity and demand, partly because planned developments are heavily focused on energy recovery; this moves focus away from activities higher up the waste hierarchy. Chronic, pervasive data deficiencies, political uncertainties and fiscal issues are major barriers to the sustainable development of a sector with real potential to provide modern jobs and services at home and for export. Regulation of the sector via environmental agencies, rather than a dedicated regulator for resource conservation, reinforces a cultural focus on waste treatment rather than resource recovery. All these factors impede progress towards the professed goal of achieving a circular economy.

ARTICLE HISTORY
Received 9 March 2017
Accepted 17 October 2017

KEYWORDS
Waste; infrastructure; resource recovery; recycling; policy

1. Introduction

The waste hierarchy prioritises prevention and minimisation of waste through e.g. design for durability, light weighting and reduced consumption. Nonetheless, significant amounts of waste continue to be generated globally that require management (United Nations Environment Program [UNEP], 2015).

Since the nineteenth century, U.K. local authorities (LAs) have had an obligation to collect rubbish (solid waste management) and provide sanitation (wastewater management), providing the public good and basic human right of preventing the health impacts of poor waste management. This obligation has been exercised via a changing mix of private contractors and council departments, which has evolved into the waste management industry. Originally focussed on 'municipal' waste (i.e. that collected from households and other premises) and wastewater, it now includes the management – i.e. collection, recovery of valuable materials, treatment and disposal of residuals – of commercial and industrial (C&I) wastes, construction and demolition wastes (CDW) and specific hazardous materials. The necessity for its existence stems from the linear 'take – make – discard' model of resource prevalent use in material-rich industrialised societies that dominate global consumption, where little thought is given to value of discarded materials because virgin materials remain relatively cheap. Traditionally, this industry has always derived some income by extracting high-value materials from waste (e.g. metals, fertilisers, re-usable artefacts) but its primary source of income is now the charge for the service it provides (UNEP, 2015; Velis & Vrancken, 2015).

By the mid-twentieth century, the role of waste management in preserving the environment (i.e. preventing environmental pollution and thus indirectly preserving human health) was recognised, adding a further driver for the expansion of the industry and associated regulation. In recent decades, this has manifested largely through various EU directives. Landfill diversion targets limit the amount of biodegradable waste allowed in landfills (to prevent methane emissions caused by their breakdown). The Waste Framework Directive sets high-level recycling targets (e.g. 50% for household waste, 70% for CDW) and also additional targets for traditional products and materials such as vehicles, packaging and batteries, and new products such as electronic equipment (see Sections 2.3 and 4.2). This has spurred the industry to develop facilities that classify, sort and recycle wastes; in many cases, some of these sorted fractions are now exported for reprocessing (Ekogen, 2011). A summary of activities undertaken by the industry is given in Appendix 1.

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1.1. Evolution of the sector towards a circular economy

A further evolution of the industry's function is in progress, from ensuring safe disposal to a focus on resource recovery, including retention of materials through reuse, recovery of materials through recycling or composting, and recovery of energy including the production of waste-derived fuels (Institution of Civil Engineers [ICE], 2016). This is driven by social and legislative pressure to move towards a 'circular economy'. The linear model of resource consumption relies on continued availability of virgin materials, which are in finite supply. As these resources become scarce, the economic and environmental costs of extracting them both rise exponentially, countries may become vulnerable to material security issues, and the linear model becomes unsustainable. In a circular economy, technical products and materials are designed to be reused and recycled with minimal energy input while biological materials are designed to be non-toxic and compostable, eliminating wastes as we currently view them.[1] There is a greater focus on preserving the service or utility that materials and products provide (e.g. by leasing rather than purchase), keeping products in service for longer (by designing for upgradeability and refurbishment) and 'closing the loop' (making sure that at the end of a product's life, its constituent materials are wholly recycled into products of equal or greater value). Current recycling practices predominantly produce reprocessed material only suitable for 'lower-grade' applications – i.e. for products of less value or utility compared with the products from which the recyclate is sourced, so-called downcycling – and thus demand for virgin materials remains higher than that for recycled materials. The first step towards a close-to-circular economy will require the elimination of downcycling and thus reverse this balance of demand.

For the waste management industry, this means a fundamental change of activity to include not only end-of-pipe treatment of discarded materials, but also engaging with stakeholders upstream (e.g. manufacturers, designers) and downstream (e.g. material reprocessors) (Velis & Vrancken, 2015). The new scope for the industry is set out in the Global Waste Management Outlook (UNEP, 2015) and includes waste prevention, minimising both arising and residual waste, embracing resource management concepts such as extended producer responsibility and embracing the circular economy concept that energy recovery and landfill represent leakage of value and must always be a last resort.

The evolution of the resource recovery infrastructure will involve changes not only in waste management but also in product specification, design and use that promote the retention, recovery and reuse of the function provided by products, as well as recycling of the materials or recovery of the energy they contain. The UK recycling sector should be reimagined to include tangible input from manufacturers. Designing for recyclability, designing out waste, eco-packaging and light weighting to drastically reduce waste volumes[2] will be essential, as waste minimisation offers the greatest 'bang for buck' in reducing waste volumes and their direct (through pollution) and indirect (through reprocessing) environmental impacts (ICE, 2016). This will require the partial transfer of responsibility for end-of-life resources from the public sector – where responsibility currently lies via LA waste management obligations – to supply chains. Extended producer responsibility requires that the producers of products and packaging retain some responsibility for these materials throughout the lifecycle, obliging them to either fund waste collection systems or integrate disassembly and remanufacturing into their operations (Velis & Vrancken, 2015). This would improve incentives to reduce waste through design for recycling as it would reduce direct costs, encourage better recyclate and secondary materials markets (Environmental Services Association [ESA], 2016), and minimise waste exports (ICE, 2016). It could also promote reuse, especially if combined with cross-sector engagement activities and support packages for the 'micro enterprises' that are common in the reuse sector (Chartered Institute of Waste Management [CIWM], 2016).

Reuse has been described as the 'neglected child' of the waste hierarchy (CIWM, 2016). While there are established markets for reuse in some areas (motor vehicles, antiques) and guidelines for the reuse of some products (e.g. WEEE PAS141, see footnote[3]), the potential significant contribution of reuse towards a circular economy remains dormant. The reuse sector is dominated by organisations with charitable and social aims. This ability for reuse to simultaneously deliver financial, social and environmental benefits is key to its promotion as an important enabler for waste prevention; reuse partnerships between private and third sector organisations can be leveraged via a Corporate Social Responsibility agenda. However, such relationships are currently ad hoc and often driven by key individuals. A stronger policy framework together with fiscal incentives that encourage more coherent investment in reuse will be required to build capacity in the sector (CIWM, 2016). Other recommendations include extending retailer 'take back' schemes, prioritising reused goods in public sector procurement, adopting British Standards for remanufacture in design to promote repairability, and using the Green Investment Bank to support innovative products designed for reuse (Local Government Association [LGA], 2014).

1.2. A continued role for waste management

Although such 'upstream' incentives will deliver the most effective responses in the medium term, waste management by LAs will remain important in the short-term. By 2020, up to 47 Mtpa of household waste will be recycled; a 20% increase on current rates (Green Investment Bank [GIB], 2014). To install this necessary extra capacity, especially as new technologies come online, more coherent investment planning will be required and LAs must work together to exploit economies of scale. Larger scale investment in energy recovery technologies such as gasification will require careful collaboration between energy companies (as energy recovery from waste will only ever be a small fraction of total generating capacity) and the waste sector to secure reliable supplies of waste material. Financing is severely affected by reliability of supply, and current individual local authority waste contracts cannot be used as financial security (ICE, 2016).

In the wastewater sector, a greater emphasis will emerge on 'green infrastructure' solutions that naturally remove pollutants from wastewater and provide buffering against flooding. Sustainable drainage systems combine reed beds, infiltration ditches and swales to allow discharge to the ground, retaining and absorbing run-off close to the source, reducing the amount of storm water reaching sewers and hence reducing wastewater treatment demand. Other demand-side interventions will be required (e.g. harvesting rainwater, reusing grey water) but technical, health and cultural barriers must be overcome, especially for retrofit to existing housing. Careful planning of new housing developments to reduce household water will also be essential (Hall, Thacker, Ives, et al., 2017; ICE, 2016). Studies of household water reuse in the U.K. show that strategies combining 'water efficiency, awareness and monitoring, rainwater harvesting and on-site wastewater reclamation and reuse for non-potable applications' can effectively reduce water use (compared to traditional properties) through e.g. use of water-saving appliances (40%) and use of reclaimed water (10%) (Wilcox, Nasiri, Bell, & Rahaman, 2016). However, the operational costs of the associated decentralised treatment infrastructure are much higher.

Dealing with water quality issues 'at source' can often be implemented for less than 20% of traditional end-of-pipe treatment. This can include working with local farmers and landowners to develop pesticide management plans, or financially incentivising the use of alternative pesticides and/or physical facilities that limit run-off. Education of public and commercial customers to discourage activities that cause wastewater treatment issues e.g. the disposal of fats, oils and grease into drains, also provides significant cost and environmental savings (OFWAT, 2015). Opportunities for the water and solid waste sectors to work together (e.g. co-digestion of food waste with sewage sludge) are technically well-developed but often impeded by cross-sector regulatory issues that impede collaboration (Iacovidou, Ohandja, & Voulvoulis, 2012).

1.3. New technologies require new resource management

A number of technological opportunities and challenges will arise in the resource recovery space as a result of changes in the mix of materials used in our products and infrastructure. These must be addressed by a combination of design for recovery and development of end-of-life recovery technologies. These include (The Knowledge Transfer Network [KTN], 2016):

- Technologies to recover the valuable and critical materials used in low-carbon energy and transport systems, in particular lithium and cobalt (used in high-performance batteries in electric vehicles) and rare-earth metals (used in high-strength permanent magnets for electric motors in vehicles and generators in wind turbines)
- Increasing use of composite materials and/or multi-material products (such as insulation-backed construction blocks and sheets)
- Decommissioning of North Sea oil infrastructure and first-generation wind turbines
- Bio-based, bio-inspired and biodegradable packaging materials will require specialist reprocessing (e.g. to capture methane through composting) rather than allowing the false encouragement of 'safe discarding'
- Advances in robotics, automation and sensing/vision technology will allow a wider range of materials to be more efficiently and reliably sorted especially if combined with tagging of materials for easy identification
- Opportunities and challenges presented by hyper-connectivity i.e. the 'Internet of Things', both in terms of data management and exploitation (opportunity) and the inclusion of WEEE in almost every item of packaging, clothing etc. (challenge).

Waste management is mentioned in the U.K.'s National Infrastructure Plan[4] (NIP) (Infrastructure and Projects Authority [IPA], 2016) as forming part of the UKCRIC science and infrastructure research investment[5] and this will stimulate research into more advanced systems.

Such advances in resource recovery technology must be considered alongside upstream policy, design and business innovations; they are interdependent. Upstream interventions need to prepare the system such that any downstream wastes are matched to the availability, capacity and evolution of emerging processing technology; technological advances in the waste processing sector must develop mindful of the ability of upstream processes to provide secondary materials of the correct quality and quantity to make them commercially, environmentally and socially viable. Too often new recovery processes are developed with no markets, or interventions are made that rely too heavily on localised or unproven reprocessing technology. Without effective public communication campaigns that help householders understand the need for and benefit of recycling, the full potential of new infrastructure will not be realised (Farmer, Shaw, & Williams, 2015). Understanding the interactions between infrastructure, services (the systems and providers that enable recycling) and behaviours, and intervening intelligently in all three domains at a local level, is essential if enhanced resource recovery rates are to be achieved (Timlett & Williams, 2011). A further key aspect of this is skills and education; the industry has reported that there are skills gaps both within the sector (e.g. insufficient energy from waste technicians) and outside it (e.g. a lack of manufacturing and packaging technologists able to make use of secondary materials) (Ekogen, 2011).

1.4. Are we ready?

The U.K.'s current waste management infrastructure has evolved from arrangements to transport waste to landfill or water bodies and retro-fitting recycling onto these systems has so far delivered little of the necessary transition (Benton & Hazell, 2014). Nonetheless, the U.K. Government's National Infrastructure Plan (NIP) (IPA, 2016) aims to have the right infrastructure in place to deal with waste, and an ambition to move towards a circular economy. This report reviews the current state of the U.K.'s resource recovery infrastructure to help assess whether we are ready to fulfil this ambition. As we are at the early stages of this transition phase between waste management and resource recovery, much of this focuses on existing and planned waste management infrastructure.

2. Existing infrastructure

2.1. Economics and investment

The U.K.'s waste infrastructure is normally considered as split across two sectors; wastewater treatment and solid waste management. Wastewater treatment is the responsibility of the U.K.'s water industry (most of which is in private ownership) funded via household and commercial water services bills. Responsibility for solid waste management (i.e. collection and treatment) is devolved to local authorities (LAs) and is their third largest expense after education and social care (ESA, 2016). Collection is normally contracted out to private companies, as is the construction and operation of waste treatment infrastructure, although LAs retain some capability, especially for municipal trade wastes.

The waste and resource management sector turns over ~£11Bn annually. The 'Water and Waste Management' sector in Office for National Statistics reports has grown steadily, with an index of production (2013 base) rising from 72.5 in 1997 to 110.3 in Q3 2016.[6] In economic terms, the waste management sector adds 0.5% to U.K. gross value added (GVA), split between (2014 figures from Department for Environment, Food & Rural Affairs [DEFRA], 2016b) waste collection (£2.9Bn), waste treatment and disposal (£1.7Bn) and materials recovery (£1.6Bn). The sector is dominated by the so-called 'big six' waste management companies[7] who have a market share of 70–80%. The sector employs 140,000 people split between remediation (12k), wholesale of waste and scrap (5k), materials recovery (24k), waste treatment and disposal (40k) and waste collection (58k). There was a 50% increase in the number of employees in the sector between 1993 and 2013 (DEFRA, 2015).

The repair, reuse and leasing sectors – arguably operating higher up the waste hierarchy – added a further £40Bn, over half of which can be attributed to the repair, renting, leasing and second-hand sales of motor vehicles (DEFRA, 2015). In Scotland, it is estimated that reuse of furniture, electrical items and textiles has a turnover of £244M pa, employing 6000 people. A further 3000 fte volunteers were also engaged, highlighting the anti-poverty and social need agendas that drive many of the actors in the sector, who are often associated with one or more charities (CIWM, 2016).

Investment in new infrastructure is largely private, although some support has previously been provided through public–private partnership finance schemes. However, none of the NIP pipeline waste projects has a public–private funding arrangement and the proportion of public money invested in the sector is only 3%; the lowest among the seven infrastructure sectors considered in the plan. Some schemes try to encourage investment in infrastructure; revenues derived by reprocessors from the sale of packaging recovery notes (PRNs) to packaging users are supposed to be invested in new reprocessing infrastructure[8] (see Section 5 below).

2.2. Waste arisings and resource recovery

Annual solid waste production (often referred to as arisings) is around 200 million tonnes (Mt, 2012 figures); 186 Mt enters final treatment of which half undergoes some sort of recovery (including backfilling), a quarter goes to landfill and a fifth to land treatment or release into water bodies. The remainder is incinerated, with about a quarter having an energy recovery component. Half of waste arisings are generated by construction, just over a quarter by commerce and industry, with the remainder split equally between households and 'other' sources (DEFRA, 2016a, 2016b). The range of solid waste management activities undertaken by the sector is summarised in Appendix 1 (Ekogen, 2011).

U.K. waste production is decreasing and the proportion diverted from landfill has been increasing since the 1990s, driven largely by EU targets (Farmer et al., 2015). Recycling or composting of U.K. waste arisings has increased from nil to 45%; there has been a 71% reduction in biodegradable waste going to landfill between 1995 and 2015, and 73% of packaging waste was recovered or recycled in 2013 (against a target of 60%). Energy from waste accounts for a third of U.K. renewable energy generation, and exports from the U.K. of refuse-derived and/or solid recovered fuels (RDF and SRF) has grown from 0.25 Mt to 3.4 Mt per annum (Mtpa).

Nonetheless, only half of the U.K.'s 200 Mtpa solid waste arisings undergoes any value recovery at all, and some EU targets have not yet been achieved. Forty-five per cent of household waste was collected for recycling (of which a significant proportion is contaminants that must be removed) in 2014 against a target of 50% for 2020, and 30% of waste packaging still goes to landfill (DEFRA, 2016b; Eunomia, 2016; ICE, 2016). There are significant regional and local differences in progress towards the various targets (Farmer et al., 2015).

In economic terms, the reuse sector is dominated by reuse, repair and leasing of motor vehicles but capacity or arisings figures on a mass basis are not given. Analyses beyond motor vehicles are rare. Back-calculation from DEFRA figures (DEFRA 2015) suggests that 0.5 Mtpa of clothing is reused in the U.K. each year, with around 30% of this being exported. In Scotland it is estimated that reuse of furniture, electrical items and textiles accounts for 89 ktpa of material. It is estimated by local government organisations that the potential scale of reuse in the U.K. could be 660 ktpa with a value of nearly £0.5Bn (CIWM, 2016).

Wastewater treatment demand is ~11 billion litres per day (DEFRA, 2012). Total investment in sewerage services 1990–2015 was £39Bn. The residue from wastewater treatment is sewage sludge. Around 75% is used in agriculture to improve soil, where it is referred to as biosolids, 15% is incinerated and a small fraction used or disposed of on other ways. The digested sludge is mixed with lime (CaO) generating heat and high pH to kill off harmful microorganisms, and then dried at >100 °C and mixed with other compostable materials (green waste, woodchip, straw) before application to farmland. Biosolids can help provide a variety of nutrients to soil including nitrogen, phosphates, potash, manganese and sulphur as well as stable organic matter essential for good soil structure.

2.3. Regulation

Regulation (i.e. implementation and enforcement of policy) in the waste sector is similarly split. For the U.K. overall and England in particular, OFWAT (the water regulator) is responsible for wastewater treatment, and the Environment Agency is responsible for solid waste management. In Wales, responsibility for both sectors lies with Natural Resources Wales. In Scotland, the respective regulators are the Water Industry Commission for Scotland (WICS) and the Scottish Environmental Protection Agency (SEPA). In Northern Ireland, water regulation falls to the Utility Regulator and waste management licences are issued by the Northern Ireland Environment Agency (NIEA). Policy and regulation is designed to create a market-based operating environment that 'drives the right incentives' (ICE, 2016) and has as key tenets the protection of public health, preventing contamination of water supplies and the environment, and the diversion of solid waste (particularly the biodegradable fraction) from landfill. Much is driven by EU targets for recycling/collection rates, water quality standards and discharge consents (see Section 4.3 for more details). All of these regulatory bodies have as their primary goal the protection of public health and/or the environment, rather than a focus on a move towards a circular economy, resource recovery or recycling.

The U.K. is '99.9% compliant' with EU wastewater directives, although some anomalies remain. The 16 Mtpa of untreated wastewater is discharged into rivers owing to overflows in Stratford (London); Brighton and Hove remains as the only large urban area without a secondary treatment system. Schemes are in place to address these (DEFRA, 2012).

2.4. Data on existing infrastructure capacity

Data from key U.K. public sources on the capacity of waste infrastructure and the amount treated is presented in Appendix 2. DEFRA (2015) reported U.K. waste management capacity as of 2012 under four headings. The first two (energy recovery and incineration) are reported with the number of facilities and the total capacity in Mtpa (totalling 11.3 Mtpa, correlating with the operational residual waste processing facilities listed in the DEFRA Waste Infrastructure Delivery Programme Residual Waste Treatment Infrastructure Project List, WIDP-IPL[9]). Other investigators (Eunomia, 2016) report that the U.K.'s effective treatment capacity for residual waste is 19.5 Mtpa including 19 IED (industrial emissions compliant) biomass and co-firing plants and 8 cement kilns. Energy generation from biowaste is reported at the U.K. level (DEFRA, 2016b) but only in terms of energy production, not the mass of biowaste treated, and so these two figures cannot be easily reconciled.

The third category (recovery other than energy recovery, including backfilling) only reports number of facilities (3452), with no capacity. The final category (landfill) reports number of facilities (594) and capacity in different units (633 Mm^3). Thus, an overall figure for waste treatment capacity in physical (i.e. mass and/or volume) terms cannot be reported.

In each of the four categories above, figures for England are also reported, but not for other U.K. countries. When additional country-level figures for capacity are examined, a familiar picture emerges. Figure 1 shows how the 187 Mt of waste generated in England in 2014 was managed across 6305 sites accepting waste in seven categories according to DEFRA figures (DEFRA, 2016b) (see Appendix 2). The mass figures are for treatment, not capacity; and since they are reported under different categories to those previously used for 2012 capacity data, it is very difficult to calculate the degree to which capacity is being reached. The only category which is the same both for reported capacity and treatment figures is incineration, with figures of 8.0 and 8.6 Mtpa respectively; i.e. either incinerations plants are operating at close to 100% (even allowing for fluctuation between 2012 and 2014 in the amount being incinerated) or some incinerators are included in the treatment figures but not the capacity figures.

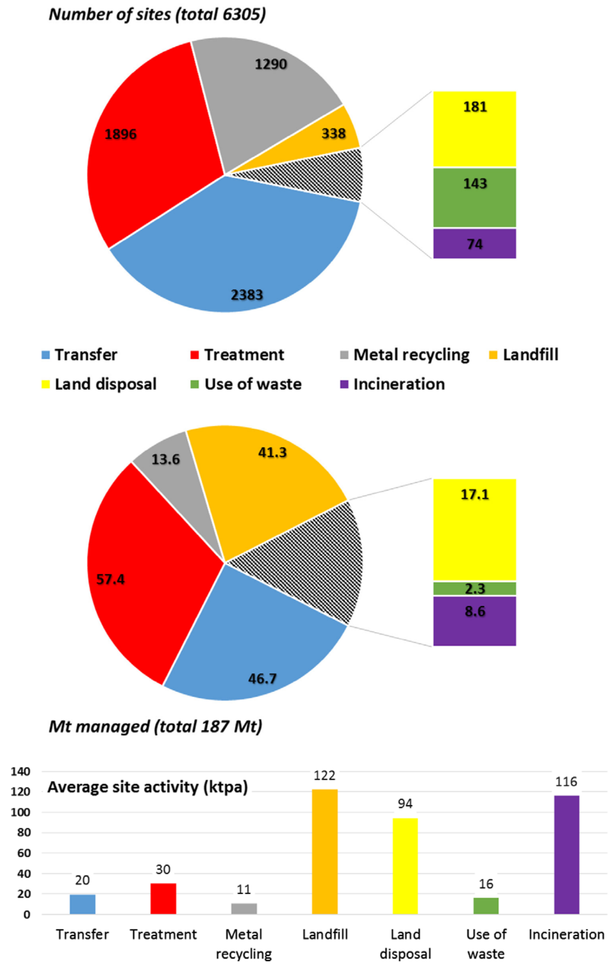

Figure 1. Analysis of waste processing facilities in England (2014 DEFRA figures).

In all categories, there are significantly fewer sites accepting waste than those permitted to in 2014 (ranging from 50% of sites accepting metals to 75% of transfer stations accepting waste) suggesting there is unused capacity in the system. Remaining landfill life based on 2014 inputs varies from 3 years in London to 13 years in the West Midlands.[10]

Capacity data for Scotland[11] (see Appendix 2) are reported under yet another set of categories, (landfill, incineration, civic amenity/recycling centre, vehicle/metal recycler, transfer station, composting, anaerobic digestion, other) and organised by site. Eight hundred and two operational sites are listed with a total permitted capacity of 54 Mtpa. Twenty-one sites undertake multiple activities, accounting for 30% of total waste inputs/treatment thus it is not straightforward to allocate capacities to each activity. Total waste inputs in 2014 were 17 Mt (i.e. around 10% of the figure for England and less than a third of the permitted capacity) of which 9 Mt was treated or recovered. This suggests that 8 Mt went to landfill and that the average Scottish landfill site handles ~140 ktpa (similar to the 122 ktpa figure derived for English landfills, see Figure 1). However, using English site activity figures for other types of process (where equivalency can be assumed) and aggregating significantly overestimates total Scottish waste processing, implying that the average site activity in Scotland is much smaller than in England.

Capacity data for waste processing facilities in Wales and Northern Ireland are not reported, and thus can only be inferred from waste processing data (in terms of waste processed other than by landfill, ~1 Mtpa in Wales and ~0.6 Mtpa in NI). Once again, different reporting categories are used in each case (see Appendix 2).

With regard to wastewater treatment capacity, The U.K. has over 600 km of sewers that collect 11 Mm^3 of wastewater each day. There are three key systems: surface water drainage; combined sewerage that collects wastewater and rainwater run-off from domestic, industrial and commercial premises; and foul drainage. These may interconnect in various ways depending on the local availability of water bodies into which surface waters can discharge

(DEFRA, 2012). A brief description of treatment processes and capacity is given in Appendix 3. There are no direct data on sewage sludge treatment capacity, so we must look at production data. As with the solid waste data, there are inconsistencies. Figures for the production of sewage sludge vary from 3–4 Mtpa (U.K. Water Industry Research Limited [UKWIR], 2015) to 1.4 Mtpa (DEFRA, 2012), presumably reflecting whether data on 'wet' or 'dry' sludge is being reported. The fraction of sewage sludge used as biosolids undergoes anaerobic digestion as a first phase of treatment. Small-scale plants use the biogas generated to run the digesters. Larger plants provide biogas for off-site CHP plants. No data are reported on the national capacity of such plants.

Even this relatively brief analysis of the data shows the statistics on the U.K.'s waste and resource recovery infrastructure (particularly for solid waste) are scattered, inconsistent and riddled with definitional and coherence issues. This makes it very difficult to produce a concise overview of waste infrastructure capability (what can be treated and how) and capacity (how much can be treated). Double counting is also likely to have taken place as an item of waste may pass through two or more processing stages. As noted by Vinogradova, Gandy, and Aplin (2013),

> mixed waste might be accepted by a transfer station, sorted and then be transported to a recycling facility or for final recovery or disposal. For this reason, waste managed is not analogous to waste arisings and no direct comparison can be made.

Even within the waste treatment supply chain, data is non-standardised. DEFRA (2016a) report that:

> Generation and final treatment are at opposite ends of what can be a complex and multiple staged treatment process. Different methodology is used to estimate generation and final treatment figures. Furthermore, final treatment excludes some treatment processes identified as predominantly intermediate, which nevertheless may effectively be the final treatment for some waste. As a result, there is no direct reconciliation between generation and final treatment of total waste. Users should also be aware that in most cases it is not possible to estimate the final treatment of waste generated by specific economic activities.

Capacity in the reuse sector does not appear to have been reported in quantitative terms. The sector includes large organisations that generate income from a closely targeted range of products and smaller scale operations that are less choosy; both these have the capacity to engage with LAs and the waste management sector for mutual benefit. There are also smaller organisations, perhaps with only one or two outlets or micro-organisations that operate without retail premises that are less likely to have the capacity to engage. Virtually, all organisations have a charitable fundraising agenda. Of 157 LAs surveyed by CIWM, 25–43% had a contractual relationship with a reuse organisation for major classes of reusable goods (white goods, furniture, WEEE and textiles); of 42 waste management companies, 10–25% had such a relationship (CIWM, 2016).

2.5. Planned infrastructure

The WIDP-IPL (see 2.4 above) lists 34 residual waste treatment projects as being in the pipeline having a total capacity of 8.5 Mtpa, with:

- 7.5 Mtpa (30 projects) of EfW
- 0.6 Mtpa (3) of biodrying mechanical and biological treatment (BMBT) and
- 0.4 Mtpa (1) of landfill mechanical and biological treatment (LFMBT).

The National Infrastructure Plan Pipeline (IPA, 2016) highlights 10 of these projects totalling £0.5Bn (Table 1 and Figure 2).

Public investment in water and waste projects listed in the NIP is less than 5% (of a total £19.7Bn) and PPP investment appears to be negligible, in contrast to all other sectors except energy.

Of these 10 listed projects, 8 involve EfW but only 2 have any mention of recycling; none mention other forms of resource recovery, re-use, remanufacturing or reprocessing. The perception that EfW is a more stable revenue stream with predictable capital costs is the most likely explanation. No waste or resource recovery programmes are listed as priority projects; the NIP explicitly states that no further investments are planned as the UK is on track to meet landfill diversion targets. It is difficult to see how the focus on this driver alone can be reconciled with the NIPs stated aim 'to have the right infrastructure in place' to achieve its ambition to move towards a circular economy. While there might be sufficient infrastructure investment in place to deal with annual growth in 'business as usual' scenarios, the radical changes needed to realign waste management infrastructure with the future role of the industry in achieving a circular economy (as outlined in 1.1–1.3 above) will require a very different pattern of investment and incentives. Even if such radical changes are slow in coming, the more pressing potential impact of the U.K.'s decision to leave the EU ('Brexit') on waste management legislation will change existing assumptions on the evolution of required capacity (see Section 4.3).

2.6. New technologies and research

Advances in resource recovery technology will allow a wider range of useful materials to be recovered from waste

Table 1. Pipeline of selected waste processing infrastructure (total capex cost) (IPA, 2016).

Surrey County Council	Quest waste disposal project	Anaerobic digestion and gasification plant within a new Eco-Park (£102M)
Cornwall	Waste management procurement	A 33-year semi integrated project, provision of all waste services (except collection) and infrastructure for materials handling, household waste recycling centres, transfer facilities, energy from waste and landfill (£202M)
Derby City Council and Derbyshire County Council	Derbyshire PPP waste management project	EfW infrastructure combining recycling capacity with an advanced gasification plant capable of generating power for up to 14,000 homes (£130M)
Gloucestershire County Council	Gloucestershire County Council waste management project	EfW facility with a capacity of 190 ktpa (£150M)
Milton Keynes	Milton Keynes waste management project	EfW facility to process non-recyclable and non-hazardous household waste using gasification technology to produce syngas and high-temperature steam capable of generating 7 MW of electricity (£n/a)
South London waste partnership	Waste management procurement	Waste treatment plant forming part of 25-year contract with the South London Waste Partnership (£191M)
Herefordshire & Worcestershire	Waste management project	EfW facility as part of an integrated 25-year contract for municipal waste management services (£166M)
North Yorkshire & City of York	Waste management project	PPP project for the construction of EfW facility (£300M)
Merseyside recycling & waste authority	Waste management project	430 ktpa Combined Heat & Power (CHP) Energy from Waste (EfW) facility supplied from a rail transfer station (£261M)
West London waste authority	West London waste authority	EfW facility will manage up to 300 ktpa of residual municipal waste (£231M)

In addition, there are two major planned investments in wastewater; the £635M Lee Tunnel (https://www.thameswater.co.uk/leetunnel) and the £3.1Bn Thames Tideway Tunnel (https://www.tideway.london/).

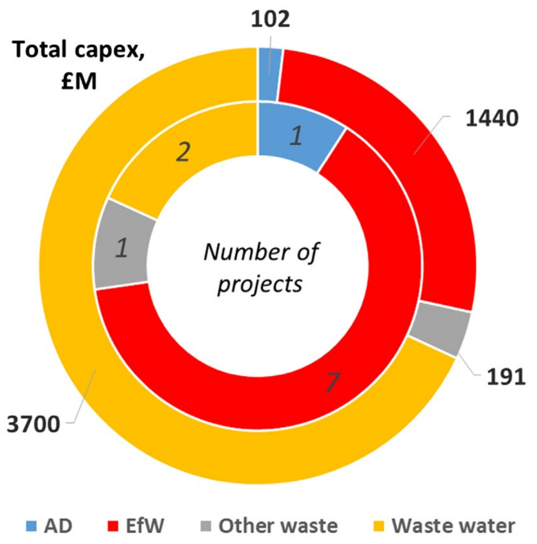

Figure 2. Waste projects with funding highlighted in the National Infrastructure Plan Pipeline. (NB: one highlighted project – Milton Keynes – not included as no funding figures supplied).

streams in the future. The range of technologies emerging evolves daily; here we provide a brief, non-exhaustive summary.

Commercial forecasters have identified a wide range of emerging resource recovery technologies at varying 'technology readiness levels' (TRL – an index of how close the technology is to being widely operational, ranging from 1 – basic science demonstrated in the laboratory, to 9 – technology successfully in operation) (Ricardo, 2016), including:

- Flexible, reconfigurable multi-material recycling facilities that sort residual waste using size and density, optical or infra-red material sensing technology and air separation to recover plastics, paper, cardboard, glass and metals (TRL9)
- Using biological enzymes to break down polyethylene tetrephthalate (PET) into its original monomers to replace traditional petroleum precursors for PET (TRL4)
- Hydro-recovery or composting processes recovering cellulose fibre from absorbent hygiene products (nappies etc.; a mixed material waste that is notoriously difficult to recycle) for use in e.g. fibreboard, acoustic panelling or biomaterials for land treatment, with recovered plastics sent for secondary reprocessing (TRL8)
- Cryogenic and ultrasonic processes for processing carpet (a pernicious mixed polymer waste stream) recovering and recycling 80% of the waste into surface coverings or polypropylene feedstock, with a further 10% being sent to EfW (TRL9)
- Pyrolysis or thermal depolymerisation of wastes to produce charcoal, oil and gas fuels, for homogenous organic waste streams (tyres or wood chips. TRL7) or mixed wastes (TRL5). The oils derived can also be used to replace virgin petroleum feedstock for commodity chemicals.
- Micro-AD systems designed for local householders or businesses, producing biogas, liquid fertiliser and solid soil conditioner.

A major academic research investment is the NERC 'Resource Recovery from Waste' programme.[12] This £7M portfolio of six complementary projects includes:

- Systematic analysis of the suitability of ash and digestate residues from biomass energy generation for use as nutrient providers and conditioners for agricultural soils, in part as replacements for mined nitrogen and phosphorus mineral fertilisers

- Using combinations of low-energy biochemical, dielectric and geochemical processes to refine and concentrate valuable and/or functional materials (including metal sulphides, nano-metallic structures, rare earth elements, 'E-tech' elements and uranium phosphates) from a variety of bulk wastes (refining slags, alkaline mine wastes etc.) either in- and/or ex-situ
- Developing complex value modelling techniques that can assess creation and dissipation of the economic, financial, environmental, social and technological value associated with production systems that currently emit wastes, to highlight upstream interventions in these systems that will prevent the dissipation of value into waste.

Other major research investments that deal with 'upstream' changes to supply systems include: redesigning metal alloys to reduce demand on strategically important elements[13]; taking a 'whole systems' approach to the upgrading and reutilisation of unavoidable food supply chain wastes to move towards closed-loop food production[14]; and developing reliable methods for recycling plastics derived from biological (i.e. non-petroleum) sources by depolymerisation for reprocessing either as new plastics or other value added chemicals.[15] A summary of total U.K. current investments in waste research is given in Figure 3.

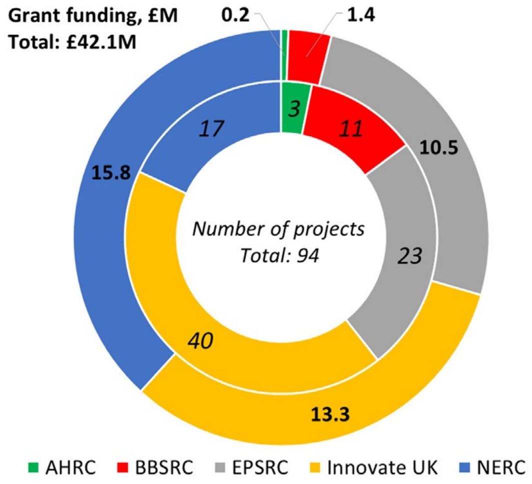

Figure 3. U.K. research council investments in 'waste' projects.
Key and links: AHRC = Arts and Humanities Research Council, http://www.ahrc.ac.uk/; BBSRC = Biotechnology and Biological Sciences Research Council, http://www.bbsrc.ac.uk/; EPSRC = Engineering and Physical Sciences Research Council, https://www.epsrc.ac.uk/; Innovate UK, https://www.gov.uk/government/organisations/innovate-uk; NERC = Natural Environment Research Council, http://www.nerc.ac.uk/; Date retrieved from Gateway to Research (http://gtr.rcuk.ac.uk/) Feb 2017.

3. The capacity gap; or surplus?

Analyses of the spare capacity in U.K. waste management and resource recovery infrastructure differ. National assessments tend to suggest that the U.K. has sufficient waste processing capacity for the near future, while analyses that disaggregate facilities (i.e. compare local arisings to local facilities) often suggest that local deficiencies exist. The difference can be reconciled by permitting bulk transport of wastes, but whether this is sustainable, desirable or practical is debatable. This apparent contradiction is strongest in the solid waste management sector (Figure 4). The National Needs Assessment (ICE, 2016) states that the U.K. possesses 'adequate capacity' to meet projected trends in waste management and 'the only infrastructure requirement will be in treatment facility renewal' (Hall et al., 2017). Other national reports, largely focused on 2020 targets to divert biodegradable municipal waste from landfill, suggest that there is a >95% probability that such targets will be met with an excess capacity of over 2 Mtpa (DEFRA, 2013).

However, investigators who took into account the detailed composition of waste streams and local variations in capacity and technology suggest that significant capacity gaps exist at regional level; the agglomeration of the data hides the high probability that there will be local treatment capacity deficits totalling up to 15 Mtpa. They also suggest that the wider implications of long-distance haulage of waste have not been taken into account (Imperial College London [ICL], 2014). In response, it has been suggested that there is no significant barrier to transporting waste between regions and that the system is 'not sensitive to restrictions in market clearing' (DEFRA, 2014). Additionally, the European Commission has proposed a 'Schengen Area' for waste, effectively removing regulatory obstacles to transnational shipments of waste in order that waste is freely 'allowed to move to the facility at which it is best treated' and limiting the application of 'proximity principles' to waste for disposal only (European Commission [EC], 2016).

Other commentators suggest that the appropriate scale for efficient and commercially viable collection and processing is dependent on the waste stream in question. WEEE reprocessing to capture maximum value and plastics recycling requiring collection of high-quality separated material, is best operated at a regional scale; anaerobic digestion of food waste should be handled at the local authority scale (Benton & Hazell, 2014). This is because the capacity of the typical processing facility in each case is well matched with the generation of the relevant material at each scale; it takes a region to produce enough plastics or WEEE to justify an appropriate processing facility, while a local authority produces enough biodegradable waste to justify an AD plant. The environmental impacts

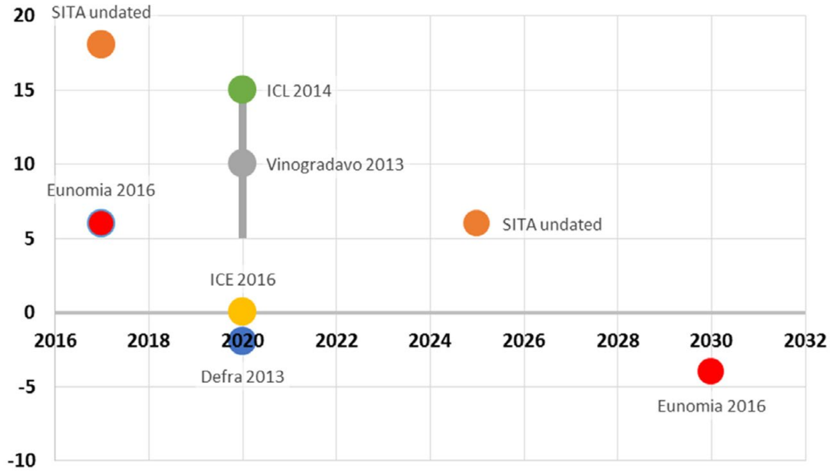

Figure 4. Variation in projections of U.K. solid waste management capacity gap (Mtpa: +ve = shortfall in capacity; −ve = surplus in capacity).

of transport distance on waste processing are generally small compared to overall impacts (Gu, Guo, Zhang, Summers, & Hall, 2017; Patterson, Esteves, Dinsdale, & Guwy, 2011) but can have a significant effect on the overall energy balance for AD (e.g. Bacenetti, Negri, Fiala, & González-García, 2013).

Other investigators have reported various figures for the U.K. capacity deficit or surplus. Some commentators suggest that a treatment capacity deficit of 5–15 Mtpa is likely by 2020 when commercial and industrial waste is taken into account (Vinogradova et al., 2013). Others suggest a current deficit (filled by over-reliance on export of SRF/RDF) between residual waste arisings and treatment capacity of between 6 Mtpa (Eunomia, 2016) and 18 Mtpa (SITA, n.d.) caused by the closure of 1500 landfill sites and the slow development of new facilities (Environmental Services Association & the Environment Agency [ESA], 2010; Environmental Services Association [ESA], 2016). This deficit is projected by some to disappear by 2020 and change to a surplus of around 4 Mtpa by 2030, owing to a reduction in waste generation and an increase in projected operational capacity (Eunomia, 2016); others suggest a capacity deficit of 6 Mt per year will remain in 2025 (SITA, n.d.). Many commentators note that projections of future waste arisings and thus capacity requirements are complicated by a lack of data on waste flows, particularly for commercial, industrial and construction wastes (e.g. DEFRA, 2013; ICE, 2016; Vinogradova et al., 2013).

Exports of waste as SRF/RDF have grown from zero in 2010 to over 3 Mtpa[16] in 2016. However, there is no reliable way of forecasting future export levels given the uncertain political, technological and economic situation. Current U.K. EfW capacity is 5 Mtpa (potentially generating up to 3000 GWh of electricity, ~1% of total U.K. electricity supply) and this will rise to 12 Mtpa by 2020 considering all projects under construction (GIB, 2014).

With regard to wastewater, the ability of receiving bodies of water to assimilate effluent will diminish as wastewater quality standards become more stringent; i.e. the degree of contamination that receiving waters are allowed to tolerate will decrease and the requirement for treatment of wastewater will concurrently increase. At a national level, this does not appear to be an issue given that the U.K. is 99.9% compliant with water quality directives (DEFRA, 2012) but in some localities wastewater has to be pumped into neighbouring catchments (ICE, 2016). For sludge treatment, given that biosolids make up less than 5% of total organic matter applied to farmland, it would seem that there is sufficient capacity for expansion (Water UK, 2010) although the geographical constraints are still under consideration.[17] The U.K.'s Office for Fair Trading has attempted to stimulate markets in this area.[18]

Various codes of practice specify the upper limits for application of biosolids to soil, mainly to prevent accumulation of harmful heavy metals such as zinc, copper, nickel, lead, chromium, cadmium and mercury. Approximately, 1500 km^2 of farmland currently receives biosolids; since the upper limit for application can be calculated as between 0.6 and 3 t/km^2 (determined by the nitrogen content, which depends on the type of pre-treatment) (UKWIR, 2015) this suggests an existing processing capacity of 1–4 Mtpa, in agreement with production figures. Since the total U.K. arable land area is on the order of 50,000 km^2 – i.e. only 3% is currently receiving biosolids – capacity issues are not likely to arise.

4. Barriers and drivers for change

General social, economic and political pressures for lower environmental impact and increased recycling will change how waste management and resource recovery infrastructure operates and develops. The role of resource recovery in reducing carbon emissions could receive increased attention. U.K. emissions associated with producing the materials that end up in waste are over 200 Mt eCO_2 per year i.e. about a third of the total[19]; the emissions avoided by current recycling (i.e. those that would have been associated with the production of the primary resource replaced) are only ~60 Mt eCO_2 per year (DEFRA, 2016b). Direct emissions from the sector are small (~7 Mt eCO_2 per year, mainly associated with methane release from landfill) and so increasing recycling and recovery rates would help balance the U.K.'s carbon budget.

The U.K. is a significant net importer of many resources, some of which (especially high technology metals) are 100% imported (European Environment Agency [EEA], 2012) and resource recovery must play a key role in securing the future availability of these materials. A large proportion of current U.K. resource recovery capacity is achieved through the export to EU countries of calorific waste processed into 'refuse-derived' or 'solid recovered' fuels (RDF, SRF) for energy from waste (EfW) facilities. EfW overcapacity in continental Europe, which drives U.K. RDF/SRF production and export, is expected either to be filled by continental RDF/SRF production or decommissioned (ICE, 2016).

Waste management operations in the U.K. other than EfW are described as fragmented and inefficient; the huge variations in how waste is presented by businesses and households impede scale-up of operations. Recycling is in decline because commodity prices are depressed, demanding that the quality of recyclates must increase to compete with virgin materials; yet fiscal austerity for LAs leads to increased contamination (ESA, 2016) as collection becomes less specific and/or less well enforced.

Other issues require special attention, as outlined below.

4.1. Data

The lack of general data and inconsistencies in that data which exist, as exemplified in Section 2.4 above, is repeatedly cited as a barrier to development and investment in the sector. There is no responsibility on many waste producers to report on the quantity or quality of the waste they produce unless it is hazardous or otherwise regulated. Data are particularly scarce in the commercial, industrial and construction/demolition sectors – which together account for three times the volume of municipal waste (DEFRA, 2013; ICE, 2016; Lee, Quinn, & Rogers, 2016) – not least because these sectors are not obligated to track and report waste arisings, in contrast to LAs who deal with municipal waste (Vinogradova et al., 2013). This problem can be further compounded by changes in the definition of waste. For example, in 2011 the definition of municipal solid waste (MSW) was changed to include waste collected by LAs not from households but similar in composition to household waste and thus the reported proportion of MSW attributable to households dropped from 90 to 50% (ICL, 2014) unless due regard is taken for new sub-categories of waste, which often appears not to be done. This is a global issue; UNEP (2015) have identified that there are no standard classifications, definitions, measurements, associated methodologies or reporting systems in place and that the industry will need to implement these before even rough mass balance of waste flows and losses can be established.

Such uncertainty and volatility surrounding waste data make it very difficult to use robust mass balance approaches to determine what new resource recovery capacity, and associated interactions with other infrastructure systems e.g. transport (Lee et al., 2016), is likely to be needed in the future. This impedes coherent policy-making which in turn increases the risk to potential investors (public or private) wishing to commission new resource recovery infrastructure (ESA, 2016).

Better data and forecasts on the arisings and quality of residual commercial, industrial and construction/demolition waste will be required to reassure investors that there is a gap in the existing market and credible new markets. A coherent, standardised approach to waste data collection, analysis and forecasting would appear to be the most effective way of reducing the investment risk for new resource recovery facilities (Vinogradova et al., 2013). Currently, waste data are only recorded and collated in response to specific regulations e.g. packaging, where the PRN/PREN system (in which producers of packaging must effectively purchase packaging recovery capacity from recyclers) provides well-defined processes for tracking waste and secondary resource flows. However, where deregulation has occurred (e.g. where EU 'end of waste' status has been achieved) or activities are not covered by regulation (e.g. prevention and re-use, commercial and industrial wastes, construction and demolition wastes) little if any data are collected. Systems have been proposed that would provide a platform for more comprehensive and coherent data analysis[20] (Aplin, 2016). Better data and information would help communication between LAs (as collectors rather than users of recyclate) to become less detached from the end markets for recovered material.

Lack of data is also cited as a barrier to reuse (CIWM, 2015), in particular the lack of standardised data collection protocols and the difficulty of devising robust methodologies that are suitable for the very wide range of stakeholder types and scales in the reuse sector.

4.2. Investment

Public–private partnership (PPP) finance agreements for LA waste processing infrastructure are coming to an end with around £1.7Bn of further investment required by 2020 of which £0.5Bn has yet to secure finance (GIB, 2014). The public-sector support has been withdrawn because targets for diversion of biodegradable material from landfill have been met; but this only a very small facet of a much wider set of goals that the industry will have to meet. The almost singular focus of PPP on EfW plants treating household waste has left investors with the perception that EfW is the only resource recovery technology available and they are now '… sceptical that there is enough waste remaining to justify building new infrastructure'. This increased risk perception has already lead to delays and cancellations (GIB, 2014) including withdrawal of PPP investment.[21] This risk is compounded by the perceived difficulties in gaining planning permission for new waste-related infrastructure in the U.K. owing to 'NIMBY-ism' (Ekogen, 2011). Brexit generates uncertainty around the U.K.'s adherence to the EU Circular Economy Package[22] which further increases investment risk for non-EfW resource recovery infrastructure.

Yet it is very clear that such public support for investment in addition to EfW is urgently needed. Most commentators agree that there will be a significant gap between waste arisings and processing capacity between now and 2025 (see Figure 4), and some are preparing to report that a gap of 14 Mtpa already exists.[23] Not closing this gap could cost 8000 jobs and cause recycling targets to be missed (ESA, 2016). More importantly, it has been estimated that an additional £5Bn to £25Bn investment in infrastructure (Environmental Services Association [ESA], 2017; ICE, 2016; SITA, n.d.) will be required to achieve a close-to-circular economy; this should now be the focus of governmental support. If the correct incentives were put in place to promote the move towards a circular economy and the associated business models, a whole raft of recycling technologies beyond EfW would become suitable targets for investment. Benton and Hazell (2014) have suggested the establishment of a £250M challenge fund for circular infrastructure, such as closed-loop plastics factories, AD plants and WEEE refurbishers. Since establishing a circular economy has been estimated to have the potential to boost GDP by £3Bn (ESA, 2017), this could be made fiscally neutral.

Fiscal stimulation of the new markets and investments required that move away from a focus on EfW towards a more balanced portfolio that also includes material resource recovery, remanufacturing and/or reuse, to realise the environmental, economic and social benefits of a circular economy, will require strong, progressive policy instruments. These are likely to be based on aggregated services models, creation of resource management networks and extended producer responsibilities for materials in the supply chain (CIWM, 2016; Viridor, n.d.). The PRN system was supposed to encourage investment in new infrastructure via collaboration between the packaging use and recycling sectors but results have been mixed.[24]

4.3. Legislation, regulation and Brexit

Specific drivers with a more immediate effect are connected to taxation intended to implement UK and/or EU legislation, rather than an awareness of the inherent value of recovered resources (ITRC[25], cited in ICE, 2016). The rise of landfill tax to over £80 per tonne (index linked) makes it now the most expensive disposal option and drives increased reliance on resource recovery systems. There are calls to introduce a tax on incineration of waste, and regulators are co-operating to reduce waste crime.[26] The Revised Waste Framework Directive[27] will effectively ban from landfill all recyclable waste (including paper, metals, glass and biodegradable materials) by 2025 and promote the sorting of construction and demolition waste for wood, aggregates, metal, glass and plaster. It will require 70% of municipal waste and 80% of packaging waste to be recycled or prepared for reuse by 2030 (GIB, 2014; ICE, 2016). Waste electric and electronic equipment (WEEE) is also subject to EU regulation, with collection (4 kg per person), recovery (70–80%) and reuse/recycling (50–75%) targets. Other targets exist for e.g. tyres,[28] end-of-life vehicles,[29] and batteries[30] (EEA, 2012) (Figure 5).

Other legislative instruments that will demand increased resource recovery infrastructure capacity include the EU packaging waste directives, Zero-Waste Plans in Scotland[31] and Wales[32] and the Waste Prevention Programme for England.[33] Allied with the projection that 15% of the U.K.'s recycling capacity will close in this timeframe (reducing recycling rates by 5% and costing 8000 jobs), some commentators suggest that waste could cost UK businesses and LAs an extra £300M–500M by 2020 (ESA, 2016).

This fragmentation and the resultant 'siloes' of regulation have promoted current levels of recycling but may limit further progress unless unifying themes and frameworks can be drafted and disseminated.

Brexit increases uncertainty around the medium-term viability of waste exports (Eunomia, 2016), both in terms of a continuing stable regulatory framework and the volatility of the £/€ exchange rate. If the proposed EU waste Schengen Area is implemented and the U.K. is excluded, exports may be banned; if the U.K. is included, then exports may actually increase. U.K. EfW capacity cannot

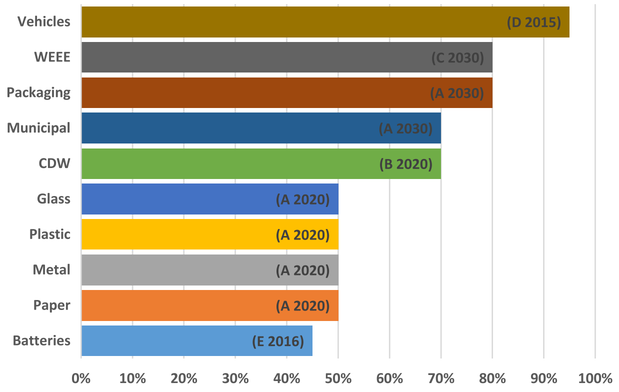

Figure 5. Maximum EU targets for selected materials and components by recovery/recycling definition (refer to key) and year.
Key: A = Recycling or preparation for reuse; B = Recycling, recovery or preparation for reuse; C = Recovery; D = Reuse and recovery; E = collection. CDW = construction and demolition waste. WEEE = waste electrical and electronic equipment. See references section.

absorb all the RDF/SRF material that might be diverted from export (ESA, 2016). While some commentators present U.K. EfW as a potential investment opportunity (GIB, 2014), there is no specific commitment to promoting EfW as a low-carbon energy source in the NIP (IPA, 2016). A recent review of the policy implications of Brexit for the sector (CIWM, 2017) notes several further specific impacts. Over half of current U.K. environmental law (which still dominate law pertaining to waste) is of EU origin and uncertainty continues over whether the U.K. will adopt the proposed EU Circular Economy Package, with its more ambitious recycling and diversion from landfill targets. As waste management is a devolved activity, the potential for greater divergence in practice between the four U.K. nations will increase if the EU framework guidance is lost. This fuels disquiet, especially in Northern Ireland and the Republic of Ireland where the prospect of increased quantities of waste crossing the border to escape EU legislation would be highest.

4.4. Wastewater

Climatic and demographic changes will force an increase in wastewater arisings; increased demand coupled with more frequent and voluminous surface water run-off will require enhancements in network size and trunk sewer capacity (ICE, 2016). Pressures on wastewater treatment include an increasing understanding that the resilience of the ecosystems with which wastewater interacts should not be taken for granted. A significant proportion of U.K. water bodies are becoming increasingly unreliable for extraction as demand increases with population. EU water directives[34] are increasingly stringent (Hall et al., 2017); only 17% of U.K. water bodies are classified as 'good' under the EU Water Framework Directive. Water companies are having to work harder prevent nitrates and pesticides accumulating in water bodies as a result of farmland run-off. Concern over 'micropollutants' such as micro-plastics and pharmaceutical residues is growing. Increased frequency and severity of flood events owing to climate change fuels concern over the resilience of wastewater treatment, both directly (i.e. flooding of water treatment works) and indirectly (i.e. the ability of water treatment systems to deal with flood waters). The investment demanded by these pressures is restricted by the need to retain affordability of customer's water bills in a time of austerity (Hall et al., 2017; OFWAT, 2015).

4.5. Reuse

The literature pertaining to barriers and drivers for reuse has been reviewed by CIWM with added data from stakeholder interviews (CIWM, 2015) although not with a specific focus on the required infrastructure. One challenge said to link organisations of all scales was the need to avoid fragmentation of the supply chain of reusable goods via waste management practices. Particular issues that can exacerbate fragmentation include policy deficits (particularly a lack of targets), providing access to goods that residents no longer want, establishing obligations for retailers and producers to prepare goods for reuse, and the difficulty of present reuse and repair as economically viable when cheap new products are available. A cultural barrier is the negative perception of used products in general, although this has long been overcome in the used vehicle sector, probably because the large cost disparity between new and used products is such that the value case is clear, particularly for those without the means to buy new cars. The lack of a clear policy framework is frequently repeated in the literature reviewed. Despite 94% of LAs surveyed reporting that they promote reuse to their residents, Beasley Associates (cited in CIWM, 2015) reported that the majority of LAs do not actively promote reuse; it is possible that LAs have a misconception of the degree to which they promote reuse. A lack of local infrastructure for reuse is given as the top reason (along with a lack of time and resource) by those reporting that they do not promote reuse.

5. Discussion and recommendations

Waste management is a growth industry, with targets being reached and exceeded. For it to continue to grow more infrastructure needs to be put in place. The current focus of infrastructure development is still largely on treatment (i.e. amelioration of the environmental and social impact of waste disposal) rather than on resource recovery (i.e. preserving the value of resources through reuse and recycling).

Where new, planned and projected infrastructure growth does involve recovery of value, it is overly focused on energy from waste, as this is seen as the easiest route to financing new waste infrastructure (see Section 2.5). While this should rightly form part of a balanced resource recovery portfolio, it should not be the whole of it, as it does not drive 'a transition to waste destinations that are more desirable under the principles of the waste hierarchy' (Farmer et al., 2015). In a commercial sense, reduced residual waste arisings and the development of more efficient recycling systems will eventually reduce the amount of waste available for EfW; uncertainty over continued viability of exports further complicates the picture.

EfW destroys technical value in the sense that once the energy value of a waste material has been recovered by burning, it is no longer available to the circular economy. An over-reliance on EfW to meet waste management targets, as appears to be the case for planned infrastructure in the U.K. (see Section 2.5) creates an infrastructure system that paradoxically relies on the continued creation of suitable waste, reducing incentives for reuse and recycling. The NIP's aspiration to move towards a circular economy will not be realised without a greater focus on preventing waste and recovering recyclates, rather than burning them. The proportion of waste that is sent for energy recovery should be a reflection of its ability to be reused or recycled, not of the ratios between the price of fuel and materials; this is a 'market failure' that needs correcting if we are to move towards a circular economy in which EfW is the last resort before landfill.

A recurrent theme in the publications reviewed here is the deficiency of data on waste flows in terms of quality, availability and consistency (see Sections 2.4, 4.1). The collection of data is driven solely by the need to achieve targets for recycling broadly defined mass fractions of waste, or requirements to account for the correct disposal of hazardous materials. The sectors producing the majority of total waste arisings are under no obligation to report on its quantity, quality or destination. The limited data collected are not of the required quantity or detail to allow mass flows of materials and their quality (i.e. useful physical properties) to be calculated. Within and between agencies, data are reported in such a wide variety of formats, typologies and units that calculating the flows of material through our economic systems is impossible. These agencies explicitly admit that it is not even possible to reconcile waste arisings with waste managed using public domain figures. Inconsistent classifications of waste not only prevent comparison between data-sets, but also increase the variability of the composition of waste streams; an serious technical impediment to recovery and recycling.

This in turn prevents the development and installation of new infrastructure technology (Section 2.6); impedes the efficient recycling of useful materials and reuse of products; adds unnecessary risk to investment in infrastructure projects required to close the capacity gap (Section 3); obscures comparative analysis at local, regional and national scales; and stymies the communication between materials suppliers, product designers and waste managers that will be necessary for the circular economy. Data collection and reporting in the sector should be rationalised, with a first priority of accounting for the value and volume of material flows. The current requirement to demonstrate adherence to health or environmental legislation would follow naturally.

The role of public investment in the sector should be re-examined. Fiscal support for the industry should be focused on protecting investments in both the supply chain from design through to recycling, and the waste infrastructure, that prevent dissipation of material value (technical, environmental and social as well as financial) into waste and close the gap between non-EfW capacity and demand (Section 4.2). This might include providing a buffer against price volatility for recovered materials; supporting markets in recyclates; incentivising design for durability, upgrading, refurbishment and reuse; providing platforms and standards for data collection; and investing in research and development in the sector. The overall aim should be to shepherd in a transition towards the infrastructure required for a circular economy by removing barriers and/or providing support for business models that move away from the linear make-use-dispose consumption of materials. Existing market support such as the PRN system should be better administered to provide a revenue stream with which to develop and install new resource recovery infrastructure that addresses the new challenges that will face the sector (Section 1.3), in collaboration with all actors in the supply chain.

All such support should be based on reinforcing a principle of extended producer responsibility, where the manufacturer of a product explicitly shares responsibility for the life cycle management of the materials from which it is made with materials suppliers, users and waste processors (Section 1.1). Public procurement processes also have the ability to send powerful economic and cultural signals; a requirement for the public sector to prioritise the use and reuse of British products made from recycled materials is a possibility in a post-Brexit U.K., for example.

All the above must be reflected in regulation of the resource recovery sector (Section 4.3). The most damaging implication of Brexit on resource recovery infrastructure development is the uncertainty over continued adherence (or otherwise) to the suite of EU regulations that dominate behaviour in the sector. Even before Brexit, the government has offered weak guidance to the sector and even descended into public ministerial squabbling about refuse collection; in contrast, stronger political messages have led to rapid improvements in resource recovery in other countries (Farmer et al., 2015). The government needs to move quickly to reassure the industry and potential investors that a stable policy and regulatory framework for waste management, recycling, resource recovery and associated activities will be quickly implemented. In this regard, it is not encouraging that waste management is currently omitted from the list of infrastructure priorities proffered as 'Pillar 3' of the government's new Industrial Strategy.[35]

Brexit also offers opportunity for fundamental changes in regulation. A radical change would be to move responsibility for waste management regulation from environmental agencies (which implicitly reinforces the culture that waste management is first and foremost an environmental protection issue) to a new Office for Resource Stewardship, with a specific focus on protecting the national interest by enforcing efficient use of materials, preventing waste and encouraging reuse and recycling (Section 2.3). Targets would be expressed in terms of recovery of value and function, rather than diversion of waste from landfill. Political drivers would include increasing the material security of the U.K. by reducing reliance on imports; creating both low- and high-skilled jobs in the reuse, recovery and recycling sectors and associated infrastructure provision; developing new recovery technologies for export; and achieving sustainable development goals.

As the U.K. embarks on developing a new industrial strategy alongside redefining our trading relationships with the world, it would seem an ideal time to reimagine the resource recovery industry as an engine for sustainable growth at home and a crucible from which we export the science, technology and services required for a global circular economy.

Notes

1. https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept.
2. NB: Eco-packaging and light weighting have to be considered with caution; often eco-packaging such as vegetable-based plastic, and light weight design can become disengaged from the need to prolong product functionality, durability and manageability by existing waste management/recovery practices, potentially creating more problems than they solve.
3. http://www.wrap.org.uk/sustainable-electricals/esap/re-use-and-recycling/guides/PAS-141-Guide.
4. https://www.gov.uk/government/collections/national-infrastructure-plan.
5. http://www.ukcric.com/.
6. https://www.ons.gov.uk/economy/economicoutputandproductivity/output/bulletins/indexofproduction/oct2016.
7. http://www.rwmexhibition.com/content/Overview-of-the-UK-Waste-Market.
8. https://www.gov.uk/guidance/packaging-waste-apply-to-be-an-accredited-reprocessor-or-exporter; http://www.legislation.gov.uk/uksi/2010/2849/regulation/12/made.
9. See https://data.gov.uk/data-set/waste-infrastructure-delivery-programme-widp-residual-waste-treatment-infrastructure-project-li.
10. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470475/Waste_management_2014_England_summary.pdf.
11. http://www.sepa.org.uk/environment/waste/waste-data/waste-data-reporting/.
12. http://www.nerc.ac.uk/research/funded/programmes/waste/, https://rrfw.org.uk/.
13. http://gtr.rcuk.ac.uk/projects?ref=EP%2FL025213%2F1.
14. http://gtr.rcuk.ac.uk/projects?ref=EP%2FP008771%2F1.
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Acknowledgements

The author would like to thank Bernie Thomas, and Dr. Eleni Iacovidou, Dr Anne Velenturf and Dr.Costas Velis for helpful comments on the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was jointly funded by the U.K.'s Natural Environment, Engineering and Physical Sciences, and Economic and Social Research Councils (NERC; EPSRC; ESRC) and DEFRA [grant number NE/L014149/1] and [grant number EP/K012398/1].

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Appendix 1. Waste Management Activity profiles and boundary processes Tables 21, 22 in Ekogen, 2011

Re-use of products to divert waste at source: Activity at the top of the hierarchy to minimise the amount of material entering waste management processes. This activity is relevant across all sectors, cuts costs and can have an impact on the image of the business.

Collection and transport: Much of the collection and initial transport of municipal waste is undertaken by local authorities and some is contracted out to large private companies. Short-term trends in this activity may be influenced by the local authority spending reviews.

Brokerage of waste: This involves arranging the collection, recycling, recovery or disposal of controlled waste on behalf of another organisation, without ever taking possession of or storing the waste. This also includes buying and selling scrap metal and other recoverable materials. There is anecdotal evidence to suggest the adverse effect of the downturn on the construction industry has affected waste brokerage activity.

Sorting and storing: The sorting and segregation of waste within recycling plants and materials recovery facilities (MRFs), is expected to become an increasingly mechanised process, including the use of mechanical biological treatment (MBT) processes to separate waste streams. This is expected to reduce labour demand.

Disposal through landfill: There has been a major political drive to reduce the amount of disposal through landfill. The increasing financial pressure to seek alternative means of disposal is expected to continue to drive long-term change in the sector.

Disposal through incineration: This involves the incineration of waste from an off-site source and the long-term trends in this sub sector are as above.

Treatment of waste: This is comprised largely of:

- *Non-hazardous waste:* includes sorting, crushing, baling of waste plastic and paper, treatment/recovery of packaging waste, glass recycling, wood treatment and recycling, and gypsum and plasterboard recycling.
- *Hazardous treatment:* tends to refer to oils and/or solvents or other hazardous wastes rather than a treatment method.
- *Other biological treatment:* a range of activities, including treatment of sludges, leachate and effluents.
- *Waste electrical and electronic equipment (WEEE) treatment:* treatment of WEEE for recovery purposes, including sorting, dismantling, shredding, grading, baling, crushing and compacting. Some facilities carry out metal recycling as a secondary activity.
- *End of life vehicle dismantling:* The reuse of parts and the reclamation of materials from motor vehicles
- *Battery treatment:* reprocessors of used batteries.
- *Ship dismantling:* dealing with end of life ships, recovering materials such as metals and disposing of hazardous components.
- *Clinical waste:* treatment of wastes produced by human and animal health care activities, some of which are considered infectious.
- *Ozone-depleting substances (ODS):* removal of ODSs for recovery, usually from waste refrigeration units.
- *Tyres:* sort, shred, crumb or otherwise treat tyres for recovery purposes.
- Other specialist treatment sub-categories are inert/construction waste treatment, container recovery and reactivation of granulated carbon.**Recycling and Processing of recyclate:** Recycling, sorting and recovering recyclable materials. This very broad definition inevitably covers a range of different activities including the recycling of textiles, plastics and so forth. The recovery, recycling and reuse of waste using technologies, such as MBTs, has substantially increased as disposal through landfill has fallen out of favour. The drive towards more cost effective means of disposal is expected to continue.

Composting: Treatment of organic, biodegradable waste by decomposing in the presence of oxygen to produce a soil improver or conditioner. Social environmental awareness may increase trends in household composting. Infrastructure development for larger scale composting may be favoured in rural areas where there is greater demand for the end product.

Energy recovery: Includes:

- *Anaerobic digestion:* treatment of biodegradable waste via a process in which natural bacteria break it down in an oxygen-free atmosphere, producing biogas and digestate.
- *Burning of waste-derived fuels:* such as gas (biogas, landfill gas), biodiesel and RDF, to produce energy.
- *Other waste-to-energy technologies:* such as pyrolysis and gasification.

Development and use of energy from waste processes as an alternative to landfill have increased over recent years.

Boundary process for main recyclates (Source: WRAP)

Material	End process	Out of scope
Paper	• Baling process	• Paper mill
Glass	• Cleaning and chopping the glass	• Glass manufacturers
Metals	• Recovery of materials from cars, construction waste, appliances etc.	• Steelworks
Wood	• Wood recyclers • Waste directive compliant boiler users	• Wood panel makers • Animal bedding suppliers
Textiles	• Sorting, grading and baling of textiles • Mechanical Recycling/re-processing	• Mattress/upholsterers • Automotive materials • Horticultural matting • Building insulation materials • Carpets/underlay • Charity shops
Plastics	• Sorting and baling • Turning into pellets/flakes by plastic recyclers	• Bottle manufacturers • Manufacturer of bins • Wood replacement plastic

Appendix 2. Reported waste management and facility capacity statistics by region and headings

U.K. waste processing capacity:
Waste processing capacities in the U.K. and England are reported as (DEFRA, 2015) (U.K./England), (number of facilities, capacity Mtpa):

- Energy recovery (27, 2.9), (13, 2.1)
- Incineration (87, 8.4), (65, 8.0)
- Recovery other than energy recovery, including backfilling (3542, n/a), (1895, n/a)
- Landfill (594, remaining capacity 633 Mm^3), (478, remaining capacity 505 Mm^3)

U.K. Energy generation from waste was reported 7.5 GWh in 2014, split between:

- landfill gas (5.0)
- sewage sludge digestion (0.8)
- animal biomass (0.6) and
- anaerobic digestion (AD) (1.0; 152 anaerobic digestion sites operate in the U.K.)

with a further 2.0 GWh contributed by the biodegradable portion of EfW fuel (DEFRA, 2016b). This accounts for 2.5% of U.K. energy generation but does not necessarily indicate capacity.

U.K. residual waste capacity:
Residual waste is that fraction of waste (normally municipal solid waste) that is not separated for recycling (i.e. what is left over after recyclates are removed from a waste stream). It may derive from household, commercial or industrial sources. The DEFRA Waste Infrastructure Delivery Programme (WIDP) Residual Waste Treatment Infrastructure Project List (IPL) 'lists residual waste treatment facilities/contracts in England [and Wales] that are tracked by WIDP for the purposes of assessing treatment capacity. The list includes both existing and pipeline facilities and is informed by WIDP monitoring of its portfolio of PFI (Private Finance Initiative) and PPP (Public Private Partnerships) projects and public domain information concerning other PPP and merchant facilities'.[36] As of 31 March 2016, it lists 96 projects, of which 62 are operational and 34 are either in construction, consented, 'post close' or with status TBC.

The operational facilities have a total capacity of 11.2 Mtpa, with:

- 8.3 Mtpa (37 projects) of EfW
- 2.2 Mtpa (20) of biodrying mechanical and biological treatment (BMBT) and 0.7 Mtpa (5) of landfill mechanical and biological treatment (LFMBT).

Sub-U.K. National figures:
England: In England, 6305 sites accepted waste in 2014, managing 187 Mt of waste. These facilities are classified by DEFRA as (number permitted, number accepting, Mt managed in 2014) (DEFRA, 2016b):

- Landfill (493, 338, 41.3)
- Transfer (3149, 2383, 46.7)
- Treatment (2545, 1896, 57.4)
- Metal recycling (2534, 1290, 13.6)
- Incineration (134, 74, 8.6)
- Use of waste (240, 143, 2.3)
- Land disposal (287, 181, 17.1).

These data are shown in Figure 1 with a calculation of the average activity at each site by type. There is little correlation between the number of sites and the amount of waste treated (e.g. metal recycling accounts for 20% of sites but only 7% of the total waste managed, a reflection of the high monetary value per tonne of metals; landfill accounts for 5% of sites but 22% of waste managed, a reflection of the bulk nature of landfills). Two clear groups of sites can be identified; those types averaging 30 ktpa or less (transfer, treatment, metal recycling and use of waste) and those averaging over 90 ktpa (landfill, land disposal and incineration).

Organics treatment capacity (DEFRA, 2015) is given as 6.6 Mtpa, broken down as:

- composting (5.1 Mtpa)
- commercial, R&D and on-farm AD (1.3)
- industrial AD (0.3)

with a further 2.4 Mtpa added by mechanical-biological treatment and 3.5 Mtpa AD co-located with drinks manufacturers.

Some double counting is likely to have taken place as an item of waste may pass through two or more of these stages. As noted by Vinogradova et al. (2013), 'mixed waste might be accepted by a transfer station, sorted and then be transported to a recycling facility or for final recovery or disposal. For this reason, waste managed is not analogous to waste arisings and no direct comparison can be made'. Comparable figures for the capacity in each category do not appear to be available for England; the 2012 capacity figures are unhelpfully reported under different headings (DEFRA, 2015) and the 2014 capacity figures are not reported (DEFRA, 2016b). However, in all categories, there are significantly more sites permitted to take waste (9382 in total) than actually accepted any (6305, see above) in 2014 suggesting there is unused capacity in the system. Remaining landfill life based on 2014 inputs varies from 3 years in London to 13 years in the West Midlands.[37]

Scotland: The Scottish Environmental Protection Agency (SEPA) publishes waste facility details[38] but the data format and typology are rather different to that supplied by DEFRA so direct comparisons are difficult. Data are organised by site and since many sites carry out multiple activities (landfill, incineration, recycling, transfer etc.) it is not straightforward to allocate capacities to each activity. Eight hundred and two operational sites are listed with a total permitted capacity of 54 Mtpa (although it is important to note that this figure will be significantly higher than the mass of waste actually treated, see below), classified by SEPA as:

- Landfill 58 (7%)
- (Co-) Incineration 11 (1%)
- Civic Amenity/Recycling centre 193 (24%)
- EOL Vehicle/Metal recycler 181 (23%)
- Transfer Station 365 (46%)
- Composting 43 (5%)
- Anaerobic Digestion 12 (1%)

- Other 128 (15%)

Twenty-one sites undertake multiple activities which account for 30% of total waste inputs/treatment. Total waste inputs in 2014 were 17 Mt (i.e. around 10% of the figure for England and less than a third of the permitted capacity) of which 9 Mt was treated or recovered. This suggests that 8 Mt went to landfill and that the average Scottish landfill site handles ~140 ktpa (similar to the 122 ktpa figure derived for English landfills, see Figure 1). However, using English site activity figures for other types of process (where equivalency can be assumed) and aggregating significantly overestimates total Scottish waste processing, implying that the average site activity in Scotland is much smaller.

Wales: The Welsh Government reports[39] waste collected by LAs (around 0.4 Mtpa) again with different formats and typologies. Of this, 60% is prepared for reuse, recycling or composting. This appears to differ from the statistics on municipal waste[40] which suggest that 1.6 Mtpa is collected, of which 60% is reused, recycled or composted, 18% is landfilled and 19% is used for energy recovery. The latter figures appear more robust. Construction and demolition waste (12 Mt in 2010) and commercial and industrial waste (3.6 Mt in 2007) arisings are also reported. Recycling tonnages are split by facility and material type, from which some idea of the relevant infrastructure in place can be implied. In 2014/15, of 873 thousand tonnes (kt):

- 520 kt went to ‘Reprocessor – recycling’
- 122 kt to windrow or other composting
- 112 kt to in-vessel composting
- 64 kt to anaerobic or aerobic digestion segregated
- 28 kt to ‘Reprocessor – reuse’
- 27 kt to export for recycling

Further amounts of less than 1 kt in total went to other management methods.

Northern Ireland: In Northern Ireland (NI), the Department of Agriculture, Environment and Rural Affairs (DAERA) publishes municipal waste statistics.[41] NI collected 1 Mt of municipal waste in 2015/2016, of which 42% was sent for preparing for reuse, dry recycling and composting; 18% was sent for energy recovery and the remainder sent to landfill. The latest NI figures for construction and demolition waste are for 2009/2010. Of the 3.5 Mt arising, 1.3 Mt was reused, recycled or treated. No readily available figures for commercial and industrial waste appear to be available, nor do figures presenting implied or direct infrastructure capacity.

Appendix 3. Details of UK water treatment capacity

Treatment has four levels:

- Preliminary: removing grit, gravel and large solids;
- Primary: settling of suspended organic matter;
- Secondary: biological breakdown of settled organic matter;
- Tertiary: removal of specific pollutants.

The U.K. has around 9000 wastewater treatment plants. The level of treatment required of each plant depends on the size of the community it serves, measured in ‘person equivalents’ (pe). One thousand eight hundred and seventy-seven of these plants serve communities of more than 2000 pe; 1234 between 2000 and 15000 pe, 562 between 15000 and 150000 pe and 81 above 150000 pe. EU directives require that all communities with over 15000 pe must apply secondary treatment before wastewater can be discharged. The U.K. is over 99.9% complaint with this; only a handful of communities remain below this standard, all of which are being addressed. Discharges to sensitive areas must receive tertiary treatment, of which 588 have been identified in the U.K. (totalling 2700 km^2).